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Book of Abstracts

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Mission

Computer Applications and Quantitative Methods in Archaeology (CAA) is an international organisation bringing together archaeologists, mathematicians, and computer scientists. Its mission is to encourage and facilitate dialogue between these disciplines, to provide an overview of the present state of the discipline, and to stimulate discussion to progress the field. Membership is open to anyone upon payment of a nominal, annual fee.

Annual Conference

CAA organises an annual international scientific conference covering a wide range of topics, including data acquisition and recording, conceptual modelling, semantic technologies, data analysis, data management, digital 3D object reconstruction, image visualisation in archaeology, geophysics, and GIS. The conference format includes thematic paper and poster sessions as well as round tables and workshops. After the conference, papers presented can be submitted for publication in the peer-reviewed CAA proceedings. Conference proceedings have been published since 1973.

National Chapters

CAA encourages the establishment of national chapters to promote the organisation's mission at a country or regional level. National chapters help to facilitate the exchange of ideas within their geographic areas and may organise their own meetings. National chapters are also encouraged to support local bids to host the international conference.

Organisational Structure

CAA is managed by an Executive Steering Committee (ESC), consisting of six voting officers elected by the membership. The ESC is advised and supported by a wider Steering Committee, which includes the local conference organising chairs, the Scientific Committee chair, the Ethics Officers, and the Outreach Officer, as well as representatives of the National Chapters. The ESC officers can also co-opt additional members as needed. For more details on CAA's governance, please see the CAA Constitution.

CAA's History

CAA held its 50th conference in 2023 in Amsterdam, Netherlands. The organisation grew out of a small group of archaeologists and mathematicians interested in computer applications and working in the United Kingdom (UK) in the early 1970s. The first meeting was convened in Birmingham, England, in 1973. The organisation continued to grow over the next two decades and held its first conference outside of the UK in 1992. Since then, the annual meeting has been held in many European countries as well as at sites in North America, Asia, and Australia. For more details, see the CAA History page.

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53. Provisioning the city, exploiting the hinterland? Assessing the economic role of the transport system around Forum Hadriani through multiplex network analysis

Philip Verhagen (Vrije Universiteit Amsterdam)*; Mark Groenhuijzen (Utrecht University)

The Roman military and urban settlement system in the border province of Germania Inferior is thought to have relied on local provisioning for at least some of its subsistence needs. In particular, it seems plausible that military and urban settlements relied on the proximity of hubs that may have acted as collection points for storage and transport of cereals (Vos 2009). Groenhuijzen (2018) applied least-cost modelling and network analysis to show that the positioning of settlements in the local transport network is largely consistent with this hypothesis. In this study, transport of cereals to the market was considered as a one-way system. However, transport of goods and people in the region served many more purposes, including the oft-cited military ones, using a multitude of transport means (pedestrian, on horseback or using pack animals, wheeled, by ship) and infrastructures (paths, roads, waterways and supporting facilities such as bridges and way stations).
In order to study what other roles the transport infrastructure played it is not sufficient to look at settlements and their connections as static isolated systems, as is often done in e.g. least-cost path analysis. Layered (aggregated) networks, also known as multiplex networks, allow to switch from one mode of transport to another, and thus to analyse the potential and relative efficiency of transport mode combinations. However, analyzing these networks is a complex task, since the intralayer and interlayer interactions represent different kinds of relations (Sánchez-García, Cozzo and Moreno 2014).
In our paper, we will further explore these aspects for the hinterland of the town of Forum Hadriani (current Voorburg near The Hague), a small Roman civitas capital on the northwestern border of the Roman Empire. Both the town, its hinterland and its relations to the outside world have been the subject of intensive archaeological research over the past decades (Bloemers 1978; Van Londen 2001; Buijtendorp 2010; de Bruin 2012; Driessen 2018), but the economic interactions with and through the local transport network have only been marginally studied. We reconstructed multiple plausible transport networks in the region, using a combination of archaeological evidence, least-cost path modelling and network construction techniques, building on the work of Groenhuijzen and Verhagen (2015; 2017), to create input layers for a multiplex network of transport infrastructures. These are then used to model the potential movement of goods and people in the area, based on different assumptions about the purposes and requirements of transport. For example, bulk goods like building stone were much cheaper to transport over water than over land, so proximity to a waterway is essential to have access to these goods. Perishable goods, such as cereals, on the other hand, would need to be transported quickly to the market after harvesting, and required access to appropriate storage facilities in order to be traded profitably. In our paper, we will present both the methodology to arrive at our models as well as the first results, and confronted these with the archaeological theories that have been proposed over the past decades on the economic function of town and hinterland.

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270. A Tale of Two Models. Supra-regional Computational Investigations of Roman Urbanism in the Northwestern Provinces

Paul Vadineanu (Universität Zu Köln)*; Eleftheria Paliou (Universität Zu Köln)

The northwestern provinces of the Roman Empire present a fruitful and as yet understudied urban landscape at a macroscale, with many important questions ready to be addressed through computational analyses. While Roman provincial archaeology has had a long and rich history of investigation and academic development, certain subfields – specifically the study of smaller secondary settlements such as civitates and vici – have been overlooked. This may in part be due to the nature of archaeological evidence, with much of it lying under modern-day cities and towns, and thus comprehensive reconstructions of Roman townscapes are difficult to attempt. Moreover, larger settlements provide us with more evidence in the form of artefacts and architecture, and as such receive far more attention than smaller sites. However, secondary agglomerations too played an active and vital role in the socio-economic landscape of the Roman provinces and cannot be ignored when trying to build a rich and detailed model of settlement interactions. Despite the challenges of collecting evidence and its incomplete nature, certain computational methodologies can be employed effectively to counteract these effects. In fact, data-driven models can be used to provide a holistic understanding of the relationships between settlements of all sizes and thus lead to a better understanding of the Roman provincial milieu.

In this presentation, we aim to discuss the nature and extent of urbanisation in the provinces of Gallia Belgica, Germania Inferior, Germania Superior and Raetia, with a particular focus on the aforementioned secondary agglomerations, their developmental trajectories and the roles they played in the larger provincial and empire-spanning structures. We will address questions such as whether or not a town's centrality in a network as identified by the models may be confirmed by the presence of urban amenities (public spaces, streets and sanitation, entertainment venues, etc), as well as how its civic status relates to their position within the provincial settlement pattern (Bekker-Nielsen 2020). To achieve this we will employ two different computational techniques particularly selected to mitigate some of the challenges presented by a fragmentary dataset and disparate access archaeological evidence. Specifically, we will be using spatial interaction models of the broad Wilson type and network analysis on a dataset of 422 towns spanning the four provinces. Where available, information was recorded for each site's chronology, size extent, and the presence of building types which are typically viewed as markers of a certain degree of urbanization. These towns will be analysed as nodes or actors in their larger urban context by exploring attributes of centrality in relation to their urban development. Each of the aforementioned methods assigns quantifiable values based on differing definitions of centrality and explorations of interactions between the nodes.

Additionally, it is also important to keep in mind this study's broader applicability across space and time, as its secondary aim is to conduct a meta-analysis into the methodologies to assess their efficacy and suitability. By comparing their results, we will attempt to answer the questions regarding the development of urban forms and hierarchies, and to shed light on the particular historical, material, and political contexts that were active in the formation of these distinctly Roman settlement systems. These models will also be contextualized by, and suitability judged against, the archaeological and historical record.

The two approaches can be seen to be marginally similar insofar as both methods require a minimal data input, making them particularly well suited for tackling archaeological questions based on fragmentary datasets. Moreover, both have been applied successfully in many archaeological contexts including those of the Roman age (e.g. Paliou & Bevan 2016, De Soto 2019), both have a spatial component, and, most importantly, both explore various measures of

centrality which could be well integrated into the study of Roman urbanism. Despite such surface level parallels, the ways in which these explorations of centrality are conceptualized, formulated, and explicitly modelled are quite different, and thus can lead to vastly different outcomes as was observed during testing and data analysis.
This presentation will attempt to highlight some important aspects of the two models and bring into discussion of the different methodologies that spatial interaction models and network analysis employ, while bringing into focus the (dis)similarities between the results obtained by applying these two models to the same dataset. Their intrinsic assumptions and abstractions will be discussed with regards to their particular applicability within the specific use-case of urban development within the northwestern provincial environment. Further, we will examine the extent of their applicability in answering research questions regarding centrality, urban formation, growth, and economic networks in our own study of the northwestern provinces and beyond.

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116. Investigating the Urban Water Management Systems in Shang Dynasty China: a Perspective of Spatial Analysis

Qin, Zhen (Henan University)*

Introduction
Zhengzhou Shang City and Yinxu represent the early and late capital cities of the Shang Dynasty in Bronze Age China. Chinese archaeologists have conducted extensive research on these two cities, revealing much about the time framework and basic layout of large urban centers in East Asia during this period. However, understanding of the hydraulic systems in these ancient urban centers remains limited, mainly due to the constraints of rare field materials and traditional methodologies. In recent years, as urban archaeological investigations have expanded, numerous water management structures have been uncovered at both Zhengzhou Shang City and Yinxu. These discoveries provide invaluable insights into Shang Dynasty hydraulic engineering within capital cities.
This study systematically examines the hydraulic remains of these Shang capitals using digital archaeological approaches, including remote sensing and Geographic Information System (GIS) analysis. Our research aims to answer several key questions: (1) What roles did these hydraulic systems play in urban planning and construction, and how did their functions evolve with the growth and decline of cities? (2) What similarities and differences exist between the two cities regarding the functionality and conceptualization of water management facilities?

Methods and Materials
This research uses excavation data from water management facilities at the Zhengzhou Shang City and Yinxu sites, including channels, ponds, and wells, as primary materials. The main methods include spatial analysis through remote sensing and GIS tools. Remote sensing images are used to locate and verify the water management remains, while GIS aids in conducting spatial analyses and extracting site-specific information.
Specifically, this study employs the hydrological analysis module in the ArcGIS platform to model flow accumulation, which helps to explore the influence of artificial channels on surface runoff patterns. Additionally, kernel density analysis is applied to examine spatial relationships between hydraulic features and other urban structures. Cluster analysis is further utilized to investigate the role of these facilities in urban planning and zoning, revealing how water management was integrated into urban layout.

Results
Our research reveals that in the inner part of Zhengzhou Shang City, several interconnected large channels were constructed. The alignment of these channels corresponds with the city's topography, and they were significantly reinforced during the later stages of the city's development. Against the backdrop of climate changes during this period, these channels played a critical role in urban drainage and flood prevention.
In contrast, the water management system at Yinxu exhibits a greater degree of prior planning. The construction of large channels south of the palace district altered the original surface runoff pattern, enabling an effective redistribution of water resources within the city and influencing the subsequent urban layout. Additionally, this channel system may have functioned as a boundary in conjunction with surrounding natural waterways, creating a relatively enclosed zone that protected the royal palace and temple areas. This feature contributed to a unique defensive system characterized by an "absence of city walls," setting Yinxu apart from other major Bronze Age capitals.

Discussion

Research on Zhengzhou Shang City and Yinxu demonstrates the extensive use of water management systems in both early and late Shang capitals, indicating that as early as the beginning of the Bronze Age, hydraulic engineering had already become a critical component of urban construction. This suggests that water management should be given high priority in urban archaeological studies. The distinct features of water facilities in each city also reflect variations in design philosophy and functionality, aspects that are significantly illuminated through the use of digital tools such as remote sensing and GIS.

We conclude that spatial analysis methods are invaluable for archaeological research on ancient water systems globally. The application of digital archaeological approaches not only enhances our understanding of site-specific characteristics but also offers new insights into the broader role of water management in ancient urban societies worldwide.

426. Statistical Modelling of Agricultural and Settlement Dynamics in Late Bronze Age city-state of Ugarit

Cristiana Liberati (University of Rome "La Sapienza")*; Giacomo Bilotti (Kiel University)

The site of Ras Shamra, ancient Ugarit, located on the northern coast of Syria (Lattakia Governorate), is an outstanding example of a multi-layered archaeological context due to its continuous occupation from the Neolithic period until the end of the 2nd millennium B.C. In particular, the Late Bronze Age city (1600–1200 BC) represents an unique site in the Levantine archaeological landscape. The destruction of the city at the end of the 12th century BC. left its remains buried beneath the surface, allowing archaeologists to uncover a remarkably well-preserved urban layout. This includes a complex network of streets, squares, residential quarters, temples, and the royal palace (Yon 2006). Moreover, valuable insights into the history of the city's final days, as well as its socio-economic and political structures, have been provided by the discovery of a large number of inscribed tablets. Thanks to this extensive corpus of textual evidence, numerous aspects of the kingdom's economy and administration have been reconstructed.

The richness and quality of the archaeological and historical data have inspired the application of modelling techniques to explore how these methods can enhance our understanding of settlement dynamics and demography in a complex urban context, surpassing traditional historical approaches. Previous studies, based on historical data, have extensively explored these topics, focusing on the reconstruction of the kingdom's topography (Van Soldt 2005) and its demography, employing various methods primarily based on an average number of inhabitants per village (Vidal 2014).

The aim of this paper is to advance these techniques by integrating the kingdom's agricultural capacity and its network of villages and subordinate settlements to better understand its organisation. Furthermore, we aim to provide a more statistically framed reconstruction, accounting for the underlying uncertainty, which has been seldom addressed in previous studies on the Late Bronze Age Levant. Building on these findings, the paper seeks to estimate the kingdom's carrying capacity. Suitability maps for the three primary crops in the kingdom's economy—cereals, olives, and vines—were created using QGIS. These maps were then used to identify areas more likely to have hosted productive sites dependent on the kingdom. Based on previous research on ancient texts, it has been estimated that there were approximately 200 hamlets supplying Ugarit with these products. Toponymical research has helped identify 17 of these hamlets, mostly located in the vicinity of Ugarit or along the coast (Van Soldt 2005).

Here, we employ point pattern analysis (PPA) to combine archaeological knowledge with agricultural productivity data to identify areas most likely to have hosted these villages. PPA is an established statistical technique that investigates first- and second-order effects, notably site relations to the environment—in this case, agricultural suitability—and site interaction (Baddeley et al. 2016). The result can be used to create a likelihood map and to study the internal organisation of the kingdom. By running a realisation of the obtained process model using a Monte Carlo simulation approach, it is possible to estimate the carrying capacity of the kingdom, which can then inform the possible range of its agricultural productivity.

The results offer a renewed perspective on the kingdom's hinterland during the Late Bronze Age, identifying areas most suitable for village locations based on economic factors. Furthermore, the carrying capacity estimation provides new insights, evaluates the reliability of previous population estimates, and determines the extent to which the kingdom could sustain its estimated population and export capacities.

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399. Population Churn and Persistence

Katherine Crawford (Arizona State University); Daniel Lawrence (Durham University); Alessio Palmisano (University of Turin); Iza Romanowska (Aarhus University)*

The scientific challenge of understanding the sources of social resilience in the face of environmental, social and political challenges is of fundamental importance for fostering strong, sustainable communities now and in the future. Archaeology, with its long-term perspective and relevant data, is uniquely positioned to look beyond simple assessments of risks and their mitigations and uncover the fundamental forces that shape the resilience of human systems at a range of scales. However, archaeology's potential for understanding the dynamics of social resilience and human responses to crisis, and for using the past to prepare for the future, is still to be fulfilled. Large-scale comparative studies are the primary means of advancing this line of research. Project CHURN: Changes in Human Urban and Rural Networks is such an attempt at characterising the dynamics of population resilience measured through landscape level persistence and total net change across Southwest Asia over the last ten thousand years.

Southwest Asia represents an excellent region in which to analyse past settlement dynamics because of the long history of both complex societies and archaeological study, particularly surveys. It is also a predominantly dryland environment, meaning small changes in precipitation can have dramatic effects on local affordances, and experienced several climate effects during the past 10,000 years. These include the well known 8.2kya and 4.2kya events and the Late Bronze Age collapse. Diachronic settlement studies focused on understanding these have tended to use substantial declines in population as evidence for societal collapse, with regional variation demonstrating pockets of resilience. However, these do not take into account baseline rates of settlement abandonment and new occupation. This study investigates population trends and settlement dynamics in the study region using a combination of computational methods applied to settlement data. Our primary objectives include identifying general population trends overall and by region, and distinguishing urban and rural trends. We also utilise the concept of 'churn', meaning net settlement changes over time to detect significant variations from baseline trends and explore correlations with climate and political shifts. The data includes archaeo-demographic and palaeoclimatic indicators from the Late Pleistocene to the Late Holocene, focusing on South-central Anatolia, Upper Mesopotamia, the Levant and Cyprus. Archaeological settlement data were harmonised from survey reports and online resources, drawing from the Digital Archaeological Atlas of the Holy Land, the West Bank and East Jerusalem Archaeological Database, and the CLaSS project database at Durham University, as well as additional desk-based research. Sites were geo-referenced and standardized by cultural periods defined in calendric years to facilitate regional comparisons. Only habitation sites were included, while non-residential contexts such as cemeteries and mines were excluded. This curated dataset has good coverage from approximately 10,000 to 500 cal. BP, that provides a robust framework for examining settlement patterns and demographic changes across multiple regions and time periods.
We leverage an updated approach to settlement data analysis, building on earlier work (Palmisano et al. 2021) that primarily used settlement data to validate radiocarbon datasets. For this project, we adopt Bayesian modelling methods (Crema 2024) to enhance accuracy and contrast results with previously applied aoristic methods. Data points include settlement counts and their associated areas, where available. A default area of 1 hectare is assumed for sites without recorded areas. Continuity during transitional periods, such as "Dark Ages", for which there is limited archaeological evidence will be explicitly considered. Finally, comparative

evaluation of Bayesian and aoristic methods will highlight methodological implications for population estimation in archaeological research.
The churn analysis focuses on net settlement change by region, tracking site continuity and the emergence of new settlements. We apply statistical methods to establish baseline churn rates and identify deviations beyond confidence intervals. For deeper insights, we explore advanced techniques, such as self-correlation and historical event analysis, to relate churn anomalies to climatic and political disruptions.
Understanding settlement change is fundamental to interpreting phenomena such as societal collapse or decline. Settlement abandonment and foundations are stochastic processes occurring for diverse reasons, and it is essential to establish a baseline of "normal" churn to identify anomalies indicative of broader disruptions. Prior research has demonstrated that settlement persistence decreases over time, raising questions about how baselines themselves evolve. For instance, deviations beyond typical rates of settlement persistence or churn may signal significant events such as climatic stress or political instability. Conversely, this study can act as an inoculant against approaches which correlate climate events with periods of collapse or decline based on a limited sample of sites. This study emphasizes the importance of recognizing and addressing these shifts while exploring whether changes exceed expected variability. By integrating these considerations, we aim to refine the understanding of settlement dynamics and contribute to broader discussions about societal resilience and transformation.

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168. Roots of Memory: The Application of Digital Preservation Methods in Protecting Biocultural Heritage Sites in Alberta, Canada

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Heritage has largely been explored from perspectives wherein valued heritage sites have oft been physical, permanent structures. However, this system of heritage undervalues the role landscapes and biological features have played in historical events and their value as sites of memory (Lindholm & Ekbolm 2019). Landscapes are a crossroads where intangible heritage, such as stories, meet physical heritage, including those of the biological and botanical kind. Biocultural heritage is the understanding of cultural landscapes from a perspective acknowledging the long-term biological and social relationships, shaping the biological features of the landscape in addition to shaping memory, experience, and knowledge (Lindholm & Ekbolm 2019, 2). Biocultural heritage acknowledges the importance of these natural, human influenced features of landscapes and emphasizes how they can be used as means of understanding history (Eriksson 2018). In Canada, much of the work within this field has primarily explored biodiversity and 'pristine' heritage landscapes, such as the Rocky Mountain parks (Cafarella et al. 2021). However, this overlooks a large number of potential heritage sites that are natural but are associated with community memories rather than the historic natural biology of an area.

In this paper, we discuss how to bridge this gap in heritage discourse through the application of digital preservation methodologies at biocultural heritage sites in Alberta, Canada. We examine the potential of terrestrial laser scanning biological feature using two case studies, the Stampede Elm and the Burmis Tree as well as discuss the future applications of these preservation methods at Indian Residential School sites based on the outcomes of the case studies. Both case study sites are heritage trees tied to community memory and have been or are at threat of being destroyed (Roudavski & Rutten 2020). The Stampede Elm was an elm tree located in the Victoria Park area of Calgary, Alberta on the Calgary Stampede grounds and was estimated to have been at least 120 years old when our team scanned it. We scanned this tree using the Z+F 5010x IMAGER terrestrial LiDAR laser scanner in 2021 and it was removed from the Stampede grounds in 2024. The Burmis Tree is a limber pine tree located in the Crowsnest Pass in southern Alberta that is estimated to have been 600 to 750 years old at the time of its death in the 1970s. As the tree has become more delicate, there is concern that the tree needs to be relocated. We scanned this tree in 2024 using the Z+F 5010X IMAGER and the GeoSLAM ZEB Horizon terrestrial LiDAR laser scanners. The digital point clouds for these sites are now housed in the Digitally Preserving Alberta's Diverse Cultural Heritage archive (https://alberta.preserve.ucalgary.ca/).

We examine how the case studies highlight the positive outcomes of using these methods for community-valued biological heritage as well as the challenges faced in using technology mainly designed for capturing built structures. The implications of the preservation of these heritage trees extends to furthering the use of digital preservation in heritage circumstances where there are no built structures remaining. Specifically, we discuss the potential for applying these methods in the preservation of Indian Residential School sites where structures no longer stand. Although the case study sites have a vastly different history compared to Indian Residential Schools, the Stampede Elm and the Burmis Tree still serve as important examples in how digital preservation methods can be applied at Indian Residential Schools that have similar biological heritage features, such as trees and hedgerows. The application potential of digital preservation is substantial and stands to aid in preserving any biological heritage sites that are closely tied to memory. The Stampede Elm, the Burmis Tree, and Indian Residential School grounds all have community-based memories associated with them, although different in nature, which supports the use of similar preservation methodologies.

Memorializing the sites of Indian Residential Schools and their associated landscapes, in order to continue to remember the tragedies that occurred there, is a critical desire for many Indigenous communities in Canada. Although many of the physical school buildings no longer exist, the schoolgrounds, vegetation, and the intangible aspects of those institutions still impact the communities forced to attend. It is paramount that the commemoration of these sites is completed through means that preserve the features of the sites that the associated Indigenous communities deem important. This means that methods to commemorate Indian Residential School sites that no longer have physical structures must be explored and used in an effort to meaningfully protect the heritage of Indigenous communities across Canada. Finding ways to commemorate former residential school sites is also among the Truth and Reconciliation Commission of Canada's Calls to Action (TRC 2015). Our team has developed a digital archive for the commemoration of the three remaining school structures in Alberta (https://irs.preserve.ucalgary.ca/), but we are now seeking to expand the preservation effort to include important landscape features identified by survivors of these schools. The initial steps taken thus far will be discussed and using the outcomes of the terrestrial LiDAR in the case studies, the potential for future capture of hedgerows, trees, and other biological heritage features at Indian Residential School sites in Alberta is assessed.

Overall, the value of preserving culturally-tied biological heritage as important markers of past human events must be examined. The case studies, as well as the future work at Indian Residential Schools, serves to highlight the value of considering the vegetal remains in preservation efforts and the ability to use digital preservation methods as a means to ensure commemoration into the future.

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405. Digital Archaeology Meets Participatory Research: Integrating Digital Tools, Public Engagement and Evaluation at Vignale-Riotorto, Italy

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This paper explores the integration of digital methodologies with community-based participatory research in archaeological research through the “Uomini e Cose a Vignale” and “ArcheologicaMente” projects, conducted in Vignale-Riotorto, Italy. These initiatives employed a bottom-up approach to investigate a coastal landscape that underwent significant transformations in the 19th-20th centuries, including land reclamation, field redistribution and the building of transport infrastructures. Our research highlights the qualitative evaluation of digital tools, methodological frameworks, and stakeholder involvement to bridge the gap between scientific research and public engagement.

The project combined digital technologies including low-resolution LiDAR data analysis, systematic field surveys aided by the use of QField and QFieldCloud on mobile devices for field data collection, and drone-based mapping. This approach revealed the substantial extent of a medieval castle complex, including extramural settlements and productive zones. These findings highlight the value of digital tools in uncovering archaeological features.

The investigation of the landscape was made possible through the active involvement of local residents in key archaeological activities, including the restoration of overgrown pathways, the organisation of events open to public participation, and the co-creation of interpretative materials designed to enhance the understanding and appreciation of the site. This participatory approach fostered a stronger connection with the local community, creating a sense of belonging and investment in the site's heritage. These engagement strategies will be evaluated, focusing on their impact on well-being and long-term site stewardship. Additionally, the impact of public archaeology activities will be assessed in terms of their contribution to understanding the landscape and its potential for future research and heritage management.

The historical information and data collected during the study of the site serve as the basis for two multimedia products: a Minecraft-based interactive experience of the castle hill and a 3D virtual tour of the area. The Minecraft experience engages players in exploring the hill where Vignale Castle is located through a series of archaeological-based activities. The virtual tour enables users to explore historical maps and highlights the archaeological features identified during the survey campaign. Both products offer an engaging and immersive way to connect with the site's history and archaeology. The use of digital tools was critically assessed throughout the project, with a focus on their usability and accessibility for diverse stakeholders, and sustainability for the research group.

This paper contributes to the broader discussion on integrating different technologies with community-driven practices in archaeology. It emphasises the need for reflexive evaluation of tools and methodologies to ensure their relevance and scalability, both for researchers and for public stakeholders.

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From site to V-site: surveying and visiting the castle hill in reality and in the Minecraft environment

315. Designing a Mobile Digital Application for the Museum of Asia Minor Culture: Enhancing Intangible Cultural Heritage through Digital Storytelling

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Introduction

The Asia Minor Catastrophe (1922) marked a pivotal moment in modern history, resulting in the forced migration of millions of individuals and the loss of invaluable tangible and intangible cultural heritage. The Museum of Asia Minor Culture in Aigaleo, Greece, aims to preserve the memory and traditions of Asia Minor refugees, who carried with them fragments of their cultural identity amidst destruction and displacement. This study explores the development of a mobile digital application that leverages interactive storytelling to document and safeguard intangible cultural heritage (ICH) tied to such historical conflicts (Smith, 2020). By drawing connections between past and present crises, the research highlights how digital tools can bridge the gap between tangible exhibits and the cultural traditions of displaced communities.

Methods and Materials

The research employed a mixed-methods approach, incorporating qualitative data collection from oral histories, archival photographs, and traditional artifacts. Technical implementation included the design and prototyping of the mobile application using state-of-the-art development tools and frameworks. Digital storytelling techniques were central to the design, integrating multimedia elements such as video, audio narrations, 3d modelling and interactive visuals. This approach draws inspiration from contemporary methodologies in digital cultural heritage, which emphasize participatory and immersive experiences (Cameron and Kenderdine 2007). User experience (UX) design principles were applied to ensure accessibility and engagement, while iterative usability testing involved target audiences, including museum visitors and Asia Minor cultural experts.

Results

The mobile application successfully linked the tangible and intangible cultural heritage of Asia Minor refugees by providing users with an immersive exploration of historical narratives, daily life stories, and traditions. Preliminary testing indicated increased visitor engagement, with users reporting a deeper understanding of the museum’s exhibits and the broader cultural context. Furthermore, interactive features such as virtual tours, narrated life stories, and multimedia galleries enhanced the personalization and relatability of the content.

Discussion

This research demonstrates the transformative potential of mobile digital applications in cultural heritage preservation and education. By emphasizing digital storytelling, the application bridges the gap between tangible artifacts and intangible traditions, making cultural heritage more accessible and engaging for diverse audiences (Trichopoulos, 2021). The study also highlights the value of leveraging technology to support museums in their mission to preserve and disseminate cultural heritage. These findings align with broader discussions on the role of digital tools in safeguarding ICH, particularly in making heritage accessible to younger generations and global audiences (Cameron and Kenderdine 2008). This project offers a valuable case study for museums and cultural institutions, providing practical insights for similar initiatives worldwide.

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425. Digital storytelling in museums and cultural heritage: an effective tool to promote and disseminate impactful research for new generations

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Digital storytelling is the evolved modern expression of the ancient art of storytelling combined with a mix of digital media, such as text, images, narration, music, and video. Since ancient times, storytelling has been used as a means of education, entertainment, preservation of culture, and a way to instill knowledge, values, and morals. Scientists believe that digital storytelling stimulates simultaneously the use of the logical and creative parts of the brain, meaning that people perceive information both visually and emotionally. The digital society has opened new opportunities for storytelling, offering new tools and environments for expression and sharing, mainly using social media. Can museums and cultural heritage promote and disseminate their research and activities for new generations (Millennials, Gen Z and Gen Alpha) using digital storytelling and how?
To discover this possibility, an online survey conducted using closed-ended questionnaires among Millennials studying and working at Greek universities. Given the fact that the literature on Greek Millennials is almost non-existent, such a survey was deemed necessary in order to record and analyze the trends and characteristics of Greek Millennials. Aiming to achieve a representative sample, the electronic questionnaire was distributed in such a way that all Millennials at Greek universities had the opportunity to participate in the survey. The survey questions focused mainly on issues of media use, such as duration and reasons for use, but also on issues that highlight their preferences in the cultural sector, the frequency of their visits to museums, the reasons why they visit or do not visit museums, as well as what they consider to be the most appropriate means to attract them to museums.
After analyzing and evaluating these data, three different digital storytelling videos was created for selected archaeological museums in Greece (the Acropolis Museum, the Museum of Cycladic Art, Archaeological Museum of Thessaloniki, Museum of Byzantine Culture). These digital storytelling videos highlight only certain aspects of the museums' exhibits in a humorous and unpretentious way and not in the strict and academic sense that is often a barrier to understanding the content by people who are not experts in archaeology. Once the digital storytelling videos has been deemed suitable, focus groups was conducted with Greek Millennials in order to produce data and insights that would explore and clarify participants' beliefs, opinions, and views on how to endorse archeological museums by employing digital storytelling. Specifically, it revolves around the impressions and feelings created by these digital stories, the associations with plot and characters, the clarity level of the message and the contingency on learning something new. This kind of feedback-evaluation in turn offers avenues for improvement in digital storytelling. In addition, the participants debated their interest in visiting the museums upon viewing digital stories and whether they would share these digital stories on social media. The data analyzed follows an initial round of findings by further examining results identified via frequency, proportional representation, interaction or perceptions of shared experiences.
Greece has about three hundred museums, more than one third of which are museums of archaeology and a lot more cultural heritage sites. What the public expects from museums is changing, particularly among the digital-native generations of Millennials, Gen Z and Gen Alpha, which now comprises the target audiences of many museums. Museums must innovate and promote their collections in creative new ways and digital storytelling, now well established as an

all-around communication tool for businesses to connect in depth with their target audience, can be an increasingly focus for museums and cultural heritage.

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186. Digitally Preserving Collapsed Heritage Buildings: the Leavings

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Reality capture technologies such as photogrammetry and terrestrial LiDAR scanning are being increasingly used to record heritage structures at risk of loss. Much of this work has focused on intact buildings, even though most heritage structures exist in varying states of collapse (Hvidberg 2020). My paper compares two reality capture technologies frequently used in digital heritage documentation: mobile and stationary terrestrial laser scanning (TLS), specifically the GeoSLAM ZEB Horizon and the Z+F 5010X IMAGER. Comparing these scanners will help to flush out the methodology by documenting a partially collapsed NWMP barn from 1884, which is at risk of loss. The Leavings site, near Claresholm, Alberta, is a provincially designated historic resource(Alberta Historic Places 2017) and has some of the oldest buildings in Southern Alberta. Named for its location along the Macleod Trail/Old North Trail, it provided a last chance for travellers to gather resources before crossing the prairie(Amundsen-Meyer 2012; Schelten-Cornish 1991). Prior to its first historical documentation in 1875, the Leavings had a rich history of precontact use that can be seen in the presence of cairns and effigies, which helps to substantiate the use of this landscape as a stopover or campsite. Henry Kountz, a whiskey trader and buffalo hunter, utilized the Leavings as a stopover in the 1870s, and it later became the second headquarters of the Oxley Ranch and a North West Mounted Police (NWMP) station in the 1880s. Since the 1940s, it has been operated as a ranch by the Maurushat family(Amundsen-Meyer, 2012).

Methods and Materials
The Leavings barn was scanned twice—first in May 2024 using the GeoSLAM and again in July 2024 with the Z+F 5010X. The two methods of scanning resulted in differences in scan time, points per second, relative accuracy, field of view, range, and equipment weight. In addition to technical specification differences, workflow methodologies varied. The GeoSLAM, weighing approximately 6 lbs (2.85 kg), requires steady motion during scanning to ensure accurate data capture, especially for overhead areas like the roof. The device must be held at a level angle to maintain scan quality, and the operator should walk smoothly. The Z+F 5010X, weighing 9.8 kg (21.6 lbs), is a stationary scanner mounted on a tripod that requires repositioning at multiple locations to gather enough data for a complete point cloud. The barn was scanned 20 times in a circular pattern to ensure full coverage. When setting up the 5010X, the scanner must be placed at a minimum distance (1 metre) from the previous position to aid in registration ("2-ZF-Imager-5010X-Datasheet.Pdf," n.d.). Both scanning methods are most effective when a predetermined path is followed, helping to avoid obstructions and ensure structure coverage (CSIRO, n.d.).

Results
The GeoSLAM scanner completed the scan of the barn within 45 minutes, making it highly efficient for mobile use, particularly in indoor settings with complex terrain. The Z+F 5010X, though more time-consuming (requiring over 4 hours for a complete scan), provided higher accuracy and resolution. When comparing the point clouds from both devices, differences in data quality were observed, particularly in areas where collapsed portions of the barn created occlusions. Despite this, both scanners effectively captured the structure's features. These differences could reflect structural alterations or shifts in alignment between the scans, which helps monitor changes in construction, terrain, or objects within the scanned environment over time.

Discussion

The GeoSLAM ZEB Horizon and the Z+F 5010X differ in their specifications and applications. The GeoSLAM is a lightweight, portable scanner designed for quick, mobile scanning, making it ideal for complex terrains and buildings in states of collapse. It offers real-time data processing and can capture data in various conditions. In contrast, the Z+F 5010X is a stationary scanner known for its high precision and resolution. It is set up on a tripod and does best in controlled environments. While the GeoSLAM works best when speed and safety are essential, the Z+F 5010X prioritizes accuracy and detail, making each suitable for heritage documentation needs. The results of this research have broader implications for heritage preservation, particularly for structures at risk of collapse due to environmental factors. The comparison of mobile and stationary scanning technologies showcases the trade-offs between speed, accuracy, and ease of use. This suggests combining both may offer the best approach for documenting collapsed heritage sites. Furthermore, this paper provides guidelines for TLS technology practices, contributing to a growing knowledge of digital heritage preservation.

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472. Bridging 3D Documentation and Traditional Methods in the Study of Miniature Objects: A Case Study of Human Body Representations on Bronze Age Aegean Seals

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Introduction

Archaeology is a visual discipline that relies heavily on various visualisation methods to record, interpret, and communicate complex narratives about the past (Opgenhaffen 2021). Despite this reliance, there is a notable lack of awareness among archaeologists regarding how contemporary digital technologies influence their visualisation practices and vice versa. While traditional methods like manual illustration and photography remain prevalent, the adoption of digital 3D technologies has not been uniform. Furthermore, the automation of existing digital practices has not necessarily resulted in the production of new knowledge, indicating a disconnect between technology adoption and effective knowledge generation.

Techniques such as laser or structured light scanning, photogrammetry, and reflectance transformation imaging have been extensively employed in recent years to digitally document archaeological artefacts. Despite the growing prevalence of 3D scanning technologies in the documentation of archaeological artefacts, their application to recording micrographic objects, such as seals, remains exceedingly rare (Bogacz et al. 2020; Finlayson et al. 2021). The current research aims to implement digital approaches for the documentation and computational analysis of seals and seal impressions with human body representations, with the objective of evaluating traditional documentation methods.

Bronze Age Aegean Seal Images

Seals are small, portable artefacts that functioned as communicative media circulating throughout the Aegean islands and Greek mainland during the Bronze Age. They are crafted from various and feature engraved designs on one or more faces, which create relief images when pressed into softer materials such as clay.

The Aegean region has produced over 10,000 Bronze Age seals and seal impressions, a key source for Aegean iconography. Modern impressions and casts of over 12,000 seal faces are available in the Corpus of Minoan and Mycenaean Seals (CMS) at the University of Heidelberg. This archive, combined with its online database and publications, enables comparative studies of glyptic material worldwide. This paper aims to explore the similarities and differences between traditional and digital methods of studying human

representations on Bronze Age seals, while also assessing the effectiveness of traditional approaches in light of 3D analysis.

Methods

The ongoing research employs a 3D approach to analyse Minoan and Mycenaean seal images. Specifically, 20 original stone seals and 7 clay sealings currently situated in Greek archaeological museums have been scanned alongside 98 modern seal impressions and casts from the CMS archive using the same scanner and procedure. A high-resolution portable structured-light scanner (HP 3D Scan Pro v5) was employed in order to scan both the original seals and the modern seal impressions. Additionally, colour correction was applied to each scan in order to ensure consistent results across the entire dataset. The post-processing of the different scans, including alignment, merging, and rendering was conducted using several software applications including the internal software of the HP Scan Pro v5 scanner, Meshlab, Gigamesh, and Blender.

A total of 125 3D models have been produced as a basis for applying various computational methods. The use of Gigamesh enables precise measurements of geometrical shapes and dimensions for dual purposes: firstly, shape analysis allows for comparison between original seals and their modern impressions; secondly, it illuminates engraving methods and techniques applied to stone seals, thereby enhancing our understanding of seal glyptic processes.

Preliminary Results

The application of computational methods, such as measuring micrographic distances and calculating tool mark depths on Bronze Age seals, has facilitated the identification of diverse engraving and carving techniques resulting from various tools. Using human body representations as a case study, 3D analysis largely corroborated observations derived from macroscopic and microscopic examinations of the same materials. Specifically, during the Early and Middle Bronze Age, human figures were predominantly depicted in a summary and abstract manner with minimal emphasis on specific bodily features; this was largely due to the local availability of soft stones for seal manufacture and their carving with hand tools. In contrast, during the Late Bronze Age, human figures were represented in a naturalistic and detailed manner with an emphasis on gender differences. Digital analysis confirmed that this shift was attributed to increased use of semi-precious hard stones and metals alongside the adoption of rotary tools for engraving.

Discussion

The adoption of 3D documentation methodologies for seals enables comprehensive recording of detailed three-dimensional information, including size, texture, and colour, without requiring direct access to the physical object. While results from such scans are frequently accessed through 2D interfaces (e.g., screens), they offer dynamic interaction capabilities. Researchers can rotate, illuminate, magnify, and explore these virtual representations, closely mimic hands-on examination of original artefacts. These attributes facilitate an in-depth study of the technological processes involved in creating seals, or the gestures required for impressing them on fresh clay.

Observations regarding operational sequences can serve as evaluative factors for traditional methods such as hand drawings, photographs, or modern impressions on soft materials. Simultaneously, traditional methods can assess 3D documentation results by challenging photorealistic reproductions against geometric accuracy. This mutual evaluation process underscores the necessity for a reflective approach that scrutinises in detail both practices or gestures involved in producing 3D objects and the creation of a dynamic methodology for holistically studying miniature seals and seal impressions.

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336. New research perspectives on LiDAR in Central Italy for understanding Final Bronze Age and Early Iron Age highland contexts: an overview of drone LiDAR survey possibilities

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Introduction

The exploration and documentation of archaeological contexts in highland areas of Central Italy have often been neglected due to extensive reforestation campaigns carried out during the last century. Consequently, many of these areas have remained marginal in recent archaeological research, except for some studies conducted by Andrea Cardarelli and Laura Bonomi Ponzi on specific sectors and different chronologies. However, the spread of increasingly advanced remote sensing technologies has opened new opportunities for territorial study and has encouraged the implementation of projects based on the use and subsequent development of these techniques for archaeological purposes. Among these, LiDAR proves fundamental for its ability to distinguish between vegetation and anthropic structures, thanks to the reflection coefficient of objects, allowing for precise reproduction of the environment.

Interest in the mountainous areas of the Apennines is fuelled by the availability of LiDAR data that was processed between 2008 and 2009 by the then Ministry of Environment (now Ministry of Environment and Energy Security) for purposes other than archaeological research, but which has enabled new research through the reprocessing of the same point clouds. However, this is not sufficient for conducting in-depth analyses of the area of interest; in fact, the available LiDAR coverage for Central Italy covers only 42% of the territory.

Method

To understand the archaeological record during the Final Bronze Age and Early Iron Age in the highland areas of Central Italy, an integrated database was created within a GIS system. It incorporated data derived from bibliographic research aimed at identifying contexts characterized by artificial defense systems. These data were subsequently verified through remote surveys using Italian ministerial LiDAR to identify any visible and recognizable traces. Additionally, a mapping of potential archaeological contexts was carried out, leading to the identification of 1122 new sites with LiDAR anomalies within an area of 26,431 km^2, corresponding to the portion of territory covered by LiDAR, out of a total of 68,858 km^2. Of these, bibliographic and chronological information, often generic, was only obtainable for 25% of the sites. However, many fundamental contexts for understanding the dynamics of protohistoric occupation and territorial control fall within the territory without LiDAR coverage, including Monte Croce Guardia (Arcevia -- AN). This already known settlement is the subject of new LiDAR investigations for better understanding of archaeological data through the use of the DJI Matrice 350 RTK drone and LiDAR sensors CHC AlphaAir 10 and DJI Zenmuse L1.

Results

The settlement of Monte Croce Guardia (Arcevia, AN) has been the subject of various excavation campaigns in different temporal phases. The first interventions date back to the 1960s, initiated following the discovery of structures during reforestation operations in the area. Subsequently, the site was reinvestigated in the late 1990s and, more recently, in a cycle of excavations conducted from 2015 to 2022 by Sapienza -- University of Rome. However, in none of these phases were artificial defense works recognized, which might today be concealed by the dense vegetation present in the area. The current LiDAR analysis aims to verify the presence of any traces of fortifications or other structures of archaeological interest, overcoming limitations related to vegetation coverage. For this investigation, two LiDAR sensors with different characteristics and capabilities are being used: the CHC AlphaAir 10 and the DJI Zenmuse L1, mounted on a DJI Matrice 350 RTK drone. The objective is twofold: on one hand, to identify hidden structures and improve knowledge of the site; on the other, to evaluate the specific potential of each sensor and their applicability in archaeological field. This methodology, which combines the analysis of detected anomalies with a systematic comparison between data collected from the two sensors, is part of a broader research context: it aims to optimize the use of LiDAR technologies for studying highland sites, where vegetation presence and access difficulties represent significant obstacles for traditional archaeological investigation.

Discussion

This work has two main goals: archaeological and technical. The first purpose concerns the identification of new traces of archaeological interest in areas covered by dense vegetation, often inaccessible through traditional investigation methods. In particular, it aims to answer unresolved questions about the presence of artificial defense works in sites like Monte Croce Guardia, where the absence of evidence during previous excavation campaigns might be due to the difficulty of direct ground analysis. The use of LiDAR, with its ability to penetrate vegetation and return detailed surface models, offers a unique opportunity to expand knowledge about fortification systems and other structures of archaeological interest. The second purpose, of a technical nature, focuses on comparing two LiDAR sensors with different characteristics and costs: the CHC AlphaAir 10, a high-end device, and the DJI Zenmuse L1, a more economical solution. Through the analysis of data collected in real operating conditions, the aim is to evaluate the performance of each sensor in terms of archaeological detail detection capability, terrain reconstruction accuracy, and reliability in discriminating between anthropic structures and natural formations. This comparison will not only determine the most suitable solution for specific archaeological contexts but will also contribute to defining new guidelines for the use of LiDAR technologies in future projects, optimizing available resources. This analysis constitutes one of the specific investigations of the author's ongoing doctoral thesis, aimed at exploring the potential of LiDAR technologies for archaeological documentation and the study of settlement dynamics in protohistoric times.

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519. New Perspectives on Iron Age Ringfort Landscapes in Öland, Sweden Based on UAV ALS/LiDAR Approaches

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Introduction
The study area for this paper is the Baltic island of Öland, located off the southeastern coast of Sweden. This elongated limestone island is characterized by a flat landscape exceptionally rich in historical and archaeological monuments (Fallgren 2006; 2008). Among them, group of ca.17 so called ringforts from the Iron Age (more precisely 3rd–7th century AD) can be described as particularly interesting. The most famous ones are fully excavated Eketorp ringfort, as well as only partially recognised through excavations Ismantorp and Sandby Borg ringforts. Within the latter one traces of a massacre from the late 5th century were discovered (Alfsdotter et al. 2018). The rest of the hillforts was only marginally investigated, which makes it difficult to fully understand their origins and significance.
The presented research was conducted as part of the interdisciplinary project "Crisis, Conflict and Climate: Social Change in Scandinavia 300–700 AD", which is focused on demography, climate, environment, politics and social change seen through the prism of the ringforts of Öland. One of the first activities conducted within this project was the acquisition of high-resolution LiDAR data. Its detailed analysis allowed subsequently to recognize, in much more precise manner than ever before, the internal structure of these objects, as well as to detect numerous potential archaeological features preserved within their surroundings, giving new insights into the recognition of the local cultural landscape, that can be related with the hillforts phenomenon. The second objective was to elaborate digital spatial framework for the results of the future phases of the project implementation.

Methods
Data was collected using two DJI LiDAR systems (L1 and L2) mounted on a UAV platform, which allowed for flexible flights at lower altitudes and acquisition of data which density ranged from 13 to 200 points per square meter (the Swedish national LiDAR data has a density ranging from 0.5 to 1 point per square meter). The obtained datasets were later processed to highlight minor topographic changes and gain a better understanding of the spatial layout of the hillforts interior, as well as their immediate surroundings. Acquired results were integrated within a GIS database, enabling visualization, comparison and further analysis.

Results and discussion
In total, 17 ringforts and alleged ringforts were surveyed, covering a cumulative area of 577 hectares. Thanks to elaborated digital elevation models (DEM) with significantly higher resolution than available governmental data, it was possible to discover previously unknown elements of the internal layout and potential archaeological structures near the ringforts.

Examples of the key observations:
• Vedby ringfort: A potential second line of ramparts was detected, intersecting the longitudinal geomorphological structure on which the ringfort is located.
• Träby and Triberga ringforts: new elements of the internal layout of the forts were discovered.
• Hässleby, Träby and Bårby ringforts: Numerous alleged barrows and other kinds of stone structures were identified near the hillforts.

• Triberga ringfort: Potential old roads and paths around the ringfort were discovered.
• Svartberga ringfort: The least preserved hillfort, only small parts of the main rampart is currently visible,however analysis of the terrain model has revealed blurred forms that may indicate the original extent of the hillfort.

Topographic analysis confirmed the thesis that hillforts were erected within areas of limited defensive significance (flat areas without elevations), which suggests their destination other than military. This issue will be the subject of further analysis within the project "Crisis, Conflict and Climate...”.

The obtained LiDAR data constitute an important step in documenting the state of preservation of these unique objects, which in some cases, despite seemingly visible erosion and large damages caused by farming activity, still have micromorphological features allowing the identification of significant parts of the internal structure. In other words, the conducted survey has not only recorded the current state of its preservation, but also discovered new, previously unnoticed elements, enriching our current knowledge about these objects.

Summary

This talk presents examples of the substantial potential of UAV based ALS/LiDAR applications in archaeology through the collection of data that aids precise documentation and analysis of sites. Newly identified elements of the earthworks and their direct vicinities contribute to a new understanding of Öland’s ringforts and their diverse spatial layouts and locations within the landscape. These findings support site protection efforts and establish a basis for further research, including geophysical and geochemical studies as well as archaeological excavations.

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311. Digitally Reconstructing an Invisible Polis: Airborne and Drone-based LiDAR Surveying and GIS Integration of Heterogeneous Data for Investigating the Archaeological Topography of Kamarina, Sicily

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Introduction

Syracusan colonists founded the Greek settlement of Kamarina at the beginning of the sixth century BC on Cammarana Hill, which overlooks the mouth of the Ippari River on the southern coast of Sicily (Ragusa Province, Italy) (Fig. 1). Kamarina grew significantly during the fifth century BC due to land reclamation and its strategic location, which controlled Central Mediterranean maritime traffic. By the end of the fourth century BC, the city underwent its most substantial urban expansion. Systematic archaeological excavations began under Paolo Orsi in 1896, focusing on several key areas, including the sanctuary of Athena and the agora in the southwestern sector of the hill (Pelagatti 2017), as well as the fortification walls and the southern sector (Di Stefano 2012). However, much of the city's history and topography still need to be explored by modern methods. For example, Kamarina’s entire northern sector, which was protected by fortification walls overlooking a channel harbor system at the mouth of the Ippari River, along with a commercial and artisan district (proasteion) located outside the city, remains largely unexplored.

Methods and Materials:

Our research began by integrating Kamarina’s topographical and archaeological data into a GIS, building on the results of previous excavations and surveys conducted at the site (Pelagatti 2017). The cartographic foundation we utilized includes a comprehensive series of historical maps, official cartography (scales ranging from 1:25,000 to 1:5,000), satellite imagery, and other remotely sensed legacy data, such as Digital Terrain Models provided by INGV (10 m resolution) and aerial laser scanning (ALS) data captured in 2015 by the Italian Ministry of the Environment (MATTM) with a scientific aircraft flying at high altitudes for coastal monitoring purposes. We post-processed the publicly available MATTM point cloud data covering the urban area of Kamarina and parts of its chora, or surrounding rural region (Fig. 2), through a new interpolation workflow proposed in a recent topographic study of South East Sicily (Brancato et al., 2024). Using the LAStools suite, we classified and filtered out modern buildings and vegetation in the MATTM dataset and generated a Digital Terrain Model (DTM) of Kamarina (Fig. 2). By creating a reconstruction of the site’s topography with a ground resolution of 0.5 m/pixel this initial DTM facilitates the detection of potential archaeological features through several square kilometers of the landscape. Therefore, we argue the MATTM dataset holds significant potential for contextualizing Sicilian archaeological sites on an exploratory scale. Using these data, we identified altimetric differences and geomorphological anomalies, particularly in the Southeast area of the hill. Based on these preliminary observations, we planned and executed a drone-based airborne laser scanning campaign at Kamarina to acquire higher-density data under the Mediterranean and fluvial vegetation covering the parts of the site we wanted to investigate further (Fig. 1d).

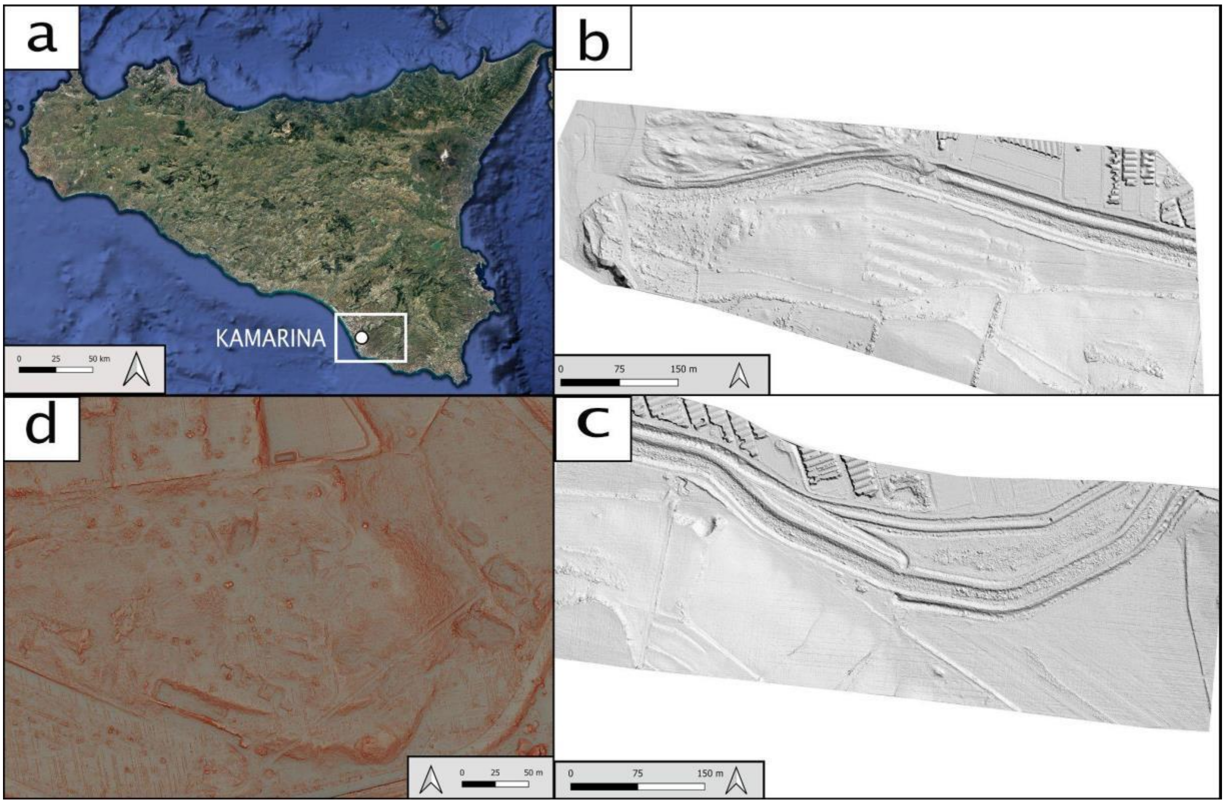

Figure 1. a) Location of Kamarina in southern Sicily; hillshade visualization of our drone-based ALS data for (b) Ippari River mouth and (c) its inland meander; d) modified Local Relief Model GIS visualization of the southeast Kamarina area, visualizing terrain under dense Mediterranean vegetation.

Utilizing a drone-based ALS workflow optimized to penetrate the Mediterranean vegetation of Southeastern Sicily (Calderone et al. 2024), we conducted a laser scanning campaign at Kamarina using a RIEGL VUX-UAV22 sensor mounted on a powerful AceCore Noa multi-rotor copter, capable of carrying payloads up to 25 kg. This drone-based ALS system allowed us to enhance the ground resolution of the derivative DTMs beyond what we obtained by interpolating MATTM ALS data. In September 2024, we flew the instrument at 60 m a.g.l. above Kamarina with a scan density of 400 points per m2, completing four flights covering approximately 80 hectares. Subsequently, we classified the resulting point clouds into 'ground,' 'vegetation,' and 'noise' using LAStools, which we also used to generate high-density DTMs with a 5cm/pixel ground resolution. Using these high-density ALS data, we produced hillshade visualizations that show the bare archaeological landscape with much more clarity than the MATTM dataset (Fig. 1c-1d). We then enhanced the derivative DTMs in the GIS, employing a custom Local Relief Model (LRM) to emphasize essential landforms and archaeological features (Fig. 1d). Finally, we integrated the MATTM-derived DTM and the drone-based DTMs into the GIS to aid our visual analysis of Kamarina's topography and urban form identifying some differences and anomalies that were not visible in the MATTM data. The interpretation of these anomalies is still ongoing, and further investigation of the data and additional ground truthing is necessary. However, our preliminary observations confirm that our multi-scale LiDAR approach allowed us to operate with remarkable precision and speed at both the landscape and intra-site levels.

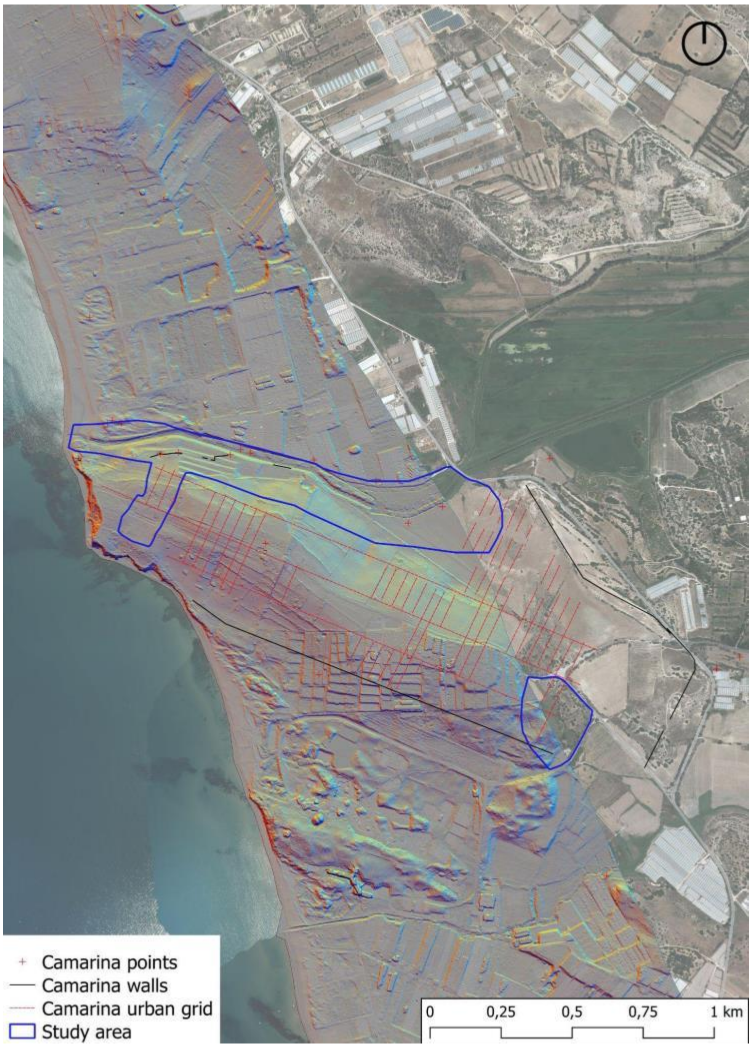

Figure 2. GIS visualization of Kamarina's legacy plan (red lines) on a MATTM ALS-derived DTM. The blue polygon indicates the areas for our 2024 drone-based LiDAR survey.

Results and Discussion:

Due to its geomorphology, this coastal site has always been vulnerable to erosion and is now at risk of sliding into the sea. In contrast, the northern sector of Kamarina, where the lower Ippari River valley extends, has likely experienced significant sedimentation, particularly at the river's mouth. Our new geospatial data can serve as the foundation for a new archaeological map of Kamarina. This map can aid in reconstructing the site's history, support territorial planning around the archaeological park, and contribute to its protection and enhancement policies. Urgent action is required from archaeologists and institutions to protect the archaeological heritage of ancient Kamarina, ensuring its preservation for future generations through focused geo-archaeological studies and environmental regeneration projects. Using non-invasive survey techniques such as LiDAR, we could contribute to protecting and studying this site by investigating hidden and buried structures, allowing for interdisciplinary research that combines archaeology, topography, and remote sensing. Our methodology enhances the understanding of Kamarina's ancient topography and changes that occurred at the river mouth and harbor system due to historical and modern land reclamation. This approach is crucial for reanalyzing complex sites like Kamarina, especially in challenging environments with Mediterranean vegetation and erosion, where traditional mapping methods are often limited.

In conclusion, our preliminary results at Kamarina indicate the viability of our proposed methodology, which integrates remote sensing survey data, both publicly available and collected using a drone-based ALS system with legacy archaeological data in a GIS environment. This data fusion allows us to generate new insights about complex archaeological sites that have been extensively studied using traditional techniques and are now threatened by various natural and human-made risks such as erosion, looting, and encroachment from intensive agriculture. Our future work at Kamarina will expand on these preliminary observations to further contribute to understanding the site topography and urban layout and enhance the site's protection.

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358. Drone-Based LiDAR Surveys of Prasat Khna and Prasat Trapeang Thnal Svay in Cambodia's Landmine-Affected Regions

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Introduction:
LiDAR (Light Detection and Ranging) technology has revolutionized archaeological research in tropical regions, particularly in Southeast Asia, where dense vegetation and difficult terrain often obscure ancient structures and urban patterns. In Cambodia, helicopter-based LiDAR surveys have enhanced our understanding of ancient cities, particularly the Angkor Archaeological Park, home to Angkor Wat (Evans et al. 2013). These surveys have revealed previously unknown structures, urban networks, and complex water management systems, prompting a reevaluation of the history of urban process and development in the region (Evans 2016). However, much of Cambodia's archaeological landscape remains inaccessible due to dense forests, rugged terrain, and unexploded ordnance (UXO) from past conflicts. Small, drone-based LiDAR technology offers a cost-effective solution to these challenges, enabling targeted mapping of previously inaccessible areas. This paper presents the 2024 LiDAR surveys of the temple centres of Prasat Khna (PKNA) and Prasat Trapeang Thnal Svay (PTTS), shedding light on their urban layouts and offering a model for future archaeological work in similar environments. Both sites, located in Preah Vihear Province in northern Cambodia, were established as political and religious centers under King Yaśovarman I in the late 9th century CE (Chea et al 2023). Many provincial sites lie outside the areas covered by earlier helicopter-based LiDAR surveys, leaving gaps in our understanding of their architectural and urban organization. Building on excavations and topographic surveys undertaken in 2019, this new LiDAR investigation significantly expands our knowledge of urban planning during the Angkorian period. The 2024 survey addresses two key research questions: How extensive were the urban networks surrounding PKNA and PTTS? Can LiDAR reveal previously unrecorded urban features—such as roads, canals, or neighborhoods—that are crucial to understanding the socio-political and economic systems of the region?

Methods and Materials:
The 2024 LiDAR surveys of PKNA and PTTS employed a Quantum Systems Trinity Pro fixed-wing drone equipped with a Qube 240 LiDAR sensor to capture high-resolution topographic data. The lightweight design and long endurance of the Trinity Pro make it ideal for dense tropical environments, allowing it to cover large areas in a single flight. The drone flew at 80 meters above the forest canopy to produce a high-density LiDAR point cloud that penetrated the vegetation. Prior to the survey, we calculated flight paths and parameters such as point density, pulse rate, and scan angle. A total of 6.5 square kilometers around PKNA and PTTS were surveyed at an average point density of 108 points/m^2, covering a much larger area than traditional mapping methods could manage. We established GPS and ground control points at key locations to ensure the accuracy of the data. The collected data was processed with Yellowscan Cloudstation software to classify point clouds to remove dense vegetation, and create digital elevation models (DEMs). We analyzed these models using QGIS to identify potential urban features such as building foundations, roads, water installations, and other infrastructure. The LiDAR data were cross-referenced with existing archaeological records to verify known structures and confirm new discoveries.

Results:

The 2024 LiDAR surveys expanded our understanding of the urban extent of both PKNA and PTTS and revealed previously unrecognized features in the surrounding landscape. Excavations within the ceremonial enclosures of both sites already provided valuable information on the monasteries of Yaśovarman I and Sūryavarman I (9th-11th centuries), but the LiDAR data revealed a much more extensive network of settlements and infrastructures around the core temple complexes. At PKNA, the survey revealed an unexpected urban scale, placing the central core of the site within a much larger earthen enclosure that was not previously known. Based on this survey, the previously known ritual core represents less than 5% of the entire urban site. Similarly, the LiDAR survey at PTTS uncovered a more complex urban settlement system surrounding the central temple, enriching our understanding of the site's layout. The surveys also revealed a variety of new features—such as basins, canals, thoroughfares, and mounds—an invaluable new dataset that will permit interpretation of historically distinct processes of urbanization in Southeast Asia during both the Angkorian and pre-Angkorian periods.

Discussion:

The application of drone-based LiDAR at PKNA and PTTS demonstrates the potential of this cost-effective method to survey large areas of tropical forest that are otherwise inaccessible due to landmines and difficult terrain. Traditional archaeological surveys in such regions are slow, labor-intensive, and dangerous. In contrast, drone-based LiDAR enables rapid, non-invasive data collection across vast areas, providing a comprehensive view of the landscape without requiring physical access to hazardous locations. The surveys also highlight LiDAR's ability to reveal urban features hidden beneath dense vegetation. LiDAR's capacity to penetrate the forest canopy and provide detailed topographic data has uncovered a wealth of previously unknown information about the layout and development of PKNA and PTTS, offering new insights into their role in the broader context of Angkorian and pre-Angkorian urbanism.

Furthermore, these findings underscore the value of advanced technologies in addressing gaps in archaeological knowledge. The urban complexities revealed by LiDAR are critical for understanding the socio-political and economic structures of the Khmer Empire. These discoveries provide a model for future archaeological research in Cambodia and other regions with similar environmental challenges, where traditional survey methods are impractical. In conclusion, the 2024 LiDAR surveys at PKNA and PTTS illustrate how small, drone-based LiDAR technology can revolutionize the study of ancient cities, particularly in difficult-to-access areas affected by landmines and rugged terrain. As LiDAR technology becomes more affordable and accessible, it is expected to play an increasingly important role in uncovering the hidden histories of ancient civilizations in Southeast Asia and beyond. The success of these surveys sets a promising precedent for future archaeological exploration and offers new opportunities to study ancient cities in ways that were previously unimaginable.

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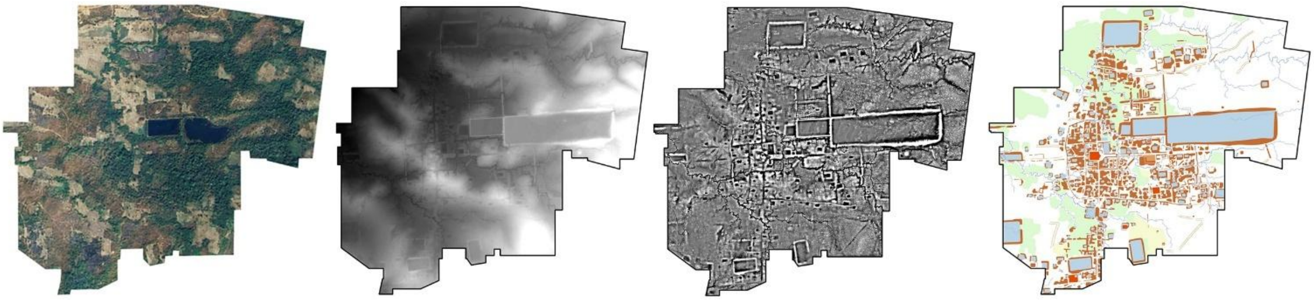

312. You Get What You Pay For? Evaluation of Drone Photogrammetry Software for Arctic Cultural Resource Management

Kelsey Pennanen (University of Calgary)*; Daniel Szot (Intergroup Consultants Ltd); Gabriella Prager (Intergroup Consultants Ltd); Tim Rast (Elfshot); Lori White (Elfshot)

This paper assesses the viability of various drone photogrammetric software for site mapping of archaeological features in the Canadian Arctic. An evaluation of three different software (Pix4DMapper, MapsMadeEasy, and WebODM) for aerial structure-from-motion (SfM) landscape reconstruction using two case studies from Baffin Island, Nunavut will be discussed. The Arctic provides a valuable opportunity to employ these new technological applications as it is rich in heritage and is a frontier of industrialization and commercialization. Although the Arctic presents a good locale for aerial landscape documentation due to limited vegetation coverage impeding visibility, it also presents a challenging environment due to extreme climates and remote logistics (see Walker 2020). Due to the remoteness of the sites, connecting to a known coordinate system can be challenging and therefore limiting to evaluate the efficacy of the data being collected. The results of this analysis have determined that drone photogrammetry was determined to be a beneficial tool for mapping Arctic sites, even without the use of ground control points (GCPs). Furthermore, as field seasons are so short in the area and logistically challenging to access (typically by helicopter or watercraft), it can be difficult to gather repeat datasets, and therefore collecting high-quality data as efficiently as possible is paramount. In this paper we provide an overview on the applicability of drone photogrammetry to meet cultural resource management (CRM) objectives in the Arctic with considerations for the client, government regulators, and heritage resource practitioners including cost, time, and resources.

For this analysis, we examine the accuracy and perform a cost-comparison analysis of the three software applications for the creation of 3D landscape reconstruction for archaeological site mapping and interpretation using two case studies. The first case study consists of an archaeological site on Baffin Island in Nunavut, Canada, homeland and traditional territory of the Inuit, comprising fox traps and tent rings dating to historic and modern time periods. Drone deployment at this locale took place in August 2021. The other case study is an archaeological site on northern Baffin Island consisting of a series of six features- five tent rings and a linear rock feature. Data collection for this site was conducted in July of 2023. As there is great variability of software options available, the authors determined that comparison of available photogrammetric software for the creation of photogrammetric data for detailed mapping of these sites was necessary. The three software being evaluated have differing payment structures; Pix4D has monthly billing options as well as a one-time purchase for a perpetual licence, MapsMadeEasy which is a subscription-based pay-per-use format, and WebODM as an open-source no/low-cost application.

Results of this analysis determined that open-source software (WebODM) provided an economically viable method of site documentation, the ground sampling distance (GSD) denoting the resolution of orthomosaics was found to be accurate to cm-scale precision. Paid subscription Pix4DMapper and pay-per-use MapsMadeEasy software were found to be accurate to sub-cm resolution. Pix4DMapper and WebODM georeferenced to each other within 25cm, and Maps Made Easy compared to Pix4DMapper and WebODM averaging 2-3m discrepancy. Each software accurately represented the topographic landscape and was found to be accurate to PolarDEM within 1-2m. A comparison of linear and transverse grid flight patterns for data collection was also conducted, and it was found that similar output resolutions could be obtained

by data capture using single grid flights as compared to a double grid thereby increasing efficiency of time in the field.
This paper includes an explanatory discussion on workflow efficiencies for expected timeframes/ labour hours, increased efficiencies for time in the field, training, hardware and software costs, fieldwork and weather constraints, challenges, and benefits. Due to the logistical challenges of Arctic fieldwork, including site remoteness and extreme climate, as well as the inherently destructive nature of archaeological excavation, this study was completed to provide evaluations relevant for data collection design.
The application of drone photogrammetry in the Arctic has been demonstrated for its efficiency in documenting rapidly changing sites. Archaeologists capturing a site with photography recognize that they are producing a legacy of a site and recognize the importance of using reliable and effective photographic strategies. A high standard of care must be practiced when observing and documenting archaeological heritage in the Arctic as the sites are often remote and challenging to access for repeat documentation. Using these collected datasets allows for further evaluation into the post-field processing and documentation, as well as comparisons of different data collection methods to determine the optimal workflow procedures for data collection in this region. This analysis provides valuable insight for heritage practitioners working in similar environments to increase the efficiency of fieldwork in order to meet output specifications and requirements. As such, this study provides insight into aerial photogrammetric processing software to ensure precise and meaningful data collection methods are employed.

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Walker, Samantha. 2020 Low-altitude aerial thermography for the archaeological investigation of arctic landscapes. Journal of Archaeological Science 117(105126): 1-15.

386. Prospection of Archaeological Sites as a Tool to Validate NIR-Based Methods for Detecting Underground Structures

Ioannis Lioumbas (Thessaloniki Water Supply and Sewerage Co. S.A.)*; Aikaterini Christodoulou (Thessaloniki Water Supply and Sewerage Co. S.A.); Alexandros Mentes (Thessaloniki Water Supply and Sewerage Co. S.A.); Petar Zidarov (Eberhard-Karls Universität Tübingen); Christian Tzankov (University of Mining and Geology "St. Ivan Rilski"); Dimitria Malamidou (Ephorate of Antiquities of Serres)

For water utilities, the use of non-invasive methods for monitoring water pipes (either for early leakages detection and maintenance purposes or for mapping of their exact position) is of crucial importance. Near-Infrared (NIR) sensors combined with the Unmanned Aerial Vehicles technology (UAV, aka. drone) have been extensively used in monitoring water networks but also in completely different applications such as studies of cultural and archaeological interest (Hadjimitsis et al. 2013). In any such case, NIR technology could be affected by environmental factors such as weather, soil moisture, and solar reflectance, which can complicate data acquisition and interpretation (Materazzi, 2022). Aiming to examine whether the above limitations could be overcome, this study aims to propose a protocol that could be used as a standard operational procedure to detect underground structures using a NIR drone based methodology. For that reason, tests were performed in a validated environment such as an archaeological site that has controlled variables such as buried structures at varying (and sometimes known) depths, diverse soil types, and varying vegetation cover. These controlled variables combined with data originating from other methodologies with higher accuracy, such as geophysical methods, could offer a great opportunity for validating the examined methodology.
This study highlights the essential need for interdisciplinary collaboration between the fields of NIR drone technology and archaeology to establish a standardized methodology applicable to both infrastructure monitoring methods and archaeological investigations. The produced big data, influenced by multiple parameters such as weather conditions, soil types, and vegetation, present both potential artifacts and valuable insights. This collaboration is essential for refining the methodology to account not only the environmental factors but also the logistics related to the flight missions and the processing times.

Methods and materials
The archaeological site chosen as a validation field is the archaeological site of Amphipolis, specifically the area within and beyond the Early Byzantine citadel. Aerial surveys over the ancient city of Amphipolis were conducted using a DJI Mavic 3m drone equipped with Near-Infrared (NIR) sensors and RGB cameras across three campaigns on 18/01/2024, 01/04/2024, and 25/05/2024. These flights covered a 6 km^2 area, in automated missions. with parallel flight paths at varying height, intervals and orientations. Figure 1 presents the total scanned area and the produced results. The surveys produced high-resolution 2D orthophoto maps with 1 cm spatial accuracy and 3D models with vertical accuracy between 5–10 cm. NIR data, captured across four spectral bands from 780 nm to 2500 nm, targeted vegetation indices like OSAVI and NDVI to identify vegetation stress and subsurface features.The combined NIR and RGB data yielded 0.5 TB of raw information. Image analysis was performed using Procreate software, where the main novelty of this work compared to literature is the methodology to create the final images by adjustments to intensity, luminosity, and image overlapping which enhanced the visibility of surface formations. The 2D and 3D maps were georeferenced and categorized using ArcGIS Pro for accurate spatial correlation. The magnetometry data, acquired by Zidarov and Tzankov applying a G-858 caesium magnetometer, were used as a reference to compare with the NIR data. This data captured variations in the magnetic field caused by stone walls with distinct magnetic properties from the

surrounding soil. High-pass filters were applied to remove interference from geological features and metal objects.

Results

Figure 1 presents the total scanned area, and the selected regime to show some indicative results. It focuses on a section of the Byzantine citadel, specifically the region east of the cistern. The top row presents a real-color (RGB) image of the scanned area, while in the middle and bottom rows, the left column displays Near-Infrared (NIR) imagery from the current study, while the right column provides magnetometry data, as previously documented by Zidarov and Tzankov. In the magnetometry results the black lines are for the detected subsurface features, including streets, walls, and building foundations and the cyan lines mark the architectural remains that are visible on the surface (traced using a dGPS). In the bottom row, a red marker indicates the area where the formations on surface look more coherent or to follow a pattern and maybe related to a subsurface construction. Interestingly, the NIR method shows a semicircular shape at a regime to the east of the cistern which is also visible in the magnetometry data. This overlap in both methods suggests the need for further archaeological investigation.

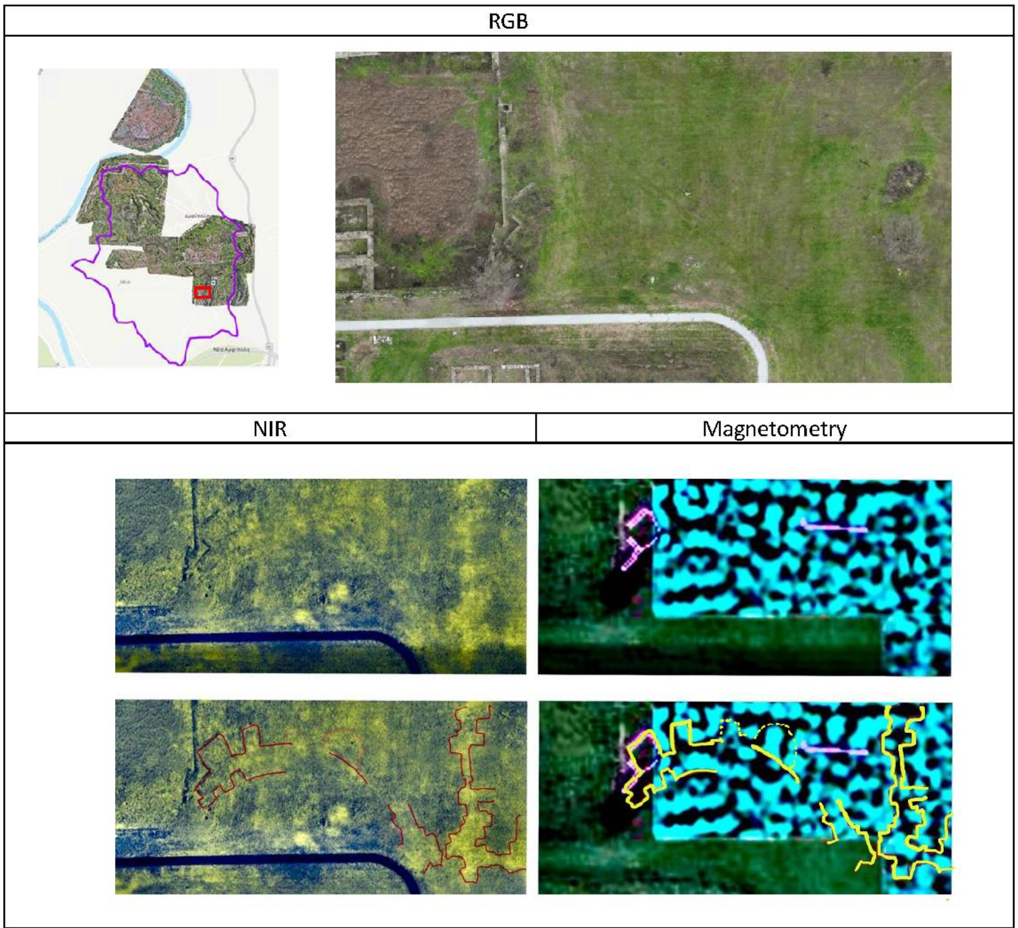

Figure 1. In the top row, both images show raw data of the scanned area. In the middleand last row, there are two sets of images comparing Near-Infrared (NIR) imagery (left) and magnetometry data (right). The red marks in the last row highlight formations that could possibly relate to buried structures. The magnetic maps are superimposed on satellite imagery (resolution 0.35x0.35m. Variation +/- 15nT).

The so far preliminary results suggest that the ability to detect surface formations was reduced as expected when the soil was dry, due to the decreased NIR reflectance caused by soil moisture uniform levels. Moreover, when the soil was dry in the warmer periods of year, the chlorophyll related indices did not exhibit the variation observed during the colder months. However, some of the preliminary results exhibit also other areas of possible interest, for future investigation, with more detailed methodologies or the repetition of the NIR campaigns. Finally, a preliminary cost-benefit analysis indicates the potential of the proposed methodology to be both efficient and cost-effective for detecting subsurface structures in various settings. Logistical challenges, but also the environmental conditions should be taken into account to maximize their effectiveness and operational consistency.

Discussion

The present study campaigns produced a large dataset (including both 2d and 3D detailed maps in visual and hyper spectral) that have been generated in considerable time and at reasonable costs. However, that large dataset needs thorough validation by experts. This validation could be valuable not only for correlating the parameters chosen during the flight with the results but also for refining the image processing steps. The present study describes a possible roadmap for future work, aiming to outline in detail the key parameters that could lead to standardizing the methodology. The ultimate goal is to make this approach a reliable and accessible tool for monitoring, utility management and archaeological services.

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532. Integration of Aerial LiDAR, Thermal, and Multispectral Data with Magnetometric Surveys: A Multi-Method Approach to Detecting Undiscovered Archaeological Features

Nenad Joncic (National Museum of Serbia)*

Advancements in modern remote sensing technologies have significantly enhanced the ability to detect and analyse archaeological sites. This paper investigates the integration of data collected by drones equipped with LiDAR sensors, and thermal, and multispectral cameras with results from ground-based magnetometric surveys. The study was conducted across several archaeological sites in different regions of Serbia, spanning diverse historical periods and characterised by varying topographic and geological conditions. Some of these sites have already been subject to magnetometric surveys and aerial imaging, while others remain unexplored. The selected sites range from the Neolithic and Iron Age to Antiquity.

The primary objective of this research is to assess the potential of combining these technologies for detecting previously unknown archaeological structures and features. The analysis involves comparing data from various sensor platforms and developing integrated interpretation models to improve the precision of subsurface feature detection. The results highlight the significant synergistic benefits of combining these methods, particularly in uncovering hidden archaeological elements that might otherwise remain undetected when using single-method approaches.

This study also seeks to address how, to what extent, and in what ways the combination of these remote sensing methods can assist in advancing the investigation of known archaeological sites, identifying and understanding previously unexplored locations, and planning future excavations. The findings aim to provide a comprehensive methodological framework for interdisciplinary archaeological research and contribute to the broader understanding of cultural heritage landscapes.

101. Multispectral remote sensing for crop-mark detection

Matthias Lang (BCDH, Universität Bonn)*

On the basis of vegetation features, aerial archaeology is repeatedly able to detect and map new archaeological structures, thus further enhancing our understanding of past cultural landscapes. Until now, small aircraft and conventional cameras have usually been used to detect new structures, while the use of UAVs in this context has only played a very minor role, since their range is highly limited compared to the airplane, only allowing the investigation of smaller areas. So-called fixed-wing UAVs, which enable large-scale semi-automatic mapping, have so far received rather little attention in this context. In addition to their ability to cover areas of up to two square kilometres in a single flight mission almost automatically, the aircraft can also carry other sensors in addition to a high-resolution RGB camera, which allow completely new insights into past landscapes.

In my contribution, I will discuss the use of a fixed-wing UAV (eBee X) equipped with a multispectral sensor (Parrot Sequoia) on the basis of two case studies and compare the results obtained with those of a conventional RGB camera. First, I will present and discuss the survey in the Etruscan necropolis on Monte Abatone in Italy and contrast it with the aerial survey of Roman sites in the Rhineland in Germany. The results show the features with astonishing clarity and are superior to conventional RGB images in almost every respect. This is because so-called vegetation indices can be derived from the multispectral images, which clearly show even the finest differences in vegetation. The calculation of these indices is carried out using an R-Script developed by us, which allows the automatic derivation of a large number of indices (https://github.com/bcdhbonn/multispectral).

In both case studies, a large number of previously unknown archaeological structures could be identified and mapped for the first time. The structures already known could be supplemented with a variety of details that allowed a completely new interpretation. Although the use of multispectral image information in archaeological research is not a new approach, it has so far been limited to the use of satellite images, whose coarse resolution in the meter range is Thus, vegetation features are not always recognisable, but depend on the degree of ripeness and health of the plants and often only appear for a few days a year. The UAV can be used at the right time in the vegetation phase and the automatic flight route planning allows the flight to be repeated in order to approximate the perfect time. The use of UAV-supported multispectral sensors has the potential to revolutionise aerial archaeology over agricultural land due to the high resolution in the centimetre range and the highly targeted use.

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271. On the 'novel' development of pottery styles in pre- and proto-historic Europe: An eye-tracking study

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Stylistic variation has been a central concern in the study of pre- and proto-historic pottery in Europe. The variation of these ceramic styles has been usually addressed through a variety of explanations, most commonly of a typo-chronological nature, but also related to evolutionary forces, technological change, shifting social boundaries, among others. Following recent studies using tools from experimental psychology, in this paper we approach stylistic variation from a cognitive perspective, i.e. according to the visual effects that pottery styles elicit on their viewers. To this end, free-viewing experiments were conducted at the State Museum of Prehistory in Halle (Saxony-Anhalt, Germany) using 41 vessels and at the Moesgaard Museum in Aarhus (Denmark) using 28 vessels that altogether span from the year 5500 to 1 BC. Using eye-tracking methods, we calculated areas of fixation as well as measured their visual cognitive effects (i.e. cognitive load). Our results show an overall progressive decline in the demand for visual exploration of pottery stylistic designs during the last five thousand years of prehistory, i.e. from the Late Mesolithic to the Late Iron Age, which we argue was linked to the increase in standardisation of pottery, the shift of creative craftsmanship towards other materials like metals and glass, and the increasing compartmentalisation of different societal spheres. As a consequence, we argue, a feedback mechanism was created between the loss of interest in pottery as the main medium of symbolic expression and its visual cognitive effects, leading to a shift in attention towards other crafts and societal spheres.

16. Generating a Synthetic Memory Transforming Punctured Blombos and Skhul Shell Beads to Tools Based on Findings from Prehistoric America

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We propose that prehistoric punctured Nassarius shells, found in coastal areas such as South Africa's Blombos cave, functioned as shell net weights (Keegan, et al, 2024). Our research question is thus, is a reinterpretation of the tool rather than ornamental use of Blombos or Skhul punctured shell beads possible? It's proposed that these punctured Nassarius shells, found in close proximity to net designs inscribed in Blombos cave ochre stones (Wynn, et al, 2024), are also the earliest evidence of fishing tools. The two methodologies discussed in this paper were effective persuading a scientific European conference audience attracting an offer from a laboratory to test our hypothesis. We also propose a visual campaign strategy to generate further acceptance of the tool use of punctured Nassarius shells in funding the creation of a replica of a prehistoric shell weight net system. Generating acceptance and funding requires creating a visual aid campaign, through institutional media, producing a shell weight and net image altering the current brain connections to that of the prehistoric memory and thinking style that would have logically interpreted the prehistoric use of punctured shells not as beads, but as net weights (Foster and Scheinost, 2024, Keegan, et al, 2009, and Wynn, et al, 2024).

METHODOLOGIES AND MATERIAL
Comparative 1. use-wear analyses of punctured shells from the Blombos coastal cave, and American prehistoric sites, and 2. digital reconstruction methods are used to generate visual convergence, or a synthetic memory, based on available scientific data, to cultivate audience agreement regarding proposed tool use of the punctured prehistoric Nassarius shells (Foster and Scheinost, 2024, and Keegan, et al, 2009). The materials specifically used are the measures of prehistoric American punctured shell net weights (Keegan, et al, 2009) contrasted with the measures of the prehistoric Blombos Cave Nassarius punctured shells. The use-wear based arrangement of the Blombos shells photograph was digitally transposed to the approximate points and similar dimensions of prehistoric American punctured shell weights arranged on the photograph of an American prehistoric fishing net to generate a synthetic memory, or motif (Foster and Scheinost, 2024). This was done to stimulate the effects of a visual in altering the mental image and interpretation of the use of punctured Blombos shells. Based on cellular biology and memory case studies, repeated or prolonged exposure to a digitally generated synthetic memory reorganizes the neuronal connections associated with mental visual units, assuming there is survivability in the environment, of a visual grammar of the subconscious, as part of the brain's memory processing. According to cellular biology case studies transposed synthetic memories can potentially last generationally. The first generation is exposed to a synthetic memory, adapting and passing on the evolved memory. Obtaining access to re-photograph and rearrange museum or institutionally stored punctured prehistoric Nassarius shells, with the few available prehistoric net artefacts is costly and difficult. Thus addressing and clarifying the photographs of strung Nassarius perforated shells, at the moment, requires digitally altering photographs to visualize the shells not as beads, though as net weights loosely or with a knot on a string (Keegan, et al, 2009). The goal of this initiative is to obtain support for further test the digitally generated punctured shell and string synthetic memory, to then create physically a punctured shell weight fishing net assumed to have been produced by prehistoric Blombos cave inhabitants. Evidence from the American continent (Keegan, et al, 2009) supports the interpretation that prehistoric African coastal populations at Blombos cave, and elsewhere, used

these punctured Nassarius shells as net weights. Establishing this alternative interpretation, based on available use-wear studies, requires recruiting prehistoric net casting expertise, project funding, and a special museum, educational, and media campaign in the form of implementing a digitally generated photograph, or synthetic memory, campaign.

RESULTS

The two methodologies of 1. comparative coastal prehistoric shell use-wear analyses, and 2. photographic digital reconstruction generating a synthetic memory to gain consensus regarding the tool use of punctured shells as net weights, were accepted at our presentation at a European conference. Additionally, an offer was made to test the hypothesis that changing how persons see the punctured shells influences their interpretation of the prehistoric shells use. Testing and measuring eye-tracking changes will require more digitally generated images, to attract adequate funding and expertise to also recreate a prehistoric net replica with punctured Nassarius shell weights. The participating audience at the above mentioned conference agreed that our presentation evidenced that the Skhul Cave, Israel bead use interpretation does not account for the shell net weight use of Nassarius shells, when contrasted with the use-wear studies of the 75,000 years old Blombos cave, South Africa punctured Nassarius shells. Furthermore, it was suggested that punctured Nassarius shells were made in large disposable quantities. The supportive evidence is based on 1. contrasting use-wear patterns of shells and their uses from different sites, 2. the proximity of the Blombos Nassarius shells to recent discoveries of fishnet like etchings on ochre stones in close proximity to the shells found in the Blombos cave, and 3. a computer generated visual presentation of a “synthetic memory” bridging the memory gap in archaeology to generate new neuronal connections of the brain (Foster and Scheinost, 2024) forming a correlational relationship to the Middle Stone Age brain, as part of the extended mind concept in cognitive archaeology and predictive theory building (Wynn, et al, 2024).

DISCUSSION

Reinterpreting punctured Nassarius shells as functional tools could lead to significant shifts in the understanding of early human tool making behavior and creativity. This would prompt museums and academic institutions to adjust their presentations and research regarding these artefacts. Rather than showcasing shells solely as beads, institutions would need to highlight their significance as tools too. Thus, besides 1. comparing use-wear measurements from various prehistoric archaeological sites, to understand their tool use, 2. a visual aid strategy, such as digitally produced synthetic images bridging present thinking to prehistoric thinking, can facilitate our interpreting their use as net weights, and further curiosity regarding early human ingenuity for both symbolic thinking and strategic net constructions.

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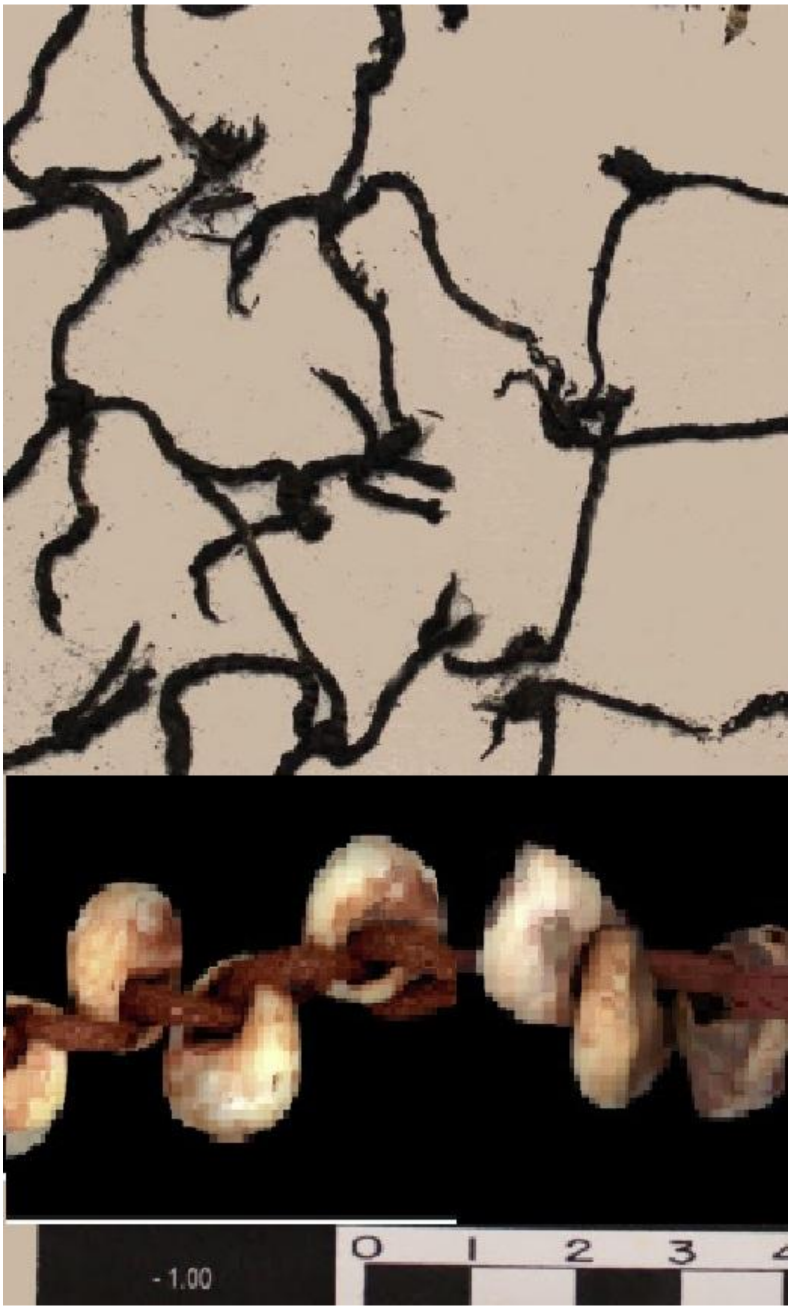

384. Cognitive structures of sensory impressions on Jomon clay figure employing Semantic Differential Method by Mixed Reality experiment

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Abstract thinking is considered one of the defining characteristics of modern humans, Homo sapiens (McBrearty and Brooks, 2000). They proposed four key cognitive abilities characteristic of modern humans: the capacity for abstract thinking, advanced planning skills, inventiveness in behavior, economic activities, and technology, and the ability to manipulate symbols. Evidence of these abilities is identified in archaeological sites and artifacts, including (1) art forms such as accessories, paintings, sculptures, and music, and (2) ritual practices. Jomon "Dogus" (anthropomorphic clay figures) are considered to be particularly closely associated with these two domains. Many archaeologists hypothesize that the deliberate destruction of numerous Jomon "Dogus" was related to their use in rituals. Furthermore, Jomon "Dogu" represents human symbolic expression, which necessitates the capacity for abstract thinking.

223. Recording data about past people and modern people recording data.

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The case

In the ongoing debate about the current transformation of archaeological practices due to the adoption and adaptation of digital innovations in existing technical traditions, the transformative enmeshed social and technological process of archaeological remains into objects of study with assistive digital technology remains underexposed. By taking an autoethnographic approach, I record and interrogate my digital research practice to explore and visualize the social dynamics on the ancient building site of the Archaic temples at Satricum (Italy). A theoretical technological lens and tangible digital 3D technology assist in studying and recording building remains in 3D, specifically stone- and earthwork. In this paper, I investigate the underlying transforming processes a piece of ancient daub becoming a modern, digital object of study by the complex, enmeshed intervention of the archaeologist(s), machine and the material.

The process

A fragment of earthen building material, some mud that past people collected, processed into building material and applied to construct monumental religious structures as well their houses, which then were at some point burnt and destroyed, accidentally firing and preserving the mud, tell modern archaeologists about ancient choices to use and alter the material properties for construction purposes, about connections between different craftspeople to collect and process that mud into something else. This same archaeologist chooses to select that fragment accidentally left yet deliberately made by those people, and elevates it into a focal point of interest.

Archaeological inquiry always (or still) starts with a visual-haptic inspection of the material by and archaeologist with intrinsic archaeological knowledge of the material under study, to assess if the fragment is a viable candidate for in-depth analysis. The piece of mud has become an object of study, an artefact. The observed characteristics and qualities are then recorded in an ad hoc project-database that follows mostly the internal logic of the researcher. Subsequently, the archaeologist may choose to investigate the fragment in submillimetre detail, and decides to record the mud in 3D. But complex morphological features of the material and the capacities and affordances of the 3D scanner, direct the choice of selection as well. This human-thing engagement is a fundamental factor in the selection process, for both digital skills and scientific expertise of the operating archaeologist and the affordances of the material and the machine, have a profound impact on the 3D visualization and further digital existence of the daub fragment.

The visualization of the mud fragment is a dynamic creative and cognitive process of generating 3D models, which is to be queried, visually enhanced and analysed with 3D software. The colourful results and sciency statistics become evidence, to be interpreted by the archaeologist. The described properties of the material and other characteristics, such as colour, measures, shape description enrich and enhance the 3D model (the working object), transforming it into a digital 3D artefact which is part of a wider collection (of which the components form together an ancient Archaic temple and its busy construction site).

The aim

More attention should be paid to the actions which archaeologists perform with their instruments and how they study and visualize archaeological material. An autoethnographic approach helps to not only create an awareness of the relational roles of researchers in knowledge producing practice, and how this affects data collection, and interpretation (Douglas and Mills 2018, 263), but forces to think to the smallest, and often confronting hardly conscious, details of a practice as well. In this way, the paper contributes to the session aims by sharing experiences with underlying social processes of selection (and exclusion or even absence) of archaeological materials, in order to transform them into objects of study.

Two practice-based archaeological visualization procedures will be highlighted in this paper: the selection and visualization procedure of my current research into Archaic earth building and the increasing complexity of selecting diagnostic material to be processed and visualized during find processing at the excavation of ancient Satricum. These two different practices are chosen to demonstrate the effectiveness of the overarching Tradition in Transition-protocol to describe the procedures.

The methodology

The Tradition in Transition conceptual framework takes a human-centred approach with a strong focus on the social context of archaeological practice while recognising the sociality of digital devices and the affordances of things. The methodology, or protocol, builds on praxeological approaches derived from sociology and fundamental archaeological theory, such as the chaîne opératoire approach, and applies this to the digital allowing to compare the technology of material culture to explain social processes. It is furthermore expanded with the current reflexive movement towards practice in archaeology. The layered approach considers a technical process as a significant sequence of performances and actions on matter to create something, a process entrenched and occurring within a given social context, e.g. an ancient construction site or an archaeological lab. These performances, actions and tools used are associated with (embodied) knowledge and technical know-how.

The impact

Breaking down the steps of the chain of archaeological visualization with this approach, with attention for the tools, actions, choices and multiple involved actants, such as researchers, operating archaeologists, 3D scanners, artefacts, apprentices, stakeholders and project directors, this detailed description of a practice has the potential to become a procedure. When successfully mobilised and accepted by the (digital) community, the new procedure is then reproduced, resulting in similar 3D artefacts, increasing comparability between different datasets and procedures. Tradition in Transition fosters awareness of these intricate processes and allows researchers to scrutinise the embedded social nature of technological development and the transmission of innovative technology and technical knowledge.

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93. Scroll or Tablet?: Importance of Complete Records and Standardized Terminologies in Researching Reading Women through the Beazley Archive Database

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The Beazley Archive Pottery Database (BAPD) is an innovative and significant resource within the field of Classical Archaeology, as it "contains records of more than 130,000 ancient pots", specifically those of "ancient Greek painted pottery", that are held by various museum, university, and private collections in one convenient database. While this is a truly valuable resource, as there is no other database quite like it, especially for other Greek artifactual media, the BAPD presents multiple issues, primarily due to the quality of its metadata.

My research concerning depiction of female figures, especially within literacy iconography, has revealed certain problems with the BAPD's approach to archaeological information management. Firstly, vases depicting female figures tend to have lower quality decoration descriptions. This becomes apparent when comparing female scenes to mythical or male scenes. For example, a vase with female iconography might just say 'Domestic, women', while the mythical and male scenes might be provided with more information about the action taking place or have figures being identified (the god/goddess/hero/heroine in mythical scenes, or youth or man in male scenes). In general, though, the decoration descriptions are confined to just minimal termwords, presumably for ease of searchability.

However, that leads to the second issue: inconsistency in the application in description termwords. This became more obviously apparent to me when researching female literacy iconography, for sometimes 'scrolls' were labeled as 'tablets' and vice versa, or replaced by action terminology such as 'reading' or 'writing'. While this might seem pedantic, it makes collecting all the records of vases depicting 'scrolls' difficult to search since there is no consistent application or even presence of the term within the database. This made it difficult for me to solely rely on the BAPD's search functions to recover all of the relevant vases for my investigation; instead, I also had to rely on the scant literature on scroll iconography to make sure I included all of the vases I needed (I found a number of vases through the literature that did not emerge from my BAPD search results).

What could combat these two issues of low quality descriptions and inconsistency in terminology is the presence of high quality imagery of the iconography. This would allow researchers to determine what is present within the iconography, and either confirm, deny or expand on the description provided. However, images are not always provided (probably due to copyright permissions, but sometimes due to the vase in question being lost), and sometimes when they are, the quality is quite inferior, whether that be due to pixelization or to only a partial image being provided (i.e. half of a scene rather than the full scene).

My argument, then, is that theories and practices from the field of information management should be applied to these vases. This includes creating a standardized terminology that is consistently applied and by increasing the metadata collected, especially concerning the iconographic descriptions. I believe both of these aspects can be achieved by following Sourvinou-Inwood's emphasis on describing every minute aspect in incredible, almost excessive, detail in order to avoid bias in what is deemed important. This is particularly important in connection to the depiction of female figures, because, historically, scholarship has tried to force these female figures into the boxes of immortals or hetairai rather than as everyday, mortal women due to their own preconceived beliefs of ancient and contemporary women. Descriptions, then, should be more encompassing, and should include type of figure, appearance of figure, positioning of figure, objects and their level of interaction with the figure(s), etc.

In terms of literacy scenes specifically, this would require the standardization of what is meant by a ‘scroll’ versus a ‘tablet’ within the iconography and in what cases one should be chosen over the other. Additionally, what would be the criteria for saying a figure is actively ‘reading’ a scroll or ‘writing’ on a tablet, versus just holding either object, or more passively interacting with it? How can the nuances in the depictions be reflected within the metadata attached to the iconography?

This discussion has therefore highlighted the issues with not applying information management standards to archaeological data, namely that the lack of consistent and accurate descriptions will lead to challenges in researcher accessibility. This is problematic as the point of the BAPD, and wider archaeological information, is to be findable by future scholars for analysis. Although the BAPD is an amazing source due to being a central hub for information concerning ancient Greek vase painting, it could and should be improved upon. With better descriptions that lead to more accurate navigability, the BAPD could be a model for not only describing Attic figured pottery, but other media across other geographic and chronological archaeological artifacts.

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212. Negotiations and Narratives: Nuances of data collection, documentation, and analysis - The case of Indus artefacts

Pallavee Gokhale (IISER Pune)*

This theme is a critical founding block of archaeological studies because physical data acquisition, identification and perception of attributes, and their subsequent documentation are nuanced processes. At each stage, we negotiate, in other words, employ ‘mechanisms of closure’ (Gero, 2007) so that the data becomes ‘standardised’ for quantitative or comparative studies. These negotiations drive the final quantity and quality of attributes, which are then used to describe the artefacts and the successive analysis, visualisation, and interpretations. With the advent of data science (DS)/ machine learning (ML) techniques, which can now be applied to such enriched datasets by using state of the art applications, there now exists a multitude of data analyses possibilities. Computational power, availability of softwares, or implementation of DS or ML algorithms are not the problems anymore. The present day challenge lies in reassessing our predispositions about attributes, their past cultural values, and mechanisms of interpretation (Whallon and Brown, 1982).

In this context, I present work on characteristic artefacts, known as ‘seals' and ‘sealings' of Indus (aka Harappan) culture from south Asia. These are at the centre of a significant portion of archaeological discourse in Indus archaeology. The scholarship revolves around hypotheses such as (i) there is a fixed set of signs which appear on these objects, (ii) the signs or sign sequences indicate linguistic components, and (iii) the primary use of seals is for creating the impressions which form `sealings'. This scholarship is an interesting case-study that provides cases for discussing almost every question raised by this session theme. This paper proposes to highlight some of these issues, reflect on their repercussions, and thus introspect the archaeological knowledge creation process.

1. Gathering data from a collection of objects and our relationship - According to the CISI volumes published in 1987 and 1991 (Joshi and Parpola, 1987; Shah and Parpola, 1991), a total of 1537 artefacts were documented from collections in India and 2138 from those in Pakistan. In 1947, following the end of colonial rule, India and Pakistan underwent a hostile partition process and became separate independent nations. Scholars notes that the Indus artefacts were divided amongst India and Pakistan. The division was a total compromise to the integrity of the collection and their collective value in terms of archaeological wealth. The aftermath of partition and spoiled political relations have almost blocked the residents of either nations from visiting the other part.

2. Data evolution - As mentioned earlier, the signs on these artefacts are assumed to represent linguistic content. In search of a fixed sign-list, scholars have published the sign-lists which vary in total number of unique signs and the sign detailing. It is a result of differences of opinions between ‘how’ to define a ‘unique’ sign. There are some recent ML studies which demonstrate automatic detection of the signs from the photographs. However, the crux lies in which sign-list is used as a training dataset.

3. Perceived use of data, its implications in data collection and notions of accuracy - The multi-volume photographic corpora mentioned earlier, CISI denotes in the preface that its aim is to provide a basic tool for the study of script, language and religion of Indus culture. The identity or features of none of these have yet been established on a solid epistemological foundation.

Besides CISI, the most popular and widely used dataset of sign sequences and sign-list is that of M77, named after its author I. Mahadevan. In the 1980s, the Tata Institute of Fundamental Research (TIFR) had assisted Mahadevan to create a refined version of his concordance with the aid of computers (Mahadevan, 1986). TIFR is India's premier institute in the domains of core scientific research and education. Despite several lacunae and opportunities to improve, now almost a 5 decade old database, scholars (including those from TIFR) continue to use M77 as is. In retrospect, its persistent use for statistical analysis by multiple scholars has apparently given it a de-facto standard and authenticity for the sign decipherment studies. Starting with Mahadevan's own preliminary study, the results continue to support other observations performed on the same dataset. Every research paper continues to refer to previous work to solidify the argument and thus authenticates the use of M77. The underlying assumption in all these studies is about the unambiguity, and adequacy of its dataset.

4. Interface of the physical object, human-intermediated data, and digitally born data - Recording of these artefacts is heavily influenced by Mesopotamian artefacts. The most prominent result of this borrowing being the recording of sign sequence. For all intaglio carved seal-like objects, the M77 and other datasets assume their use to produce sealings, by creating impressions on soft clay. Thus, these databases record the reverse sign sequence, as it would appear on the hypothetical sealing. Despite several issues around comparative quantities, the state and context of artefacts, and their place in the socio-cultural systems, this practice has become a norm in this specific data creation process. Besides signs, there are inconsistencies in documentation of size of artefacts. Some of these actually mislead us to interpretation and thus underline the criticality of how we translate the physical artefact into a set of attributes. Such examples also demonstrate how the popular narratives could be a result of flawed rudimentary data.

5. Human-intermediated data collection, 'small data', 'slow' methodologies, and informed computational work - For the sign sequences mentioned above, ML experiments have been performed to identify the sign patterns and predict the signs. However, in these experiments, the signs have been completely divorced from their contexts and have been used like a random statistical dataset. Also, data selected for experiment is curated and does not include variations present in the dataset. When a similar experiment has been performed in present study with enriched context, the prediction accuracy diminishes.

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342. Geometric Morphometric Analysis Sheds New Light on Silver Bullion Production Systems of the Southern Song Period

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Introduction:

Silver bullions have been used in historical China since the 7th century as a medium for storing and transporting tributes, taxes, and other payments across government offices. In the Southern Song Dynasty, silver played a vital role in the financial system. Local governments converted tributes and taxes into standardized bullions (e.g., 12.5 taels, 25 taels, 50 taels) for transport to central or regional storages. The Southern Song Dynasty had a complex system for the production of silver bullions as both local governments and commercial shops were allowed to cast bullions for official uses. The shops that produced bullions are named the shop of gold, silver, and certificates of monopolized products, as their main business was trading these items. The Southern Song bullions produced at these shops commonly have a punched shop name and a punch mark of“bullions produced at the capital” as most of these shops were concentrated in Lin’an. These shop-made bullions bore inscriptions indicating the type of tax or tribute, similar to those made by local governments, yet little research has addressed the distinctions and relationships between the two types. Evidence suggests that apart from casting bullions at their own local workshops, the regional government would also buy some shop-made bullions with punch marks and later inscribe types of tax and the name of region on it.

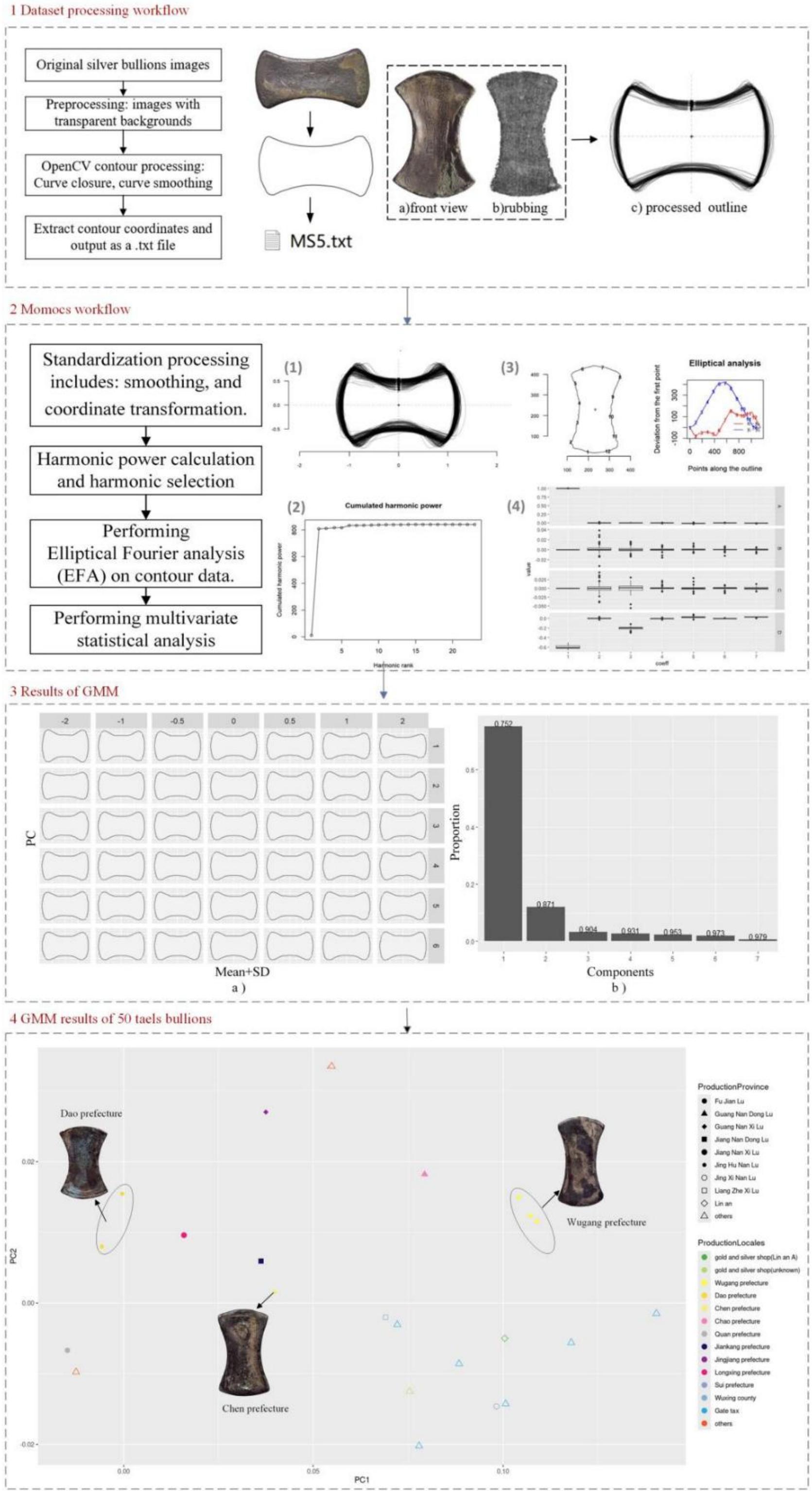
While prior studies have primarily focused on inscriptions, limited attention has been given to the physical characteristics of these bullions, such as their shape, production techniques, and chemical composition. Despite their apparent simplicity, silver bullions reflect a sophisticated production and circulation network. Traditional typological approaches often fall short of revealing subtle shape differences and their underlying causes. To address this gap, this study employs two-dimensional geometric morphometrics (GMM) to analyze the morphology of Southern Song silver bullions, uncovering insights into their production and distribution systems.

Methods and Materials:

The dataset comprises 113 orthoimages of Southern Song silver bullions sourced from excavation reports and museum catalogs. Employs two-dimensional geometric morphometrics (2D-GMM) to analyze the morphological characteristics of Southern Song silver bullions. Since these bullions are flat and slab-shaped, top-view images sufficiently capture their morphological features. Image processing involved extracting contours using Adobe Photoshop 7.0 and the OpenCV 3.3.0 toolkit in Python 3.8, followed by curve closure and smoothing for quality enhancement. Contour coordinates were then analyzed using the Momocs, a specialized morphometrics analysis toolkit (Bonhomme et al. 2014) based on R (R Core Team 2013). Elliptical Fourier Analysis (EFA) was applied to quantify the outlines, with the optimal harmonic count determined by reaching 99% cumulative harmonic power (achieved with seven harmonics). This process generated 28 Fourier descriptors per bullion, forming the basis for quantitative shape analysis. Then using principle component analysis (PCA) and hierarchical cluster analysis (HCA) to identify clusters and explore their differences with ggplot2 (Wickham, 2016) to visualize the result.

Results:

Principal Component Analysis (PCA) revealed significant morphological variations. The shape evolution represented by each principal component varies distinctly. PC1 captures the primary direction of shape change among all samples and is negatively correlated with the head and waist width of bullions. PC2 is associated with the curvature of the bullion waist. The PC contribution graph shows that PC1 (75.2%) and PC2 (11.9%) explains most shape variation among samples.



The result shows these samples can be generally divided into two primary groups. This classification corresponds well to the weight of the silver bullions. The first group mainly consists of 50 taels bullions, while the other group mainly consists of 25 and 12.5 taels. Bullions weighing 50 taels tend to exhibit elongated forms with less curvature at the head, whereas those weighing 25 taels and 12.5 taels share a similar morphology characterized by a narrower waist and a more curved head. Additionally, among bullions of the same weight, each production locale tends to have their own characteristic shapes, indicating a de-centralized bullion production system involving numerous prefecture level governments. The exception to this pattern is the gate tax bullions, which show a high degree of uniformity across different weights. Although its nature remains contentious in economic history, it can be inferred that most gate tax silver bullions seem to adhere to a production standards different from others. Notably, a substantial number of silver bullions produced by gold and silver shops exhibit highly consistent shapes, although each shop had its own workshop and some of them were geographically distant from each other. This morphological uniformity implies the existence of a silver circulation system among these shops that operated independently of the official tax and tribute payment system. Frequent exchanges between certificates and silver bullion at these shops likely contributed to a high uniformity of bullion shapes.

Discussion:
This study demonstrates the power of two-dimensional geometric morphometrics (GMM) in the analysis of artefacts with highly similar shapes e.g. silver bullions. It helps to reveal a complex silver bullion production system during the Southern Song period. This research provides new insights into Southern Song economic and administrative structures and establishes a methodological framework for studying artifact morphology. The application of GMM holds promising potential for future silver bullion research, offering a valuable tool for identifying the production locales of bullions with unknown origins and enabling chronological studies by analyzing morphological differences across time periods.

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28. The Ipad - the fieldwork multitool

Martin Kim (University of Applied Sciences Mannheim)*

Why would you need more than an Ipad in these times for your fieldwork?
With the Ipad Pro M1 it became os powerfull as an Apple Laptop and with its built in Lidar scanner in addition to camera based SFM Apps are able to produce high quality 3d modells. When an NRTIP module like the VIGRAM is added to it up to 3cm location measurements can be added to the models. Combining this with fieldwork apps like Field Desktop (DAI) or iDig (ASCSA) the whole excavation or survey documention might be done with the Ipad. This report shows if these methods worked under real life conditions and where further developments are needed.

97. A Blender-Based Tool for the Standardised Capture of Images of 3D Objects

Jordy Orellana Figueroa (University of Tübingen)*; William Snyder (University of Tübingen)

Recent advances in 3D and CT (computer tomography) scanning technology have led to the digitisation of archaeological artefacts becoming an important part of archaeological research (Göldner, Karakostis and Falcucci 2022). When preparing archaeological artefacts for print publication (i.e. creating a diagram or illustration), the items must generally be photographed or illustrated manually (the latter especially true for lithic artefacts), even when digital models of these artefacts exist, converting them to images is not a trivial task. Although programs such as Microsoft's Paint 3D and MeshLab allow users to export images of 3D objects, the results from one researcher to another would likely be inconsistent (e.g. in terms of perspective vs. orthographic view, lighting, or background). Photographing the actual artefacts is not without its challenges as well (e.g. a consistent and appropriate lighting setup, positioning, and rotation of an irregularly shaped object), likely along with a postprocessing step (e.g. removing the background, adding a scale). Imaging artefacts is useful for print publication, since images can be used for further analysis, or in the case for lithic artefacts, for producing lithic illustrations (Cerasoni 2021). Thus a fast and simple protocol for the capture of images from digitised artefacts would be a useful tool for archaeologists.

We thus present here a tool under development that allows for the fast capture of orthographic images of 3D objects from all cartesian directions (i.e. positive and negative x, y, and z), which is part of a larger protocol for digitising and imaging archaeological artefacts. The tool was developed using Blender, a free and open-source 3D graphics program, and allows for the importing of digital 3D models and the rendering of these with consistent lighting and includes a scale bar for every image. Since the program has a large number of features and associated elements in the user interface, and (like any other 3D graphics software) it requires a small pre-processing stage when importing the object to be imaged, the protocol serves as a simple step-by-step guide that provides users the ability to effortlessly image the desired object. Additional instructions for more advanced tasks (e.g. changing the object's colour or changing the strength of the lighting) are available as well for users who wish to customise their results further. Future development would take advantage of Blender's comprehensive Python scripting API for an even simpler user experience.

With this tool, we seek to provide researchers with a rapid, standardised, and uncomplicated avenue for producing 2D images from 3D models of archaeological artefacts and other 3D objects in general.

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Göldner, D, Karakostis, FA and Falcucci, A. 2022 Practical and technical aspects for the 3D scanning of lithic artefacts using micro-computed tomography techniques and laser light scanners for subsequent geometric morphometric analysis. Introducing the StyroStone protocol. PLOS ONE 17(4): e0267163. DOI: https://doi.org/10.1371/journal.pone.0267163.

510. From Collapse to Stratigraphy: volumetric analysis for reproduction

Lutz Schubert (Universität Köln)*; Tom Noack (Universität zu Köln)

In this lightning talk we want to talk about a tool being developed in the context of a PhD thesis.

In the context of Maya excavations in Belize, we frequently dismiss collapse due to its lacking interpretability. Within the Maya architecture, most building materials are heterogeneous, but uniform in the sense that they have little discernible features. The difference between fill, wall and broken material is thereby difficult to draw. However, frequency and size of larger rocks can give an indication of potential building structures.

Basing on the Master thesis by Tom Noack, we have started to develop a series of tools that try to “invert” the stratigraphic processes to try to determine which taphonomic processes could have acted on the excavation site. In a first step, we use simple volumetric information to draw conclusions about the potential shape and size of the structure.

In future steps we aim at taking physical processes (gravity, friction etc.) into consideration to further refine our argumentation.

21. A sparqling little minion? Linked Open Data in Action with the SPARQLing Unicorn QGIS Plugin

Florian Thiery (LEIZA)*

In computational archaeology and Linked Open Data (LOD), the collaborative collection and FAIRification (making data Findable, Accessible, Interoperable, and Reusable) of research data is increasingly vital, particularly within the Citizen Science community.
Integrating archaeological datasets into larger knowledge graphs with well-structured data supports linking to global datasets and participating in initiatives like NFDI4Objects, Wikidata, and OpenStreetMap. However, the availability of open-source (FOSS) tools for research and FAIRification is often limited, hindering broader participation.
Community initiatives like the Research Squirrel Engineers Network, founded in 2019, address this need by developing open tools for FAIR data management. This network, comprising Linked Open Data enthusiasts, research software engineers, and citizen scientists, focuses on creating tools that integrate FAIR principles in archaeology and digital humanities projects.
An essential contribution from this network is the SPARQL Unicorn, a suite of tools designed to streamline LOD workflows. A notable implementation is the SPARQLing Unicorn QGIS Plugin, which enables users to perform (Geo)SPARQL queries within QGIS, a widely used geospatial platform.
The plugin provides three core functions: (A) simplified querying of Semantic Web data sources to allow archaeologists and geospatial researchers to access linked datasets more easily; (B) transformation of QGIS vector layers into RDF, enabling geospatial data to be converted into a format suitable for integration into LOD frameworks; and (C)
documentation of LOD data, generating HTML pages that can easily be shared with the broader community. This makes the tool particularly valuable for archaeologists working on geospatial data who wish to contribute to global knowledge graphs.
Additionally, the SPARQL Unicorn Ontology Documentation Tool automates the generation of HTML pages for documenting LOD datasets and integrates with GitHub Actions to support seamless publishing workflows. These tools are essential in advancing FAIR and LOD principles within archaeological and geospatial research.
This minion talk introduces the Research Squirrel Engineers Network. It highlights the SPARQLing Unicorn QGIS Plugin's applications in managing spatial research data and integrating Linked Open Data in archaeology and geosciences.

Function A
The SPARQLing Unicorn QGIS Plugin can interact with several triple repositories, such as local RDF files, RDF files on the World Wide Web, triplestores, and solid pods, e.g.:
● via the Wikidata SPARQL endpoint (Wikibase) to query, e.g. Holy Wells (Q1371047, Q126443332), Irish Ogham stones and sites (Q72617071), caves with prehistoric art (Q11269813), castrum (Q88205), Limes castrum (Q88205 P361 Q146924)
● via the FactGrid SPARQL endpoint (Wikibase) to query, e.g. buildings in Koblenz
● via the nomisma.org SPARQL endpoint to query all coins found in
Northamptonshire, ordered chronologically by issue
● via the Roman Open Data SPARQL endpoint to query Gauloise 4 Amphoras
● via the Squirrel Store SPARQL endpoint to query Hadrian's wall forts
● via the Ogham Store SPARQL endpoint to query Ogham Stones with the inscription MAQI (engl. son of)

● via the NFDI4Objects Knowledge Graph SPARQL endpoint to query Samian Ware discovery sites, production centres, kiln regions [1], and Irish Ogham Stones (Figure 1).
● via the Campanian Ignimbrite Solid Pod [2] that represents the Campanian Ignimbrite eruption, which occurred 39,940 yr b2k ± 150 years [3], was one of the most significant volcanic events in the Phlegraean Fields, near present-day Naples, Italy.

Function B

The Unicorn can convert data from formats such as CSV and GeoJSON into RDF, including GeoSPARQL. This process can be illustrated using the Campanian Ignimbrite CSV [5], where the file is first transformed into a geospatial layer within QGIS. This layer then serves as the foundation for the "convert layer to graph" function, employing the GeoSPARQL vocabulary to generate an RDF file [6].

Function C

The SPARQLing Unicorn QGIS Plugin allows for the automated generation of interactive HTML pages, making Linked Open Data accessible and shareable within the broader community. By leveraging GitHub actions, researchers can streamline documenting and publishing their datasets. Some examples of this functionality include:
● Irish Ogham Stones/Sites [7]: This project focuses on visualising and documenting archaeological data on Irish Ogham stones, early medieval inscribed monoliths, through linked open data. The generated HTML pages provide an interactive platform for exploring these culturally significant sites, facilitating broader scholarly engagement.
● Sites of the Campanian Ignimbrite Eruption as a part of Fiona Schenk's [8]: Data on the geospatial distribution of sites affected by the Campanian Ignimbrite eruption in the Phlegraean Fields (39,940 yr b2k ± 150 years) [4], often overlapping with archaeological sites such as Toplitsa Cave in Bulgaria [9], has been converted into Linked Open Data. The interactive HTML visualisation allows researchers to explore the spatial relationship between these volcanic deposits and human habitation patterns.
● Sophie C. Schmidt's Dissertation on 'Brandenburg 5,000 BC' [10]: This study involves converting a CIDOC CRM-based data model from Sophie C. Schmidt's dissertation on prehistoric Brandenburg (circa 5,000 BC) into Linked Open Data. The resulting HTML pages enable the visualisation of complex archaeological and historical data, offering an interactive tool for both researchers and the public.
● Stefanie Baars' Dissertation on Coinage in Croton [11]: This study documents the findspots of ancient coinage from Croton, integrating geospatial and archaeological data into Linked Open Data. The interactive HTML visualisations provide a detailed view of the distribution and context of these numismatic artefacts, aiding in studying ancient economies.

Footnotes

[1] https://t1p.de/mdvhn
[2] https://fuzzy-sl.solidweb.org/campanian-ignimbrite-geo/ci_full.ttl
[3] https://github.com/Research-Squirrel-Engineers/workshop-osf24-mainz/blob/main/src/cifindspots_part_full.csv
[4] https://doi.org/10.3390/quat7020017
[5] https://github.com/Research-Squirrel-Engineers/workshop-osf24-mainz/blob/main/transform/cifindspots_part_full.ttl
[6] e.g. https://linkedopenogham.github.io/ogham-lod/OghamSite_collection/index.html
[8] e.g. https://research-squirrel-engineers.github.io/campanian-ignimbrite-geo/Site_collection/index.html
[9] http://fuzzy-sl.squirrel.link/data/cisite_44
[10] e.g. https://research-squirrel-engineers.github.io/bb-5kbc/Site_collection/index.html

[11] e.g. https://research-squirrel-engineers.github.io/croton-geo/Site_collection/index.html

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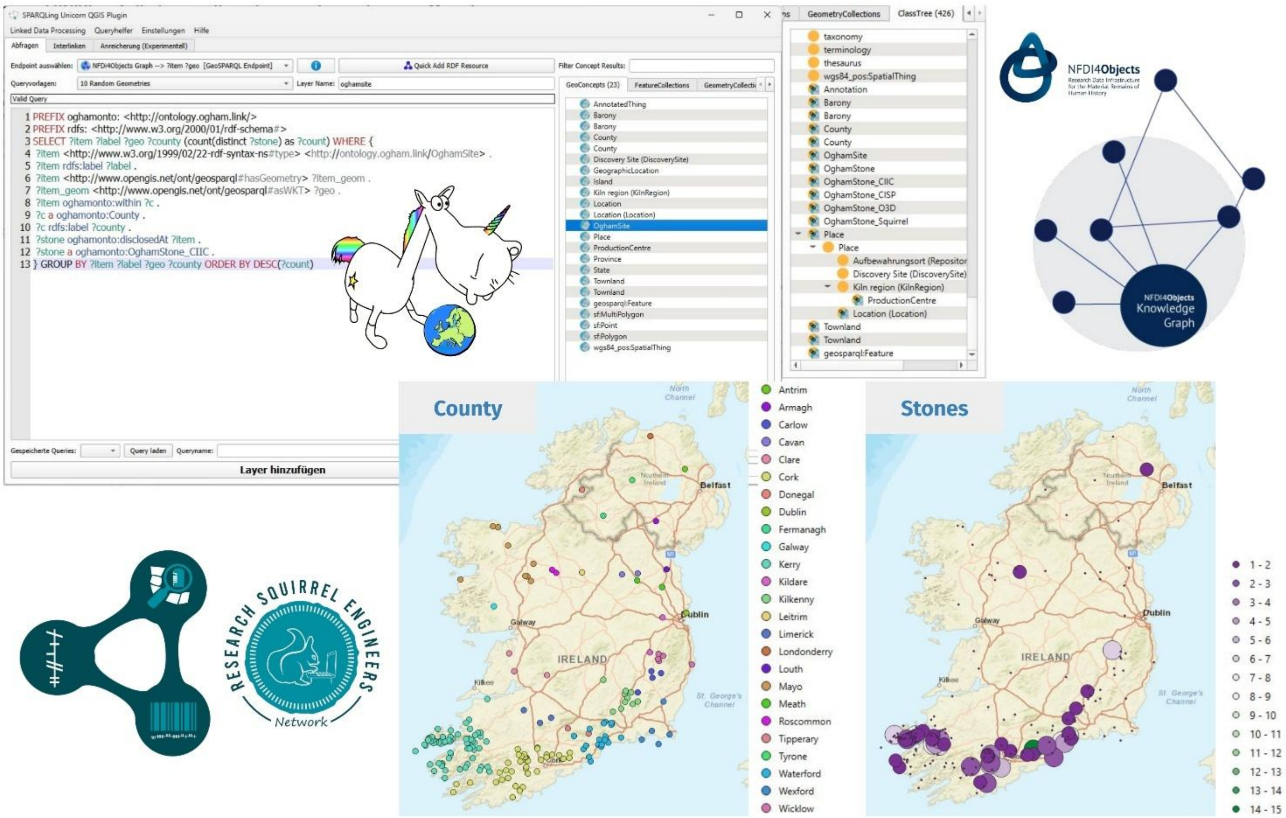

Fig. 1. Top: SPARQL query (via https://t1p.de/v0lg7) on the NFDI4Objects Knowledge Graph using the SPARQLing Unicorn QGIS Plugin to get the counties and count of Irish Ogham Stones; bottom: Result as map in QGIS using the SPARQLing Unicorn QGIS Plugin. anonymous, CC BY 4.0.

411. RDFier – generating RDF from CSV-files and try different ways to model uncertainty

Karsten Tolle (Goethe-University)*; Jan Luca Pöpperl (Goethe-University)

The tool RDFier provides an easily way to transform a CSV file into Resource Description Framework (RDF) data. It is open-source [1] but also can be used without installation as a Web App [2]. The main effort is to set the column names correctly. This way, the tool can handle different datatypes, languages, and blank nodes, and it also allows the usage of prefixes for abbreviation.
Another reason for the creation of the tool was to provide different ways to model uncertain data in RDF. By adding "^^certainty" at the end of a column name, one can specify a column as such and can select out of eight different modeling ways that are 100% in RDF. In addition it provides two ways to model it in RDF-Star.
We will present the tool that was generated by Jan Luca Pöpperl in the context of his master's thesis [3], with some use cases to show its potential.

References:

Jan Luca Pöpperl: RDFier (2023) License: CC-BY-NC-4.0 https://github.com/poepperl/rdfier

https://rdfier.streamlit.app/

Jan Luca Pöpperl: Modellierung von Unsicherheiten in Daten: Benchmarktests verschiedener Ansätze (2023)
https://github.com/UncertaintyC/unco/blob/42a561ca68543ffbde32e953cd71f18093628824/master_thesis.pdf

381. Go Go KG Gadget - what Python can do for you

Daria Stefan (TU Wien)*

A swiss army knife - style presentation of different aspects of Knowledge Graphs and how to navigate them. From data types to storage options, query languages, different types of reasoning (logical vs graph-based) and machine learning approaches (Embeddings vs. GNNs), this presentation will touch upon the basics needed to get practical results from your KG.

The example bases on the KG build with data about illicit antiques trade by Graham et al.

Reference:

Graham S, Yates D, El-Roby A, Brousseau C, Ellens J, McDermott C. Relationship Prediction in a Knowledge Graph Embedding Model of the Illicit Antiquities Trade. Advances in Archaeological Practice. 2023;11(2):126-138. doi:10.1017/aap.2023.1

214. My Jupyter Python Minion! Jupyter Notebooks to SPARQL query Wikidata and Solid Pods

Florian Thiery (LEIZA)*

The Semantic Web is a sprawling knowledge graph brimming with research data with immense potential for cultural heritage and archaeological research (Schmidt, Thiery, and Trognitz 2022). From triplestores like the NFDI4Objects Knowledge Graph to Wikibase instances such as Wikidata and FactGrid, or even Solid Pods housing geoscience data, including archaeological findspots, the possibilities are endless. However, working with this data isn't always straightforward. Writing SPARQL queries can be a challenge, and even if you master that, visualising the results — whether in sparql-results+xml or sparql-results+json — can be an uphill battle.
While Wikidata offers rich SPARQL visualisation tools like maps, image grids, line and bar charts, scatterplots, tree maps, timelines, and graphs, many other Linked Open Data (LOD) interfaces, like triplestores and Solid Pods, lack such capabilities. This means researchers need a mix of data science skills (mostly Python or R) and geodetic expertise to project maps correctly. Even then, the question arises: how do we share these workflows so others can use and adapt them? Enter Jupyter Notebooks — a perfect platform for creating shareable, interactive tools.
In this minion talk, I'll introduce my Little Jupyter Python Minion (Thiery 2024), a handy companion designed to simplify SPARQL querying and data exploration. This minion demonstrates how to query the Wikidata SPARQL endpoint and Solid Pods while employing various visualisation techniques such as bar charts, maps, pie charts, and word clouds. I'll also showcase how tools like ChatGPT can assist in generating Python scripts, empowering researchers to become data scientists for archaeological and geoscience-related datasets in Wikidata and other LOD repositories.
To bring this to life, I'll present several practical use cases to demonstrate its versatility and potential. The Little Jupyter Python Minion showcases its versatility through five compelling use cases, showing how SPARQL queries and Python libraries can unlock new insights and visualisations from Linked Open Data (LOD). These examples highlight the tool's ability to tackle diverse datasets, ranging from cultural heritage to geosciences, and present them engaging and informatively.

(1) Exploring Pokémon Data with Visualisations: My first experiments were inspired by Open Data Zurich and their wikidata-training initiative, which used a playful Pokémon dataset to demonstrate the power of Python and Jupyter Notebooks. Building on their example, I refined the SPARQL query to explore Pokémon properties, explicitly using the P462 (colour) and P2067 (mass) properties. Using the pyplot library, I created scatter and bar plots to visualise these attributes. The analysis revealed that blue Pokémon are the most common, followed by brown, green, grey, red, yellow, purple, white, pink, and black.
Drilling deeper, I observed significant variation in mass within the yellow Pokémon group, ranging from Uxie's modest 0.3 kg to Pikachu's iconic 6 kg and Raikou's impressive 178 kg. This example demonstrates the ease of data exploration using SPARQL and underscores the potential of visualisations in revealing patterns.

(2) Mapping Samian Ware Kiln Sites: To delve into archaeological datasets, I analysed Samian ware kiln sites (Q102202026) and their associated kiln regions (Q102201947) using Wikidata. With 103 production centres, I used pyplot to create stacked bar charts and pie charts, offering a clear breakdown of production sites by region. The visualisations revealed that 28.2% of sites are

Spanish, 16.5% are Italian, 13.6% are East Gaul, and 12.6% are South Gaul, with smaller proportions in Upper Germany and Aragon. These insights highlight the regional distribution of production centres and demonstrate how simple visualisation tools can bring historical datasets to life.

(3) Uncovering the Etymology of Irish Holy Wells: Next, I turned to the study of Irish Holy Wells (Q1371047) to explore their etymology. Combining pyplot and the wordcloud Python library, I created pie charts and word clouds to visualise the naming patterns of these wells. The analysis revealed that 11.8% are named after Mary, 5.6% after Brigit of Kildare, and 5.1% after Saint Patrick, with 7.7% named after the townlands where they are located.
These visual tools provide a compelling overview of the cultural and religious significance encoded in the naming conventions of these sites.

(4) Mapping the Spatial Distribution of Irish Ogham Stones: Focusing on Irish Ogham Stones (Q2016147), I explored their geographical distribution to understand where these markers of medieval Irish history are most concentrated. Using pyplot, I generated bar plots to show the distribution by county, identifying Cork, Kerry, and Waterford as the counties with the highest numbers of stones. For instance, key sites in Cork include Ballyknock and Ballyhank, while Kerry boasts Ballintaggart and Ballinrannig. To enhance spatial visualisation, I employed libraries such as geopandas, shapely.geometry, and contextily to create maps. These included OpenStreetMap-based distributions, county-coloured maps, and density maps. The Dingle Peninsula in Kerry stood out with approximately 60 Ogham stones, illustrating a remarkable concentration. Interestingly, similar stones are also found in Britain, particularly in regions influenced by post-Roman Irish colonisation, such as Wales, Devon, and Cornwall.

(5) Visualising Geoarchaeological Findspots from Solid Pods: To integrate geoscientific data, I examined RDF/LOD data stored in a Solid Pod containing findspots from the Campanian Ignimbrite eruption (CI), a significant volcanic event of the late Quaternary. This eruption 39,940 yr b2k ± 150 years ago (Schenk et al. 2024), centred on the Campi Flegrei caldera near Naples, Italy, left an extensive ash fallout that reached Central Europe.
Using SPARQL queries and Python, I visualised the spatial distribution of findspots, which often overlap with archaeological sites. Key locations include Crvena Stiljena Cave, Franchthi Cave, and geological sites such as Auel Maar AU3/AU4 and Dehner Maar DE3 (Schenk et al. 2024). I categorised these findspots by spatial type — caves, lakes, mountains, and more — using bar charts to highlight their diversity. This geoscientific and archaeological data integration illustrates how Linked Open Data can be leveraged to bridge disciplines and reveal complex spatial patterns.

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Schenk, Fiona, Ulrich Hambach, Sarah Britzius, Daniel Veres, and Frank Sirocko. 2024. 'A Cryptotephra Layer in Sediments of an Infilled Maar Lake from the Eifel (Germany): First Evidence of Campanian Ignimbrite Ash Airfall in Central Europe'. Quaternary 7 (2): 17. https://doi.org/10.3390/quat7020017.

Schmidt, Sophie C., Florian Thiery, and Martina Trognitz. 2022. 'Practices of Linked Open Data in Archaeology and Their Realisation in Wikidata'. Digital 2 (3): 333–64. https://doi.org/10.3390/digital2030019.

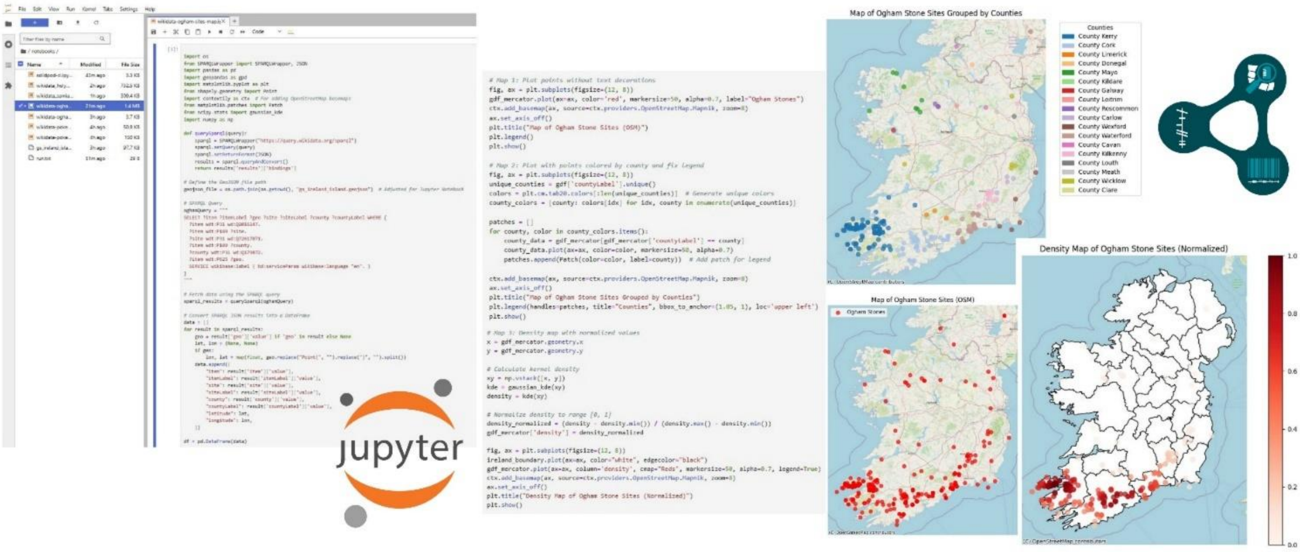

Fig. 1. Top: Jupyter Notebook wikidata-ogham-sites-map.ipynb (via https://github.com/Research-Squirrel-Engineers/jupyter-nb-lod/) to SPARQL query Wikidata to get data ofIrish Ogham Stones. anonymous, CC BY 4.0.

18. Student Perceptions of Immersive Course Content: A Case Study from Greek Archaeology

Robert Stephan (University of Arizona)*; Aviva Doery (University of Arizona); Caleb Simmons (University of Arizona)

At last year's CAA conference, we presented a paper that introduced a methodology for using 360-degree immersive video to enhance archaeology courses. This year, our paper moves beyond methodology to provide an in-depth analysis of student feedback from the initial offering of Classics 315: The Seven Wonders of Ancient Greece at the University of Arizona. While the previous study outlined the technical and logistical challenges of creating on-site VR content, this presentation shifts focus to evaluating the pedagogical outcomes of integrating immersive video in higher education.

Virtual reality (VR) and immersive video have proven to be transformative tools in making archaeological site visits more accessible, especially for students facing geographical and financial barriers (Liu et al., eds. 2017). In The Seven Wonders of Ancient Greece course, we aimed to replicate the experience of visiting iconic archaeological sites in Greece by providing 360-degree video content, allowing students to engage with these environments interactively, even from a remote setting. The preliminary results suggest that this approach not only enhances engagement but also broadens participation in study-abroad-like experiences by making them more inclusive and accessible to a diverse student body.

The paper presents qualitative and quantitative feedback from students who experienced the course, highlighting the benefits and areas for improvement in using immersive technologies for archaeological education. This feedback is critical for understanding the potential of such tools to supplement traditional learning methods and will guide future iterations of the course. Specific topics include student engagement with the virtual content, perceptions of realism and immersion, and suggestions for enhancing the VR experience to better simulate on-site learning.

By examining the pedagogical impact of immersive video technology, this presentation contributes to the broader discourse on innovative approaches to teaching archaeology in higher education (Boboc et al. 2022; Garstki, Larkee, and LaDisa 2019). The findings serve as a valuable resource for educators and administrators aiming to integrate similar technologies into their curricula, providing a scalable model for incorporating site-based learning into online courses. This paper advocates for continued exploration of VR and immersive video as tools for fostering equitable access to global archaeological education, bridging the gap between physical presence and digital learning.

References:

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204. Evaluating Virtual Reality as a learning environment

Jitte Waagen (Universiteit van Amsterdam)*

Introduction

Virtual Reality as a learning environment has seen various experiments in the field of archaeological education. Whereas the advantage of allowing access to remote sites, reconstructed worlds, or inaccessible places appears obvious, there are also prospections of increased learning outcomes. These are expected from e.g. an increased spatial awareness, the stimulation of an active learning attitude, a more comprehensive structuring of learning materials, and so on and so forth. Although in general the often qualitative and small-scale evaluations are on average positive, more systematic evaluations are rare. To advance a more solid empirical basis for such claims, and to facilitate good practice for embedding Virtual Reality as learning environments in archaeological education, more research is needed. Therefore, in the context of the Virtual Past Places project at the University of Amsterdam executed by the 4D Research Lab (Waagen et al., 2024), a systematic evaluation programme has been developed and executed for tailor-made Virtual Reality environments for different courses in Humanities disciplines.

Methods and materials

The goal of the Virtual Past Places project has been to conceptualise, develop, implement, and evaluate several VR environments for humanities education at the University of Amsterdam, focusing on (ancient) history, archaeology and art history. A so-called Online Collaborative VR platform called Hubs was chosen for this project, as it is relatively easily accessible, scalable, and usable (https://hubsfoundation.org/). Hubs works with desktop web browsers, but can also be used with head-mounted displays. This has some clear for practical advantages related to available equipment, accessibility, and course organisation (cf. Jensen & Konradsen 2018), allowing for research with a relatively large number of participants. For the design of the VR learning experiences we organised conceptualisation brainstorms, co-creation sessions, and course design workshops, with students, teachers, education experts, researchers, and VR developers. For the latter we course design workshops, we applied the Active, Blended, Connected (ABC) curriculum design approach, that challenges teachers to redesign an existing course based on the “constructive alignment” principles, which refers to the explicit alignment of intended learning outcomes, specific teaching and learning activities, and assessment.

The model for evaluating the impact of the VR learning activities was designed in collaboration with experts from the Teaching and Learning Center at the University of Amsterdam, aimed at collecting both quantitative data as well as in-depth qualitative feedback on the VR applications, collecting data on three aspects; the VR designs themselves; student motivation, and student learning outcomes. For this purpose, we tried to use as much as possible validated questionnaires which were completed by the students directly after they completed VR-based or non-VR-based learning activities. We applied three subscales of the Intrinsic Motivation Inventory (IMI) were applied (Center for Self-Determination Theory, n.d.). For the evaluation of technical and functional design as well as the System Usability Scale (SUS) was used (Brooke 1996). Furthermore, we collected feedback on course-specific VR design choices via open questions in the questionnaires. Finally we organised focus group discussions (Finch et al. 2014). In addition, we applied controlled tests complemented by teacher interviews to retrieve qualitative assessments of student skill development.

Results/discussion

Five virtual learning environments have been implemented so far, and have been actively used for teaching. The evaluation studies have been completed: 133 students participated in the studies with 52 students using a VR learning environment, and 81 students using both VR and non-VR learning materials for comparison. In total, 22 students participated in focus groups after four of the VR learning activities. In this presentation, the tentative outcomes of these evaluations will be shared and discussed.

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479. The Third Dimension of archaeological teaching: agency, challenges, and perspectives at Université Paris 1 Panthéon-Sorbonne

Francois Giligny (FR)*; Vincenzo Capozzoli (Université Paris 1 Panthéon-Sorbonne)

Context
Archaeology, a discipline that is by nature spatially and temporally orientated, has experienced a significant methodological change with the introduction of 3D technologies. From stratigraphic analysis to the study of artefacts, the three-dimensional perspective is an indispensable tool. The ubiquitous use of 3D models in both research and outreach has led to a re-evaluation of traditional teaching methods, with 3D tools becoming a central component of archaeological pedagogy. Université Paris 1 Panthéon-Sorbonne has been a pioneer in France in integrating these technologies into its archaeological curriculum. In addition to emphasizing technical skills, the university also attaches great importance to promoting critical engagement with epistemological and ethical issues.
Nevertheless, challenges remain. Many degree programs emphasize technical skills without critically engaging with the epistemological implications of these technologies, leaving students with a limited understanding of their impact on interpretive processes. At Université Paris 1 Panthéon-Sorbonne, the integration of 3D tools aims to bridge this gap and make students active agents of their learning, while rethinking pedagogical strategies and reshaping the future of archaeological education.

Main argument
The main argument of this paper is that the incorporation of 3D technologies into the field of archaeological education has the potential to redefine the concepts of materiality and agency in learning environments. This integration offers a unique opportunity to bridge the gap between theoretical knowledge and practical application, while at the same time posing a number of pedagogical and ethical challenges. Drawing on initiatives at the Université Paris 1 Panthéon-Sorbonne, this paper explores how 3D technologies are fostering a deeper understanding of spatial, stratigraphic and material contexts, transforming the way archaeology is taught and learnt.
The concept of 3D agency is key to understanding the role of students in this evolving pedagogical landscape. 3D technologies enable learners to not only consume, but also actively produce and critique digital representations of archaeological heritage. This approach has been tested in collaborative 3D modelling projects where students recreate archaeological contexts and objects and engage with the interplay between physical artefacts and their digital counterparts.
However, the use of 3D technologies also brings with it complex issues: technical barriers, sustainability issues and ethical considerations around digital replication and cultural sensitivity.

Applications or implications
The integration of 3D technologies has far-reaching implications for pedagogy, accessibility and critical thinking in archaeology.
• Experiential learning and critical thinking
Interactive 3D models allow students to visualize archaeological contexts, enhancing spatial understanding and critical analysis. By exploring different perspectives, students learn to challenge assumptions and interpret data more holistically. Discussions about “extended Harris matrices” at Université Paris 1 are an example of this shift, encouraging students to rethink stratigraphy in a dynamic way.

- Collaborative and project-based learning

The collaborative nature of 3D projects encourages teamwork and interdisciplinary communication. Université Paris 1 students work together to reconstruct virtual environments and develop narratives, which fosters problem-solving skills and shared responsibility. Such projects mirror professional archaeological workflows and prepare students for careers in research, conservation and cultural heritage management.

- Ethical considerations

The use of 3D technologies raises ethical issues such as data ownership, digital sustainability and cultural sensitivity. At Université Paris 1, courses emphasize the responsible use of digital tools, with students learning to deal with issues such as the environmental impact of large datasets and the representation of cultural heritage.

- Expanding the commitment to cultural heritage

Platforms such as CND3D (French repository for 3 models) and Sketchfab encourage public engagement by allowing students to share their models with a wider audience.

The introduction of 3D technologies at Université Paris 1 Panthéon-Sorbonne demonstrates innovative methods that go beyond technical training. The integration of 3D tools requires students to develop detailed project protocols, including workflow diagrams that outline each phase from photogrammetric acquisition to file optimization and export. These frameworks emphasize transparency and reproducibility while encouraging critical planning and interdisciplinary collaboration.
From an institutional perspective, this paper argues for increased investment in digital infrastructure and the systematic inclusion of 3D methods in the curriculum. The integration of tools such as photogrammetry, 3D modeling and RTI into courses has proven effective in bridging the gaps between technical skills and theoretical understanding. The use of these technologies must also be done ethically to ensure that digital replicas respect the cultural and historical significance of the original objects.
Epistemologically, the use of 3D tools is reshaping archaeology itself. The transition from two-dimensional documentation to dynamic 3D models encourages us to rethink key concepts such as stratigraphy and spatiality. At Université Paris 1, for example, the use of extended matrices derived from Harris diagrams demonstrates how 3D modeling can extend the traditional analytical framework. In addition, the use of eye-tracking technologies and haptic feedback devices opens up new ways of exploring sensory interaction with archeological data and highlights the interplay between digital and physical domains.

Conclusion

The integration of 3D technologies is not just a technical development, but a pedagogical revolution that is reshaping the way archaeology is taught and learnt. While these tools enrich the learning experience, they also require a rethinking of teaching methods and ethical responsibility. By encouraging critical action, improving accessibility and bridging the gap between the digital and material worlds, 3D technologies are redefining the role of students as active participants in the creation and interpretation of archaeological knowledge.

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26. Digital Heritage and Ethical Display: Student Reflections on Recreating Funerary Contexts in Virtual Reality

Montine Rummel (La Sapienza)*; Robert Stephan (University of Arizona)

In this paper, we present a project aimed at engaging students in a digital reconstruction of tombs in and near the Valley of the Kings, utilizing 3D modeling and virtual reality (VR) to explore ancient burial sites and the ethical complexities faced by modern-day archaeologists. The project, designed for a university-level archaeology course, asks students to create an interactive VR experience that showcases architecture, artifacts, and wall paintings while integrating ethical frameworks for the digital portrayal of human remains.

Building on previous VR-based pedagogical experiments, this project incorporates VR into an immersive storytelling environment to increase the engagement of students with course material during the course (Lund and Wang, 2019). Students not only design a VR walkthrough of a tomb but also craft an interactive VR experience that allows their classmates to thoughtfully explore and engage with ethical dilemmas in archaeology, especially those centered on the display of human remains. By focusing on participation and meaning-making, the project empowers students to take an active role in shaping the narrative of their digital reconstruction, creating personal connections with the material (Squire, 2011).

Students choose to create one of several interactive environments - including virtual museum exhibits, choose your own adventure stories, and escape rooms - helping them hone their problem-solving and groupwork skills as they collaborate to develop complex narratives and solutions to archaeological dilemmas, moving beyond traditional methodologies to foster creativity and teamwork (Angelelli et al., 2023). The project explores the technical and pedagogical challenges of combining VR with dynamic storytelling, along with the impact on student engagement, empathy toward ancient cultures, and ethical decision-making to build a strong connection with the course material (Squire, 2011).

This case study contributes to the ongoing discourse on digital pedagogy in archaeology by addressing both the technological potential and ethical responsibilities inherent in using immersive technologies to depict ancient heritage. We found that students engaged in the project showed greater empathy toward ancient cultures and demonstrated higher levels of engagement compared to other classes they've taken. The results offer insight into the effectiveness of VR for fostering ethical awareness and cultural sensitivity in archaeology education.

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503. On the pursuit of the ideal course or how to increase digital fluency in archeology with caution

Vasiliki Lagari (International Hellenic University)*

INTRODUCTION - CONTEXT

Today's archaeology – or to be more specific conducting archaeological research in the 21st century - is permeated by fluidity. "Endless" digital applications and the lack of standardized workflows alongside with the different pragmatic conditions of every research program (different levels of digital literacy, different levels of financial capacity) paint an abstract landscape that needs rethinking. Archaeological education with the use of digital technologies is the first crucial stage that enhances the understanding of different theoretical concepts, brings "hidden" or distant archaeological material into the class and equips the students with additional methodological tools in their quiver.

By using the example of the MA course that is taught / instructed by the author of this proposal, both benefits and challenges of its structure will be mentioned in an effort to highlight the importance of the inclusion of digital technologies in the classroom together with the "walking on eggshells" pathway that those pave. Students need to learn by experience that digital simulations and techniques are not omnipotent and infallible while constantly questioning their choices (ethical considerations, level of fidelity of their results, combination of digital workflows with theoretical frameworks, future dissemination channels, etc).

CORE – DESCRIPTION OF THE COURSE - OUTCOMES

The course is split into different thematic seminars with the aspiration to refer to important fields of archaeological study that make extensive use of the rapid technological advancements (archaeometry, archaeological prospection, remote sensing, GIS). Throughout the teaching hours the students are prompted to visit various web-based platforms and explore archaeological projects that manifest what is being taught (interactive maps, excavations' simulations, 3d viewers). Emphasis is given to the significance of data curation and the urgency of open-data dissemination (via guidance through the European data repository chaotic landscape).

An important part of the course is the practical aspect of it with tutorials on photogrammetry, GIS, and objects 3d reconstruction from drawings (highly detailed workflows using mostly open-source software). The students are provided with datasets and follow specific steps to get acquainted with the main ideas and commands of specific software to overcome their "fear of complicated interfaces". They are not evaluated on their performance or completion of these tasks. What matters at this level is to have the opportunity to learn the basics and have the help they need to start their endeavors with certain techniques.

The last part of every seminar is dedicated to discussions on given reading material relevant to the respective topic. The students are asked to submit discussion points that range from purely practical questions to a deep critique of what they read. This last part is always the most surprising one. In the first lessons, the discussion points received are usually simple questions on difficult to perceive parts of the articles. The participation of the students is also smaller. Through the participatory discussion encouraged by the teacher their interest grows, they start to reflect and shape a multifaceted view that leads to very interesting arguments; their discussion points change direction by time and mirror their more substantial understanding, sometimes even philosophical.

For their final evaluation, the students are requested to write a paper by the end of the semester. The topic could be characterized as semi-free (certain given conditions that need to be taken in account, but subject chosen by them): they are asked to write a project proposal within the framework of a hypothetical institution of which they are project leaders. There are different restrictions for each one of them (for example budget limitations, mobility limitations, material sensitivity) that are dictated by the teacher. The students choose the material and the field / technique / workflow they would like to work with. This allows them to work with something closer to their interests and research more about it. Some of them that opted for 3d reconstructions and digital games, they even acted on their project proposals and offered us the end-results (which was not prior requested).

EPILOGUE - DISCUSSION

Teaching digital technologies and incorporating them in an archaeological course is a fascinating process but also complex and challenging. Along with the teacher's continuous update on the increasing literature and the current developments, attention should be given not to turn the students to "digital" archaeologists but archaeologists who have the skills to harness digital tools for the benefit of their research and its dissemination. Archaeologists who are armored with an acute critical thinking that allows them to view and analyze their material through a lens that seems modern and old at the same time, "multispectral" if we would like to create a metaphor that expresses the numerous options, combinations and possibilities. With this paper the author would like to offer an insight into the strategy followed on her course and put forth the continuous challenges for a more open, participatory, inclusive and nuanced approach in teaching archaeology. Furthermore, the author advocates and supports the perspective of a comparative study on training methods regarding CAA and would like to initiate through her presentation a dialogue on designing CAA training prototypes (even a standardized repository of trainings?).

379. Teaching the Scientific Method via Medieval Archery Combat Simulation

Stephane Lemieux (MacEwan University)*; Sean Hannan (Macewan University); Sam Qorbani (Macewan University)

Introduction

We have developed an original, free to use, computer simulation of medieval archery battles. Suitable for research and educational purposes, it specifically allows archeologists, historians, and anthropologists to teach the scientific method through inquiry-based learning. The simulation can be downloaded here: https://github.com/lummucks/MACS

Archeological evidence of medieval European warbows, specifically English and Welsh longbows, is sparse. Rare finds during the Viking age, and the Tudor period act as bookends for the nearly 500 intervening years with no finds. As a result, even the simplest questions—like "how powerful were English longbows?"—are still subject to much debate. What is known is the profound impact that such bows had in deciding battles such as Crecy (1346), Poitiers (1356), and Agincourt (1415) in favour of numerically inferior English forces that were heavily dependent on archers. Archeological and historical evidence of the armour worn during these battles is also better represented.

Methods and Materials

The Medieval Archery Combat Simulation (MACS) is comprised of interconnected models calibrated, via archeological experiments and commercially deployed engineering software, to accurately portray the underlying physics of bow design and flexing, arrow flight, arrow targeting with error, archer fatigue, and arrow impacts with armours of various thicknesses. It also uses AI to simulate opposing troop movements. The software allows students and researchers to form hypotheses regarding the power, accuracy, strategy and efficacy of medieval archers. Rather than detail how the model was built and calibrated, we focus on its intended use in the classroom.

As can be seen from the attached figure, MACS is a less textured and detailed environment than typical VR tools. Instead, it offers more versatility of configuration and the ease of repeating simulations so that students can enact the tenets of the scientific method while employing inquiry-based learning.

To use this tool effectively, students should be encouraged to perform a literature review regarding an appropriate battle where medieval archers are known to have played a pivotal role. Based on their findings, students can configure the mounted opponents' armour thickness, charging speed, troop levels and placement.

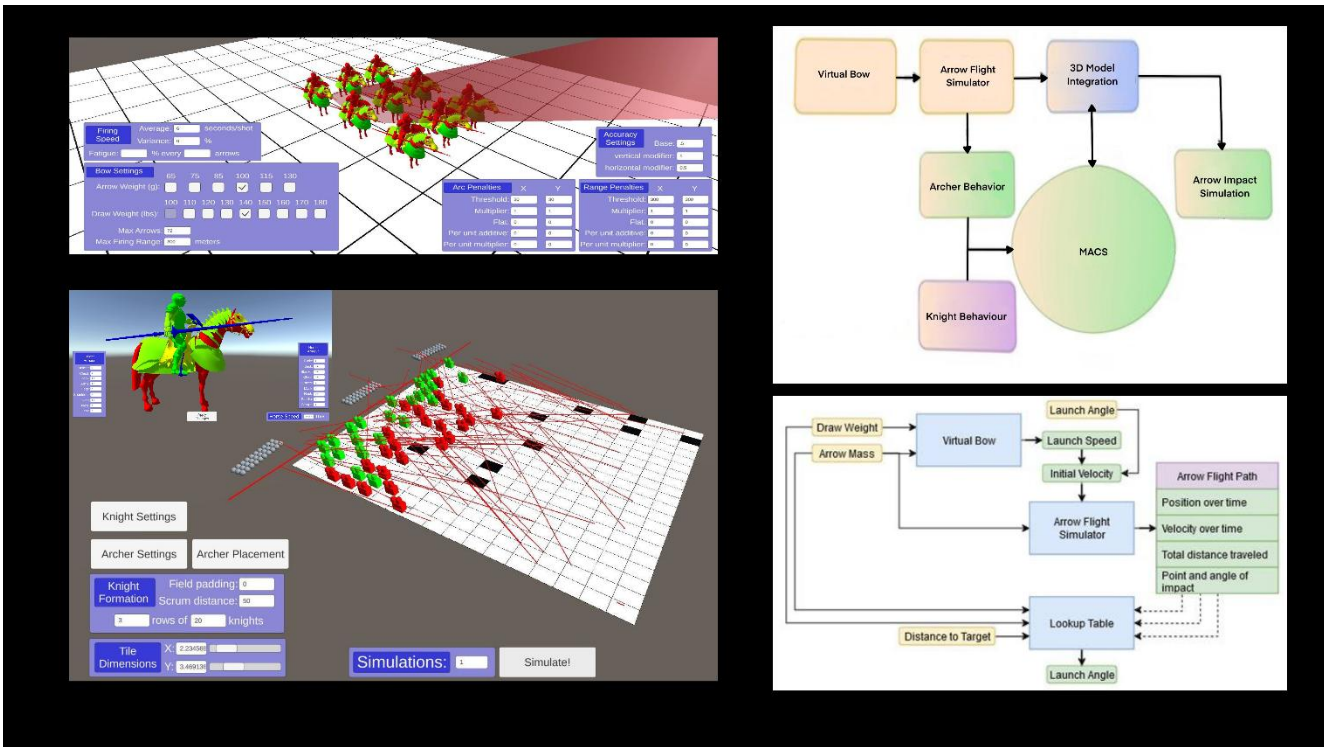
Next, they can be challenged to form inquiry-based hypotheses regarding the traits of the archers. By making evidence-based assumptions about the remaining archers' parameters, students can run simulations to test their hypotheses in the most reliable and historically grounded manner possible.

Fundamental to the scientific method is the notion that hypotheses cannot be proven but can be disproven. Students should be advised to explore a number of seemingly plausible scenarios. Then, based on simulation results, they can employ critical thinking to determine which hypotheses cannot possibly be true and which may possibly be true. They ought to seek a range of possible answers rather than a single definitive value. Consider a student who chooses to ask, "What is an effective draw weight for an archer in the Battle of Crécy?" That student should be looking to exclude draw weights that are too low to be effective and those so high as to be completely unnecessary. The result should be a range of draw weights that are plausible.

It is important for students to state the assumptions they are making and the variables they are controlling for. If time permits, they should test the sensitivity of their results to the assumptions they made and the controls they put in place. For example, students may make an educated guess on the ratio of melee combatants on either side of the battle, as well as the proportion of opposing melee combatants that must be slowed, injured or killed by the archers while charging, in order for the archer's melee forces to have a reasonable hope for victory. Students may also need to assume a level of accuracy of the archers. Varying each of these parameters in isolation and rerunning the simulation will determine which of the parameters play a significant role in results. Students should then be inspired to spend more time, if possible, researching the accuracy of their assumptions for these parameters. Less significant parameters do not need this extra scrutiny.

Ultimately, students should feel welcomed to examine the simulation itself critically. What assumptions were made in producing the software tool? Which of those assumptions were likely critical to the results? Students will be free to reach out to the authors to offer feedback or suggested improvements and pose more detailed questions about the design process.

This simulation is a work in progress. Improvements should be expected as time permits. The arrow impact simulator, in Ansys Autodyne, is a bottleneck in the refinement process. However, simulations are ongoing to test different arrowheads, hardness of materials, and curvature of armour pieces. With student and instructor feedback, we expect the simulation will continue to improve. The simulation was built with significant contributions from undergraduates, and ongoing improvements will involve new computer science and history students. The simulation provides learning opportunities to humanities and science majors alike, lending both insight into the other's field of study. The hope is that interdepartmental cross pollination will lead to ever stronger results for both.



DISCUSSION:
This project significantly advances the use of technology in the reconstruction of medieval warfare. Doing so would help to bring Medieval Studies and the archaeology of the Middle Ages up to the standards being set in fields like Classics and classical archaeology. Even in recent scholarship (Jones 2020, Askew et al. 2012), experimental tests of arrows and armour were being conducted physically, albeit sometimes with the aid of technologies like ACT (Axial Computer Tomography). Our model, however, will allow users to run an exponentially greater number of simulations in a much shorter amount of time, while still retaining reliability. This would empower researchers to reexamine key turning-points in late medieval military history and invite students to explore the Middle Ages in a way that is both quantitatively accurate and qualitatively engaging.

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37. The chronoverse – towards a common language for chronological modelling in R

Joe Roe (University of Bern)*

There are now quite a large number of R packages for chronological modelling (Marwick et al. 2023). These include methods developed specifically by or for archaeologists as well as those borrowed from adjacent fields. Many other types of analysis incorporate chronological data in an ad hoc way. As the range and complexity of these analytic procedures increases, it is can be difficult to integrate the varied data types, interfaces, and output formats into a single workflow – to get different packages to “talk to each other”. This is a common problem, especially in decentralised software ecosystems such as R. In other domains, the solution has often common in the form of computational ‘infrastructure’: packages that smooth the way by providing consistent formal representations, a common set of basic methods, and a predictable user interface patterns.

In this paper, I introduce three interconnected R packages:

• era provides formal representations of year-based time scales of the type usually used by archaeologists and other palaeoscientists (e.g. Before Present)
• c14 facilitates ‘tidy’ analysis of radiocarbon data, including further formal classes for uncalibrated measurements and calibrated, calendar probability distributions, as well as functions for converting data types from existing radiocarbon-analysis packages into tidy formats
• stratigraphr is a framework for working with stratigraphies and relative chronologies as directed graphs, with tools for reading, analysing, and visualing these stratigraphic graphs (‘Harris matrices’)

As well as implementing various analytical methods, the aim of these packages is to provide a common infrastructure for the formal representation of chronological data and a set of consistent tools for reasoning with it. All three make extensive use of tooling and design patterns from the tidyverse (Wickham et al. 2019) to present a predictable user interface that fits into a wider ecosystem of R packages. In particular, they use vctrs-based formalisms to represent different types of chronological vectors, a functional paradigm for composing programs, and assume/encourage the use of a tidy data workflow (Wickham 2014).

A common computational infrastructure for chronological data makes it easier to ‘glue together’ varied packages for chronological modelling within a single analysis. And by linking it to an existing, widely-used paradigm (the tidyverse) we can take this further, smoothing the way for the integration of chronological data into a wide range of other methodologies. The packages outlined here are not intended to be the definitive version of such an infrastructure but, I suggest, could serve as the rudiments of a common language for chronological modelling in R – a ‘chronoverse’.

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2. Toward 'Grand Unified' Chronologies: New R Packages for Total Chronological Modeling

Stephen Collins-Elliott (University of Tennessee, Knoxville)*

Formal methods for chronological modeling have been well applied since the advent of computing in archaeology over a half a century ago to specific problems, such as the calibration of radiocarbon dates, their constraint to relative sequences, or the mean date of occupation of a site based on the dates of attendant ceramics. Nevertheless, many aspects of chronology-building remain informal, based on expert judgment, especially with the date of artifact types. It is desirable to work such knowledge into a formal framework, but often this involves awkward, piecemeal, or otherwise ad hoc interventions on the part of researchers (e.g., having to provide intervals of dates such as [345,365] for "around the middle of the 4th century CE"). Typologies are likewise always in a state of flux and disagreement, and moreover the conditional structure of the chronology underlying those typologies is not always obvious. How can a formal model accommodate these issues?

This paper proposes a solution that involves returning to fundamental premises, focusing on the roles of similarity and ordered sequences. This 'grand unified' chronology consists of a joint conditional probability density, predicated upon the familiar variates of sequences of events, elements pertaining to those events (and their types, which are treated not as a unity, but rather as a set of characteristics), and absolute constraints (termini post/ante quem) on those events, from any number of sites or regions. In brief, relative sequences are distinguished between those which are fixed, such as with soil stratigraphy, and those which are not, such as contextual seriations of disparate pits. Contextual seriation is first applied to obtain one or more optimal orderings of contexts and find-types, grouping like with like, to relate unstratified and stratified contexts together in an optimal ordering. Then, those optimal orderings are constrained to known, fixed sequences, effectively keeping single contexts as proximate as possible to contexts most similar to them. The date of any one event can then be marginalized from this full joint conditional density. Depositional dates are obtained by simulating estimates between any upper and lower bounds in sequences via a Gibbs sampler. Production dates of artifacts and artifact types require the imposition of a rule, such as a "naïve" one, which states that the production of an artifact-type takes place at any time from just before the earliest deposition of that type anywhere and the deposition of that particular artifact itself. Use dates are then conditioned upon dates of production and deposition.

By returning to the basics of typology and contextual similarity, this approach escapes the need to group contexts by phases or construct qualitative labels for time-periods. Furthermore, it entails greater emphasis on the role of chronology in the criticism and evaluation of the ontological structure of archaeological types themselves. Types are not monolithic, concrete entities, but complicated ontologies that have their own characteristics, serving primarily to establish links between artifacts or other elements on the basis of their similarities. This principle lies at the heart of contextual seriation to begin with, such that chronology and typology are inextricably linked phenomena. The identification of certain types, classes, or otherwise characteristics as key chronological determinants can be revealed through the critical evaluation of how much they contribute to or confuse seriated sequences over time.

This approach is illustrated using two newly developed packages in R available from CRAN, lakhesis: Consensus Seriation for Binary Data, which provides a graphical platform for performing and evaluating seriated matrices of presence/absence data, and eratosthenes: Archaeological Synchronism, which marginalizes dates of deposition, production, and external termini post/ante quem from a joint conditional density.

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485. Two open-source tools for archaeological temporal expressions

Douglas Tudhope (University of South Wales)*; Ceri Binding (University of South Wales)

Temporal expressions occur in archaeological datasets, publications and grey literature reports in different formats, each with a wide variety of patterns. Temporal expressions can occur as ordinal named or numbered centuries, years and year spans, decades/centuries and spans and also named periods (which can vary according to place). The issue is compounded in multilingual contexts. This gives rise to major difficulties for automatic analysis and comparison of archaeological outputs and even within the same dataset or report. It also presents problems for automatic analysis of temporal metadata. This presentation reports on the design, implementation and use of two open-source software tools to resolve and normalise temporal expressions to standard formats.

One Python tool normalises textual temporal expressions in different languages to a numerical time axis. Textual patterns for seven categories of temporal expression are normalized: Ordinal named or numbered centuries, Year spans; Single year (with tolerance); Decades; Century spans; Single year with prefix; Named periods. The following languages are currently supported: Dutch, English, French, German, Italian, Norwegian, Spanish, Swedish, Welsh. The input is a temporal text string and a language code (ISO639-1). The output is a tab delimited text file with start/end years (in ISO 8601 format), relative to Common Era (CE). The normalized outputs are provided as additional attributes along with the original text expression for consuming software to employ in end-user applications. This tool has been applied in various applications, including a selection of datasets from ADS Archive, the ARIADNE project multilingual demonstrator and ARIADNEplus data aggregation [1].

The other tool is an automatic, vocabulary-based, subject indexing (hybrid Named Entity Recognition) recommendation system that includes temporal expressions as a major element. The tool has been applied to the OASIS online index of fieldwork events and their unpublished reports [2] and is currently being applied in the ATRIUM research infrastructure project [3]. The automatic indexing tool includes a specialised temporal annotator and a (SKOS) vocabulary annotator (currently using the FISH Archaeological Object Thesaurus and the FISH Thesaurus of Monument Types). In addition to numerical date and century expressions, archaeological named periods are taken from PeriodO. Currently the Historic England ‘Archaeological and Cultural Periods’ PeriodO authority is used but other PeriodO authorities are possible. The system is implemented using the spaCy open-source Natural Language processing (NLP) library. A suite of spaCy ‘patterns’ has been developed as Python modules together with a series of specialised NER pipeline components to identify and tag various types of temporal entity within passages of free text. Output includes the suggested metadata, lists of span entities representing the vocabulary and temporal concepts identified (including their corresponding positions within the input text), together with aggregated counts of the identified spans. Bulk processing scripts and Python notebooks are included to demonstrate usage and to highlight aspects of the available functionality.

Resolving dates and periods to standard formats potentially affords data integration, interchange, search, comparison and visualization. Open-source tools can offer a step in this direction.

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[3] ATRIUM Project. https://atrium-research.eu/

481. How can we model time information for Linked Open Data?

Martina Trognitz (Austrian Centre for Digital Humanities and Cultural Heritage, ÖAW Wien)*; Iro Mathioudaki (University of Louvain); Diamantis Panagiotopoulos (Heidelberg University)

The Minoan chronology, a tripartite system for the classification of Minoan civilisation periods into Early, Middle, and Late Minoan, needs to be revised due to several issues accumulated since its introduction by Arthur Evans and Duncan Mackenzie (Evans 1906). Originally, the Minoan chronology system was devised as a relative chronology based on pottery from Knossos. Because the succession of styles was basically correct and due to the easy to comprehend symmetry of the system, subsequent generations of archaeologists adopted Evans and Mackenzie's system of the Knossian sequence with little to no changes and applied it to all other regions of the island as well as to other object classes thus transforming the (primarily) Knossian to a Cretan chronology.

Due to the lack of defined, objective and unambiguous criteria for classifying a shape/motif as belonging to one ceramic period or another, and the need for chronological alignments, the chronological system is subject to an endless chain of interventions, including changes in the definition of individual phases or the introduction of further subdivisions (Shelmerdine 2008, 3–5). Furthermore, the practice of attaching absolute dates to the classification system, and thus attaching a chronological significance to the system, has led to the transformation of an originally stylistic classification system into an apparently well defined absolute chronology, suggesting that Minoan Crete has well-defined transitions and sequences within neatly defined chronologically absolute ceramic phases (Momigliano 2007).

For a systematic and objective revision of this century-old chronological framework, intra-site and regional sequences based on mostly homogeneous ceramic deposits from stratigraphic sequences need to be interlinked and analysed. We present the basic technical requirements for a computational approach based on machine-readable Linked Open Data (LOD), which requires standardised and open documentation of Minoan pottery, related finds with absolute dates, and any known relative sequences to allow for a systematic comparison with other sites, regions and periods. A more elaborate model for temporal information will be presented. The development of the model based on CIDOC CRM and its extension CRMarchaeo has taken into account existing models such as LIDO, Linked.Art and kerameikos.org as well as existing applications of CIDOC CRM. In contrast to current approaches, which are too simplistic and often combine stylistic and absolute dating, the new model aims to properly separate evidence from interpretation to allow for clean chronological reasoning. To improve interoperability, ready-to-use authority files, controlled vocabularies and gazetteers will be discussed in terms of the type of temporal values they provide.

The way in which the temporal information is modelled is not specific to the aforementioned use case. Consequently, the approach taken to model temporal information can be applied in other scenarios and integrated into existing ontologies, such as the kerameikos.org ontology.

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538. The SVI Flow: A New Erosion Model for Sediment Abrasion on Bones in Fluvial Environments

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Archaeologists and paleoanthropologists recognize that sediment abrasion on the surfaces of bone fragments deposited in fluvial environments can lead to rounding of the edges of the breaks. This can occur via transport of the bone fragment down the river or via water washing sediments across a bone that is fixed in place in the river bed. Being able to mathematically model a time series of the rounding of break edges could provide crucial information about the depositional history, transport dynamics, and taphonomic processes influencing archaeological (and paleontological) site formation. Such advances in our understanding of the erosion of bone fragments in fluvial settings could offer insights into the degree to which bones were transported or experienced abrasive activity, and in different stratigraphic contexts how fluvial activity changed over time and how that might correlate with environmental, and perhaps climatic, changes. Furthermore, it could further disentangle issues of equifinality allowing us to better differentiate between anthropogenic bone modifications from other taphonomic processes, part of which includes understanding how to identify anthropogenic bone modifications that have undergone additional taphonomic processes that obscure such modification – which is inevitable at sites that are thousands or even millions of years old. Creating useful mathematical models to analyze edge rounding can contribute to a larger body of predictive models of site formation processes.

In the following work we present a new erosion model developed for sediment abrasion on 3D models of bone fragments. This method leverages the Spherical Volume Invariant (SVI) (O'Neill et al., 2020) to model the exposure of a point on the surface to incident particles. At a point on the fragment surface, the SVI computes the volume bounded by a sphere centered at the point and the inside of the surface. This measure is inversely linked to mean curvature - lower for sharp points (such as those along a break edge), and higher for convex regions (e.g. endosteal surfaces). For example if the surface is flat, the SVI is exactly half the volume of the bounding sphere.

A well established model for surface erosion is mean curvature flow, where points on the surface iteratively recede inwards (i.e. opposite the surface normal) at a rate proportional to the mean curvature. When considering the likelihood of particles (e.g. sand) striking the surface, the local morphology should be considered - points in crevices will erode less quickly, while points on exposed prominences will erode more quickly. Curvature is an infinitesmally local quantity, and in practice approximated over extremely small neighborhoods. Therefore, something capturing a broader yet still local region (i.e. the SVI) of the surface may be more ideal and offers a more intuitive physical model.

We applied our model to a sample of bone fragments acquired through experiments in which spotted hyena (Crocuta crocuta) at the Irvine Park Zoo in Wisconsin were fed white-tailed deer (Odocoileus virginianus) metapodia. Bone fragments from these feedings were collected for analysis and cleaned following the protocol provided in Coil, Tappen, and Yezzi-Woodley, 2017. For this project, twenty cleaned fragments were scanned using a Shining 3D TranscanC and the 3D models were saved as.ply files. Once they were scanned, they were subjected to 7 days of continuous tumbling in a 15 lb capacity Thumler's Tumbler Model B 140 (1550 rpm). All the fragments were tumbled together in a mixture of sand and water (900 ml/2100 ml respectively) following the protocol provided by Shipman and Rose, 1983. After tumbling, the fragments were extracted from the tumbler, rinsed under tap water, and set to dry for 48 hours after which the

process of scanning and tumbling was repeated. The process was repeated twice resulting in three sets of models in the time series: pre-tumbled, tumble 1, and tumble 2.
After tumbling, all 3 models in the time series were 3D scanned and represented via high resolution triangle meshes. Then, to test the efficacy of SVI in modeling erosion, the SVI flow was implemented in Python, which essentially takes each point on the surface and moves it inwards at a rate specified by the SVI for some fixed radius of the sphere. While we focus our efforts on eroded bone, the SVI erosion code may run on any mesh to test its potential use in modeling erosion of other archaeological materials, e.g. for ceramics or lithics. Our experimental workflow began with the pre-tumbled mesh. Then, SVI erosion code was applied to transform the mesh for an experimentally identified number of timesteps, and the output was compared to the true tumble 1 mesh.
The SVI erosion model was run again on the synthetically eroded mesh and compared to the true tumble 2 mesh. The efficacy of the SVI erosion model was tested in two ways: first, the true and synthetically eroded meshes were aligned, and a heatmap was created between them, capturing the vertex-wise distance. The mean and max distances between the surfaces were measured; an example is shown in Figure 1. Second, distance heatmaps between the true tumbled meshes and original were compared with distance heatmaps between the synthetically eroded mesh and original. If these heatmaps closely match, the SVI flow is a good model of erosion. Our preliminary results suggest the SVI flow is a promising erosion model that can be utilized in the taphonomic analysis of fossil bones at archaeological sites, among other applications. Further research merits studying the number of timesteps, neighborhood size, and other hyperparameters to ascertain the physical ramifications of these parameters and link to rate of erosion and sediment size for various environments.

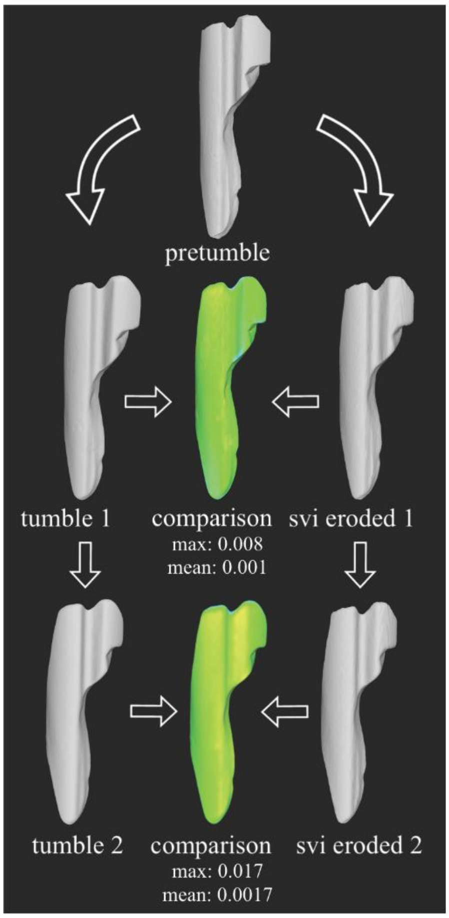

Figure 1: Overview of our workflow. Digital models of the fragment were created before tumbling, after tumble 1, and after tumble 2. The SVI erosion model was applied to the original pretumbled mesh and compared to the tumbled scans. Shown in green is the heatmap comparison between the synthetically eroded and true eroded meshes (blue is lowest, green is low, red is highest, normalized for each plot), with the mean and max distance measurements below. The patches of blue along interesting break edges and crevices in particular suggests the SVI flow merits further study for erosion modeling.

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281. Building a tree-walk interpreter - a didactic deep dive into the age modelling language of the currycarbon software tool

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Scientific software should not just enable useful research applications, but also allow for automation and computational reproducibility. One way to facilitate this is to implement it as well compartmentalised libraries for scripting languages like R or Python. Unfortunately such an embedded interface renders tools more inaccessible to users not familiar with the host language, and is thus in conflict with another desired property: Ease of use. Scientific software tools should be easy to use and avoid unnecessary technical hurdles beyond the irreducible complexity of the system under study. I think domain-specific languages (DSLs) are one way to address this divide and unlock the advantages of programming interfaces, while keeping technical complexity at a necessary minimum. They deserve more attention from the growing community of archaeologists writing software for archaeologists [1].

Hudak 1998 argues vigorously for DSLs: “A well-designed DSL should capture the essence of one’s application domain, and in that sense there is no better way to structure one’s software system” [2]. He notes a number of concrete advantages compared to general purpose languages, among which one stands out in particular: “they can often be written by non-programmers”. Given the user is knowledgeable about the domain semantics, a well-designed mini-language can help them to express their query to a scientific software tool efficiently and reproducibly. The OxCal (https://c14.arch.ox.ac.uk/oxcal.html) age modelling language is an example for a DSL in archaeology realising some of this potential.

To motivate my fellow computational archaeologists to equip future tools with powerful mini-languages where appropriate, in this paper I will go through the concrete steps of implementing an interpreted, external (not embedded) DSL [3]. Lexing reads the source code and transforms it into a clean sequence of meaningful tokens. Parsing composes these tokens according to the “grammar” of a language and builds a nested tree of expressions. This Abstract Syntax Tree (AST) can be the starting point for static analysis, the construction of various intermediate representations, optimization, and finally (byte)code generation – so the steps of programming language compilation. This exceeds what is relevant for most research software, though. I will limit this taster course in DSL development to a basic tree-walk interpreter, which traverses the AST and evaluates all expressions immediately.

To illustrate and exemplify my introduction, I will show some of the inner workings of the mini-language interpreted by the currycarbon software tool (https://github.com/nevrome/currycarbon). currycarbon implements radiocarbon calibration and user-defined computations on archaeological age ranges through a small, dedicated DSL. Expressions of this language are, for example, uncalibrated radiocarbon ages or specific probability distributions over age ranges, which can be combined through addition (for sum calibration) or multiplication. It is written in Haskell, a functional programming language with built-in Algebraic Data Types (ADTs) and sophisticated parser combinator libraries particularly well suited for the design of DSLs.

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242. Untapped Potential or Unusable Complexity? Challenges of Providing APIs for Archaeologists

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The German Archaeological Institute (DAI) provides several online services, unified under the banner of the iDAI.world (Fless et al. 2021): These include among other systems iDAI.objects (formerly known as Arachne and initially developed at the Universität zu Köln) - a database of archaeological objects and entities which in its more than 20 year tenure has changed its appearance and expanded the bounds of its content multiple times; iDAI.gazetteer, an authority system for archaeological 'places' and their names; and iDAI.chronontology, a platform that allows the structured presentation of time periods and their spatial extent. In one way or another, all of these systems also provide their own application programming interface (API), allowing dynamic access to the underlying data. However, these APIs are not equally successful in terms of utilization. They vary greatly in what they can do and, as far as we can tell, people's use of them is also quite heterogeneous to non-existent. On the one hand, perhaps our target audience is simply not familiar with using programming interfaces to compile data, as this requires at least some experience and training in programming languages or scripting (see ODATE 2020). On the other hand, perhaps our APIs and their documentation, or the data itself, are the problem?

The most successful API of the three systems in terms of data utilization is by far the REST API of iDAI.gazetteer. This is demonstrated not only by external links and automated imports into other online systems, such as pleiades.stoa.org and digitalrepository.biaa.ac.uk, but also by the QGIS plugin "kgr-finder" (github.com/dainst/kgr_finder), recently developed in the context of the Cultural Heritage Response Unit (CHRU), and of course accesses iDAI.gazetteer's API. The plugin makes it easy to add places from iDAI.gazetteer to any map with just a few clicks. Projects such as this show the value that APIs can provide to our systems in terms of data accessibility and reusability.

However, this is mostly possible because the type of data we provide on this platform is not exceedingly complex, and there are already very well-established standards for representing geodata. Despite the relatively good documentation, there are still some issues and deficiencies of the Gazetteers API that we want to address.

As a second in-between example, the API of iDAI.chronontology is rarely used and its documentation is currently buried in the application's GitHub repository. iDAI.chronontology could ideally be integrated with other databases to provide chronological information on objects linked to specific time periods and their geographical extent. It could also be used to supplement statistical analyses with additional information in the form of authority data. However, in order to help researchers use the system in this way for their own work, we need to re-examine the state of the systems data alongside its API, and provide a documentation which helps users navigate and understand the responses and queries.

Finally, iDAI.objects demonstrates the limits of reasonable API usage with archaeological data in general. The system contains more than 4 million entries in total, spanning across categories such as images, books, single objects, architecture and topographies. Its data model is as complex and varied as its development history. While certain subsets of entities in iDAI.objects where mapped to, e.g. the Cidoc CRM, and the website itself provides an OAI interface for accessing archival documents, the ambition has never been to make the bulk of the underlying data available for re-use by researchers and the public. Instead, it was largely aimed at providing "machine-readable metadata" for a curated selection in the context of Semantic Web-strategies and linked open data (Förtsch 2015:23). Nonetheless, again there is also a REST-API, originally designed for the communication between back-end and frontend of the current version, and again, its documentation is tucked away on GitHub.

A clear and restrictive data model is – from the perspective of development – a prerequisite for designing a functional, well-documented and easy-to-use API. The three systems and their APIs clearly demonstrate this in the way our users and other systems interact with them, and with the varying degrees of prominence and utilization. However, changing and remodelling legacy data is not always possible or advisable. We need to approach the topic from a perspective where standardisation and normalisation of data at a large scale is not – at present – an option.

As an archaeological infrastructure provider, we want to encourage more researchers to make use of these APIs, and ultimately make our treasure trove of data more accessible to external collaborators. Since most of our potential users are archaeologists, and not software developers, we need to provide very clear and intuitive endpoints, query options, and responses, as well as a layman-friendly documentation which can guide even inexperienced users in navigating the API. Thus, with our talk in this session, we want to present some of the challenges we face in developing these APIs, and present as well as discuss suggestions for improvement with a community experienced in using various APIs for their own purposes.

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429. Open-Source Bayesian Chronological Modeling: The Role of a Domain-Specific Language

Martin Hinz (Institute of Archaeological Sciences, University of Bern)*; Joe Roe (University of Bern)

Radiocarbon (^14C) dating is a fundamental tool in archaeology and related disciplines for establishing chronological frameworks. Calibration of radiocarbon dates is essential to account for fluctuations in atmospheric ^14C over time, and Bayesian statistical methods have become increasingly important for refining these calibrations with additional information. For decades, OxCal has been the dominant software for radiocarbon calibration, particularly renowned for its ability to integrate stratigraphic and prior information through its domain-specific language (DSL) [1]. OxCal's DSL allows users to construct complex chronological models that incorporate sequences, phases, and other stratigraphic relationships, making it indispensable for many researchers.

While other calibration software exists — such as BCal [2], CalPal [3], ChronoModel [4], and the R packages 'rcarbon' [5] and 'Bchron' [6] — these tools have not yet fully replicated OxCal's capacity to merge stratigraphic information with dating results in a comprehensive Bayesian framework. This limitation restricts the ability of researchers to construct detailed chronological models within a single, open-source environment.

Our own tool, 'OxcAAR' [7], has been developed as an interface between R and OxCal, allowing users to access OxCal's functionalities directly from R scripts. OxcAAR translates elements of OxCal's DSL into R commands, enabling some degree of integration and automation within the R environment. However, it remains dependent on OxCal as the underlying engine, which poses challenges related to software dependency, licensing, and extensibility.

The ultimate goal is to develop a fully open-source alternative to OxCal that matches or surpasses its functionality, particularly in terms of integrating stratigraphic information and radiocarbon dating within a Bayesian framework. This endeavor raises critical questions about the approach to adopting or adapting a DSL for the new software. Should we continue with OxCal's existing DSL to maintain familiarity and ease the transition for users, or should we develop a new DSL that could offer improved functionality and integration with modern programming languages?

Continuing with OxCal's DSL presents both opportunities and obstacles. On one hand, it could facilitate adoption by allowing users to apply their existing knowledge and potentially port their models with minimal adjustments. On the other hand, OxCal's DSL may have limitations that are not easily adapted to an open-source context or may not align well with the syntax and paradigms of languages like R or Python. Furthermore, replicating the DSL in a new software could raise concerns about intellectual property and might limit the potential for innovation in the modeling language.

Alternatively, developing a new DSL tailored to the open-source environment offers the possibility of creating a language that integrates seamlessly with modern programming practices, enhances usability, and allows for greater extensibility. However, this approach comes with the challenge of requiring users to learn a new language, which could hinder adoption. It also necessitates careful design to ensure that the new DSL is capable of expressing the complex chronological models that researchers require.

In our efforts to create an open-source alternative, we are aiming for practically addressing these questions through the development of a new R package. This package shall provide the functionalities of OxCal within the R environment, leveraging R's powerful statistical and programming capabilities. We are exploring the design of a DSL that is both expressive and user-friendly, allowing researchers to define complex chronological models while taking advantage of R's syntax and structures.

One approach under consideration is to create a DSL that borrows concepts from OxCal but is adapted to fit naturally within R's programming paradigm. This could involve using R functions and syntax to represent sequences, phases, and stratigraphic relationships, thereby providing a familiar yet flexible interface for users. By integrating the DSL within R, we aim to enhance reproducibility, facilitate integration with other analytical workflows, and promote open science practices.

As we progress, we are mindful of the need to balance the advantages of familiarity with the benefits of innovation. We would like to engage with the research community to gather feedback on aspects of usability, required features, and potential barriers to adoption. Lessons learned from the implementation of OxcAAR suggest that it is feasible to replicate key functionalities of OxCal within an open-source framework, though further work is needed to fully realize this potential.

In this presentation, we will discuss the conceptual framework of our initiative, the considerations involved in choosing or designing a DSL for chronological modeling, and the practical steps that need to be taken to develop such a software. We will highlight the capabilities of existing calibration software, and how our approach seeks to complement and extend these tools by incorporating stratigraphic information in a Bayesian context.

By sharing our experiences and the challenges, we aim to contribute to the broader discussion on advancing open-source tools in radiocarbon calibration and chronological modeling. Our goal is to foster collaboration and invite input from the community to develop a tool that meets the evolving needs of researchers in archaeology and related fields.

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286. Etruscan Chamber Tombs Portal: a case study in the use of interconnected web software through dedicated APIs

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The sets of skills required to build a proper database, and make the data findable, accessible, interoperable and reusable, while also approachable by researchers and laymen alike, are often rare to be found in one single individual. Because of this, on one hand many datasets are published in ways that can be obscure to explore; on the other hand, tools that allow for rich visual exploration of data often lack a coherent database structure that makes an approach to the raw data difficult to manage.
In our research group, this impasse has been approached by employing people with specific sets of skills that answer to specific processes in the workflow from data collection to the release of a user interface. At the center of their collaboration is the usage and development of different APIs to connect separate pieces of software. We found that the collaboration between expertise specialized in frontend development and expertise specialized in backend development led to a very fast output of new tools for the exploration of datasets relevant for archaeology and cultural heritage. Since 2023, with the workflow that we developed in our research group, we have been able to serve eight different projects, all including an extensive database of datapoints from different sources and in different media types. The case study that we present here, the Etruscan Chamber Tombs portal (http://etruscan.dh.gu.se), was developed in 2023 into a functional tool in just a few weeks of part-time work after obtaining the raw data.

Our infrastructure makes use of modern frameworks that are considered the standard in web development, such as Django (for the backend) and Vue 3 (for the frontend). In addition to these two pillars, several open source tools are used and plugged in a modular way. We often operate on datasets that include pieces of data from different media and different sources, such as images, videos, 3D meshes, Reflectance Transformation Imaging (RTI) photographs or pointclouds. For this reason, the user interfaces need to interact with a plethora of open source tools which we can interface through their dedicated API. In our projects, the key piece to communicate between the database and the user interface is the Django REST framework, a powerful and flexible toolkit for generating Web APIs. This framework makes the Django environment easy to serialize and manipulate to send data to the frontend in a structured way. The Django REST framework also makes accessible several packages for the easy development of filters or authentication policies.

The Etruscan Chamber Tombs portal, started from a dataset of photographs and drawings collected by Fredrik Tobin-Dodd in 2013 and extended to different types of 3D scans in collaboration with Jonathan Westin in 2016. The dataset included 289 tombs found in San Giovenale (close to Blera, Italy), of which 9 had 3D scans. The tombs were further classified into different types, in different necropoli, and dated to three different eras of the Iron Age (700-200 BC). For most tombs, the dataset contained at least one photograph or a drawing. Currently, with the addition of a few tombs from a second dataset provided by the Swedish Institute in Rome, the portal portrays 298 tombs, for a total of 271 pictures, 16 drawings and 18 3D models.

The portal, like other projects built by our group, makes use of different tools that provide an API working “out-of-the-box”. The frontend interacts with the database through the Django REST framework but it is not a requirement: any API providing data in a structured format (e.g. JSON) would be accessible from the frontend. This is why it is important that the project includes people skilled both in frontend and backend development. The development of the API for the needs of the user interface is a continuous process that extends far beyond the upload of data to a server, and often continues until the whole product is finished. The main view consists of a map showing the location of the tombs, with controls for filtering the aforementioned categories. The map is built with the OpenLayers library, which can interface different standard mapping APIs. When clicking on a tomb point, a preview card pops up, and upon clicking on "More Info", the user is directed to a summary of the data attached to the tomb in question. To visualize the data we have built a module-based web-application using Express and JavaScript that handles high resolution and layered images using the International Image Interoperability Framework (IIIF), 3d meshes through 3dHOP, pointclouds through the Potree.js library, and Reflectance Transformation Imaging (RTI) models using the OpenLime library. Organising these modules through a separate, but well integrated, web-application allows us to include jQuery-based libraries not supported by the Vue-framework (Westin, Bridge and Tomasini 2024).

In the last two years we have built a team of people with specific skills in web development. We have made use of out-of-the-box APIs from known actors in the web space, as well as developing our own APIs to interface a reactive frontend to a functional and well-structured database. The usage of these tools makes all our databases open both to the interested layman and to researchers who are interested in working directly with the data. Through the use of our dynamic and reactive frontend, we are able to make accessible data in different formats that are not just stored on a static server, but are a live contribution to the research that can be built upon this data. The pipelines that we have built for working with multimodal data can now be exploited and developed further for each project and lead to viable products in a matter of weeks. APIs play a pivotal role in our modus operandi, as they allow to make otherwise incompatible pieces of software cooperate smoothly. As an example of the efficiency of this work, we have produced a plethora of projects with very different datasets encompassing historical times from the Iron Age to modern times: beyond the Etruscan Tombs Portal (https://etruscan.dh.gu.se), examples are Saint Sophia's Inscriptions (https://saintsophia.dh.gu.se/), Sonora (https://sonora.dh.gu.se/), Reading the signs (release TBA in early 2025), and the Gothenburg 1923 Jubilee (https://jubileet1923.dh.gu.se/).

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73. Using digital imaging to reassess trends in subcutaneous packing of Egyptian mummies

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Aims:
The principal objective of this study was to investigate the aspects of subcutaneous packing that are ever-present in any discussion of Dynasty 21 embalming practices. There has been no study in the past century examining the practice of packing the body subcutaneously in both royal and non-royal mummies. Therefore, this study sets out to provide foundational research for the purpose of future studies on the topic.

Methods:
A combined qualitative and quantitative methodological approach was used. The first section of this study analyses the relevant literature, identifying trends in statements and verifying source material. The second section of this study analyses the CT data of 31 mummies from both the New Kingdom and Third Intermediate Periods, in order to examine trends in the practice.

Results:
Results showed that most of the literature is based on a study published in 1906, which presents outdated results that do not correspond to our current understanding of Egyptian culture and funerary practices. As a result, most modern discussions of Dynasty 21 packing are incorrect.
It is evidently clear from the findings that subcutaneous packing was also popular during the New Kingdom and is most often found in Theban mummies. It is present in both royal and non-royal mummies, as well as in both male and female mummies. It is also most commonly found in the face and neck.

260. MICROAGE: Supervised machine learning tool for age-at-death estimation of human individuals

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Age-at-death of individuals is a key information for paleodemographical analysis and forensic investigations. Histological methods have been developed utilizing specific bone microstructures, e.g., secondary osteons and osteon fragments, for assessing the age-at-death with high accuracy. However, the application of these methods is time consuming and, in some cases, inter- observer analysis yields imprecise estimates. To streamline the histological analysis and reduce estimation error we generated MICROAGE, a tool that performs automated step by step histological analysis and provide highly accurate age-at-death estimates.
MICROAGE identifies the secondary osteons and osteon fragments in micro-images and calculates the Haversian system density (HD). For assessing the age-at-death the tool performs a histomorphometric method based on HD, and utilizes the corresponding regression equation, that results standard estimation error of ±3years. For the training phase of the tool, machine-learning algorithms were developed using data (number of secondary osteons, number of osteon fragments and HD) and micro-images from modern individuals of known age and sex collected from anthropological reference collections and forensic cases. The data were retrieved manually, according to the histomorphometric method, prior to the machine-learning performance. The results of the algorithms, were thereafter validated for the accuracy of microstructure identification and calculation of the HD values. The algorithm's effectiveness was further tested on micro-images from archaeological material exhibiting taphonomic and diagenetic alterations.
MICROAGE introduces a rapid and automated performance of histological analysis and age-at-death estimations with high accuracy, that enables the retrieval of significant information from ancient and modern individuals. The algorithm was able to identify approximately 70% of the secondary osteons and approximately 60% of the osteon fragments. Specific taphonomical conditions of low birefringence of the microstructures, and bacterial activity were the primary factors contributing to microstructures' misidentification. In light of the promising outcomes, further development of the tool for assessing age-at-death is expected to occur in the forthcoming period.

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269. SALEM: a standalone software for isotope data analysis in paleodietary research

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Introduction

Stable isotope analysis has emerged as a cornerstone in archaeological and anthropological research, offering critical insights into dietary reconstructions. To interpret δ13C and δ15N data, researchers often rely on visualization techniques such as scatterplots, boxplots, and density plots, categorized by variables like sex, chronological periods, and archaeological sites. Traditionally, these analyses involve manual data processing in spreadsheets or, for those with advanced computational expertise, custom scripts in languages like R or Python.

However, this dependence on manual solutions exposes a significant methodological gap. Such labour-intensive approaches, while foundational, are increasingly inadequate for addressing the growing complexity of isotopic data. Recognizing this challenge, we have developed SALEM, a robust and efficient analytical pipeline designed to streamline and enhance isotopic data analysis across disciplines. SALEM delivers a comprehensive, user-friendly solution, bridging the gap between simplicity and sophistication in stable isotope research.

Materials and Methods

SALEM is developed using the R programming language, a widely adopted and versatile platform for statistical computing and data visualization. The application leverages the Shiny package (https://shiny.posit.co/) to provide an interactive and user-friendly interface. The application is organized into a series of distinct tabs, each representing a procedural step in the analysis workflow. This structured design functions as a streamlined pipeline, guiding users through every stage of the process. From data input to visualization and interpretation, SALEM ensures researchers can efficiently generate comprehensive and insightful reports tailored to their isotopic data.

1. QC and Data Processing Tab: users can evaluate the quality of their collagen data and determine which entries are suitable for further analysis. The application requires the entry of a CSV file containing the carbon, nitrogen, and sulphur percentages for each sample. Once uploaded, users can choose to calculate the CN ratio, CS ratio, or NS ratio by selecting the desired option and clicking "Calculate." The application automatically filters the dataset, excluding entries that fail to meet the quality control (QC) criteria outlined in Table 1. This critical first step ensures that only high-quality data proceeds to the subsequent stages of analysis.

2. Analytical Uncertainty Tab: users can assess the analytical uncertainty of their dataset, adhering to the guidelines provided by Szpak et al. (2017). Users upload a CSV file containing the required columns, as specified in the original publication. The application performs the recommended calculations and provides users with a downloadable CSV file of the results. Additionally, a formatted document is generated, including the text necessary for reporting the uncertainty findings.

3. Test and Plot Tab: this tab offers options for calculating descriptive statistics and assessing the normality of datasets using either the Shapiro-Wilk or Kolmogorov-Smirnov tests. Users begin by uploading a CSV file containing the relevant data for analysis. In the plotting section, users can

create a variety of visualizations, all generated with the robust ggplot2 package in R. These customizable plots allow researchers to effectively explore and present their data.

4. Analysis Decision Tree: serves as an interactive guide, assisting researchers in selecting the most suitable tools and models to address their specific hypotheses. Users can choose from a range of models commonly applied in dietary research, including isotopic mixing models (Stock et al. 2018) and methods for reconstructing weaning patterns (Ganiatsou, Souleles, and Papageorgopoulou 2023). The decision tree is designed with clickable references that link directly to the original publications of each method. These resources offer detailed implementation instructions and clear descriptions of the expected outcomes, ensuring users have the necessary guidance to apply the models effectively.

Results and Discussion

The application can be freely downloaded and comes together with a manual that includes instructions on column naming and file formatting. The new application we present offers a comprehensive and streamlined solution for researchers analysing isotopic data related to paleodiet. Key features of the application include advanced statistical analysis capabilities, high-quality visualization tools to effectively communicate results, and a standardized reporting format designed to promote transparency and reproducibility. By addressing the lack of a unified approach for managing the increasing volume of isotopic data, this all-in-one tool supports researchers in navigating the complexities of paleodiet studies. With its robust and user-friendly interface, the application has the potential to accelerate discovery and facilitate the dissemination of significant findings in this rapidly evolving field.

At the core of the application is its reporting pipeline, which provides a seamless and standardized workflow for data input, analysis, and presentation. The pipeline begins with an intuitive data input and formatting step, enabling researchers to easily upload isotopic data in a compatible format. The workflow then progresses to a robust analysis stage, executing a suite of statistical tests and creating insightful visualizations. From simple descriptive statistics to advanced multivariate analyses, the pipeline ensures a thorough and rigorous exploration of the data.

In the final step, the application generates detailed, professional-grade reports that allow researchers to effectively share their findings with the scientific community. This streamlined process not only enhances the transparency and reproducibility of isotopic studies but also establishes a much-needed standard for data presentation in the field. By integrating analysis and reporting into a single platform, the application sets a new benchmark for isotopic research, promoting efficiency, consistency, and innovation.

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103. A global deep learning detector of qanat underground water distribution systems using cold war satellite imagery

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Qanats are traditional underground irrigation systems designed for water distribution in arid areas. They can be recognized on the ground by a series of surface shafts, which can be identified using satellite imagery. Typically, mapping qanats has required manual digitization in GIS, a time-consuming task. Automated detection methods have been developed using morphological filters, U-Net, YOLOv5, Mask R-CNN, ResNet-50 and using high-resolution RGB and CORONA images, which hold a greater significance for archaeological investigations. However, the effectiveness of U-Net model to detect qanats on black-and-white CORONA images has been limited, often leading to a high rate of false positives (Soroush et al. 2020; Altaweel et al. 2022).
This approach is utilizing YOLOv9 architecture and black-and-white images from the HEXAGON (KH-9) high-resolution spy satellite system, which was launched in 1971. The study focused on two regions: Maiwand in Afghanistan and Gorgan Plain in Iran. The dataset have been created utilizing real, augmented, and artificial data, we generalized qanats into linear groups of circular features. Labeling individual qanats and their pairs as separate classes helped reduce isolated and clustered false positives. The dataset was enhanced with the Albumentation library to increase the number of image tiles. A dedicated post-processing workflow have been created, which allows to eliminate majority of false positives. The model's performance was evaluated using HEXAGON imagery from Afghanistan, Iran, and Morocco, as well as CORONA imagery from Iran. The model can predicts qanat shaft locations with over 0.881 precision and 0.627 recall across various case studies. This is the first investigation to detect qanats in diverse landscapes using different satellite imagery types (Buławka, Orengo, and Berganzo-Besga 2024).
The paper presents the results of Object Detection using YOLOv9, discusses the challenges of qanat detection with satellite imagery and deep learning, and will cover recent improvements to the model.

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523. Remote Sensing Approaches to Study Ancient Water Harvesting System at Vadnagar, a Historical Settlement in the Semi-Arid Zone of Western India.

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Efficient rainwater harvesting and storage systems are indispensable for sustainable living and agrarian economies, especially in regions with scant and erratic rainfall. The climate, geological structure, soil and topography of any region have historically influenced water resource management strategies. Gujarat, situated in western India, falls under arid to tropical semi-arid climatic zones. The environmental challenges complicate water storage and retention during extended dry spells. Despite these adversities, human settlements have thrived in this region over millennia, showcasing their adaptability and innovative water conservation strategies. The construction of tanks, bunds, and wells, dating back to the Bronze Age Indus Valley Civilization, serves as a testament to this ingenuity (Bisht 2000).

The emergence of urban societies in early historic India is closely linked to the development of irrigation infrastructure. These systems not only supported agriculture but also fostered urban growth and social complexity (Shaw, 2011). Religious institutions, particularly those associated with Buddhist and Brahmanical traditions during the Mauryan and later periods, further promoted sustainable irrigation and agricultural practices (Shah, 2007).

Archaeological studies at Vadnagar—an ancient settlement in Gujarat also known historically as Anandapura, Anartapura, Chamatkarpur, or Nagaraka—have revealed a continuous sequence of habitation extending from the Mauryan era (4th–3rd century BCE) to the present day. The resilience of Vadnagar, despite its location in a semi-arid region and climatic fluctuations in the past, raises important questions about its water management strategies. Vadnagar's significance as a hub of religious, cultural, and economic activity is further highlighted in Ain-i-Akbari (1590 CE), which describes the city, then called Barnagar, as a large settlement populated predominantly by Brahmins. Importantly, it also records the presence of approximately 3,000 temples, each accompanied by a water tank (Blochmann, 1873). These descriptions highlight the critical role of water resources in sustaining the city's inhabitants and institutions.

This study attempts to understand the hydrological and geographical factors that enabled Vadnagar to sustain continuous human habitation over millennia despite its location away from the river in a harsh climatic condition. Central to this investigation is the understanding the present network of waterbody and their connection, whether they were naturally occurring or modified through human interventions. It also explores the origins and development of Vadnagar's water bodies, examining the interplay of natural processes and human ingenuity in their creation. The research further aims to assess the extent to which these water bodies were interconnected and the mechanisms that sustained them during dry periods.

This study uses a multi-scalar approach, combining a watershed-level analysis of the Sabarmati and Rupen River basins with site-specific investigations using satellite remote sensing, Digital Elevation Model and detailed fieldwork. Satellite imagery is used to map paleochannels, identify interconnections between water bodies, and assess possible human interventions in the landscape. Ground-truthing through field surveys provided critical data to validate and refine these observations. This research enhanced our understanding of the strategies employed by the ancient inhabitants of Vadnagar to overcome environmental challenges and ensure water security. By examining the historical water management systems, this study also sheds light on the resilience of past societies and offers insights into modern approaches to sustainable water management in regions facing similar climatic constraints.

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480. Reconstructing the Historical dynamics of the hydrographic network in the region of the ancient Greek colony of Abdera (Thrace, NE gr.) using a Multi-temporal and Multi-source Remote Sensing approach.

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Water bodies, from lagoons to deltas to seasonal streams, are a central component of coastal Mediterranean landscapes, defining their morphology and the life of its inhabitants. Looking from a historical and geoarchaeological perspective, rivers, deltas, and coastal lagoons are changing elements that are highly sensible to environmental and human factors. Undertaking the reconstruction of the Historical dynamics of the hydrographic systems is a complex process; its results, however, provide the primary clues to understand large landscape morphodynamics, address the History of water management systems and analyse the archaeological record in aspects where water bodies play a significant role, such as the study of settlement patterns or taphonomic processes.

In the case of study presented here (Canudas et al. 2024), the reconstruction of ancient water landforms is part of an interdisciplinary landscape archaeology project focused on the territory of the Ancient city of Abdera, located in present-day province of Xanthi (Eastern Macedonia and Thrace, Greece). The project aims to understand the human-environmental interactions linked to the foundation of a Greek colony (Apoikia) in a territory occupied mostly by Thracian groups (Georgiadis et al. 2022). The region is characterised by a complex system of water bodies, including the delta formed by the Nestos River, a series of smaller rivers and seasonal streams and a chain of coastal lagoons, including the Vistonida Lake, the largest in the region. With the specific aim of understanding the changes in the region's water systems and their influence on the archaeological record, we developed an integrated and multi-source remote sensing approach to characterise at a micro-regional scale the geomorphology of the lowlands in the territory around the ancient colony.

For that purpose, we combined different computational techniques applied to remote sensing methods. The algorithms have been implemented using Google Earth Engine or the Relief Visualization Toolbox plug-in in QGIS. The methods used include, in the first place, DEM-derived products from EUDEM (25 m/pixel) and TanDEM-X (10 m/pixel), with particular attention to Local Relief Models (SLRM and MSRM). Multi-temporal satellite imagery has been analysed using different composites, including Seasonal Multi-Temporal Vegetation Indices (SMTVI), Principal Component Analysis (PCA) and Tasseled Cap Transformation (TCT). Different present-day and Historical cartographic sources and orthophotography complemented the analysis and provided a first chronological information.

Combining the different sources and derivate products, we detected and mapped more than 1000 km of former coastal and alluvial landforms. The most common features identified are small fluvial paleochannels and banks of larger paleochannels. Coastlines, lacustrine banks and artificial channels complement the resulting dataset. The implementation of the multi-temporal and multi-source approach has demonstrated its potential for overcoming the spatio-temporal and resolution limits of single-method studies. The different methods resulted complementary, with some features being visible through only one or few of the products, and also facilitating the documentation of features present in several of the materials used here. The mapping of these geomorphological features was cross-checked with an archaeological site database of the whole area and historical data about modern towns. The archaeological dataset was created from a comprehensive archaeological catalogue elaborated by the Service for Antiquities of Xanthi (Kallintzi 2011) and updated with the results of the surveys developed in some areas by the Archaeological Project of Abdera and Xanthi (Georgiadis et al. 2022). These data allowed us to elaborate a reconstruction of the area's geomorphological dynamics and palaeogeographic evolution since the Antiquity.

Our results indicate that the Eastern part of the Nestos delta was formed mainly from the Hellenistic period onwards, and reached a similar shape to nowadays in the Late Antiquity. However, most of the large paleochannels clearly visible in aerial imagery are significantly younger, and likely correspond to short-lived avulsions during the last centuries. The Kosynthos plain also prograded significantly eastwards since the Antiquity. This dynamic accelerated in Byzantine and Ottoman ages, and even more in the 20th c., causing the silting and a marked size reduction of the lakes Lafra and Vistonida. Conversely, other wetlands and lagoons in the coast of Porto Lagos that are not connected to major river systems seem rather stable during the last millennia, with only very minor coastline progradation and silting. Forthcoming geoarchaeological, geomorphological and palaeoenvironmental research will give us more precise insights about the dynamics and drivers of socio-environmental interaction, landscape change and social adaptation in this area of Aegean Thrace over the longue durée.

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452. Using modern teeth for estimating the individual ages of ancient cattle

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Introduction

Estimating the ages of domesticated animals is essential for understanding the livestock management strategies of past societies (flock composition, products exploited during life or post-mortem). Over the past 50 years, research in archaeozoology has developed methodological approaches to determine mortality ages, particularly for archaeological cattle. However, these methods remain incomplete. Reference datasets are scarce, especially for young animals, data collection can be useless for embedded teeth, and unreliable ages for isolated teeth. Moreover, the age estimates rarely exceed 10 years for adults, despite cattle lifespans can surpass 20 years.

To address these challenges, we have created a new modern dental reference database consisting of 122 cattle from the Camargue in southern France (Blaise, Garberi, Helmer, Gourichon in progress). We also propose a robust and archaeologically adaptable mathematical solution that integrates with other existing methods to predict the individual ages of ancient specimens (dental rows or isolated teeth).

This method was designed to:
- Incorporate parameters from the Camargue cattle reference dataset as well as mechanical and biological principles underlying dental system modifications (eruption, use/attrition wear) throughout life.
- Address intra- and inter-population variability and the limitations of using raw crown height as a parameter depending on age.

This communication aims to present the established protocol, the statistical and mathematical methods implemented – specifically the k-nearest neighbors (KNN) method and the bootstrap principle (Carlson, 2017) - and their application to an archaeological assemblage.

Material and methods

The corpus comprises 75 mandibles from Camargue cattle (54 females and 21 males), aged between 20 days and around 20 years. Measurements were taken for the three adult lower molars (M1, M2 and M3) and the deciduous fourth premolar (dP4) for the young individuals (<39 months). The reference dataset includes 36 dP4, 55 M1, 52 M2 and 46 M3. Five quantitative crown height measurements were selected. In addition, occlusal wear stages were treated as quantitative variables.
Age predictions are based on several quantitative and/or qualitative variables. The reference database serves as a training dataset for supervised classification.
Among the various supervised learning models, KNN was selected for several reasons. Our training database contains many missing values, which are common issues we face with archaeological material.
KNN operates on the principle that similar individuals will be ‘close’ in the data space. The algorithm calculates a predefined distance (Euclidean) between the target individual and all the individuals within the dataset, using the closest K neighbors to make a prediction (with K as a user-defined parameter). Although KNN is sensitive to extreme values (i.e. outliers), the broad age range in our dataset minimizes this issue.

As KNN does not provide confidence intervals and other usual statistical indices, a resampling method with replacement (bootstrap) was implemented to enhance the robustness of the predictions (Carlson, David L. 2017). The combination of these two methods generates multiple predictions for a single individual, yielding a distribution of age estimates rather than a single value and so usual statistical measures.

Results

A R-based function was created to enable users to input data for archaeological individuals (dental rows or isolated teeth) and rapidly obtain predictions in the form of graphs and tables. The algorithm selects the same variables from the centered and scaled reference dataset and optionally performs a k-fold to optimize the number of neighbors (by default K=3). Predictions are then bootstrapped 1,000 times, providing users with the usual statistical indices (mean, median, mode, 95% confidence interval) and a density curve of predicted ages.

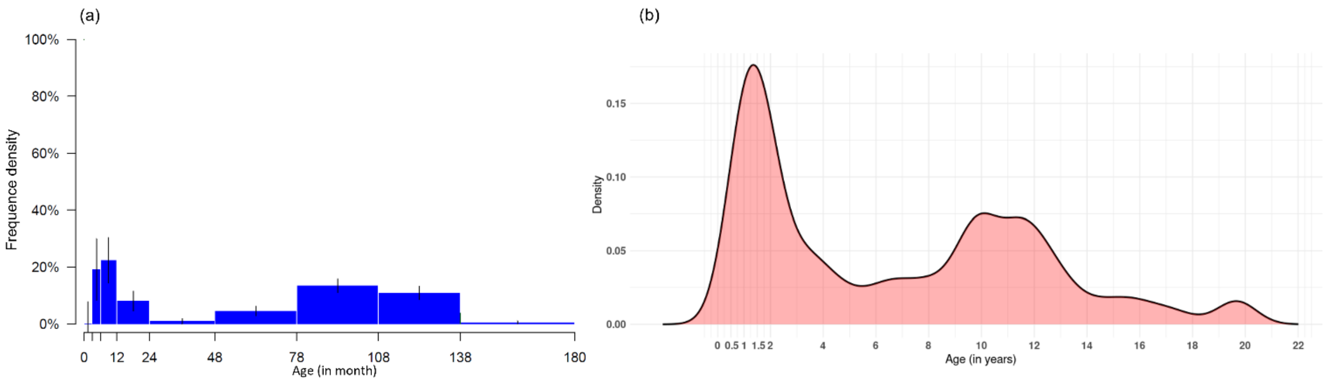
The mortality age prediction model was applied to the dental remains of Neolithic cattle from the La Citadelle site (Final Neolithic, southeastern France, 3rd mill. BC; Blaise 2010). The corpus consists of 86 measurable teeth, including 41 lower teeth. Calculations for each individual (mandible or isolated teeth) generated a density curve of age predictions. The results confirm the presence of calves (<2 years old) and old or very old adults (Fig.). They also provide greater precision and visibility for age distribution between a few months and four years and highlight the presence of older individuals aged 8-15 and 15-20 years.

Discussion

This method eliminates the need for class-based ages and provides predicted ages for the archaeological data.

Nevertheless, it is also possible to define age classes based on life stages of the animals (e.g. weaning, sexual maturity, separation of males, decline in milk production, fertility, strength, final culling, life expectancy, etc.).

To increase the model's robustness and reliability, the initial data set can be enlarged with 47 additional individuals. Users will also be able to enhance the model by sharing data from modern cattle with precisely known ages.



Mortality ages of cattle from La Citadelle site
(a) Frequences density of cattle ages classes, after Blaise 2010 (b) Cumulative density of predicted ages, after Blaise, Helmer, Garberi, Gourichon in progress

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417. First considerations on automatic valve-pairing of marine shells

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INTRODUCTION. Recent advancements in the domain of archaeology are characterised by the implementation of innovative methodologies regarding the analysis of artefacts and the processing of quantitative data that are typically discontinuous, incomplete or heterogeneous. The structuring and interpretation of data no longer rely solely on the skills of archaeologists, and data can now be processed through enhanced methodological approaches, drawing on borrowings from computer science and applied mathematics and/or new developments in collaboration with specialists in these fields.
Archaeological assemblages of marine shells from shellfish sites found all over the world can yield thousands of valves, which constitute waste products, and their study forms a separate discipline within archaeology. One of the zooarchaeological methods used to identify the exploitation practices of these marine resources, from harvesting strategies to consumption practices, is to estimate the number of bivalves based on the number of valves (a bivalve is made up of two valves), by manually matching right and left valves based on the one-to-one measurement of the size of each valve (Koike 1979). This tedious and time-consuming task makes it difficult to implement, contributing to the loss of information crucial to our knowledge of prehistoric hunter-fisher societies. To overcome this technical challenge, we propose an automatic valves measurement and matching from photographic images, as a support of archaeological research. The aim of this methodological approach is therefore to raise the informative potential and resolution of archaeological shell studies, following the first results on Machine Learning (ML) techniques for the analysis of shellfish midden remains from archaeological sites (Bickler 2018).

METHODS AND MATERIALS. An incremental analysis protocol based on a corpus of valve photos was designed as follows.
Step I: Dataset collection and annotation The dataset is composed by a set of high resolution (24 mm, 5168 x 3448) photographic images (on both graph paper and white paper) of valves from a large modern labelled collection of more than two thousand left and right valves of the species Cerastoderma glaucum, each valve being photographed on both external side and internal side. Each valve Region of interest (ROI) is labelled as “Left” or “Right” and “External” or “Internal” with VGG Image Annotator tool to enable the use of supervised learning methods. 2273 shells across 495 image files have been annotated. Each image file contains 15 to 26 shells.
Step II to Step IV are done with Detectron2 platform (Wu et al., 2019). Step II: Automatic object segmentation. The extraction of single shell from images containing multiple shells is done by shell localization via Object Detection tool: Object detection identifies and localizes each shell, allowing focused analysis by isolating shells from background elements. We use a ROI threshold of 0.7 to filter out low scoring bounding boxes.
Step III: Automatic estimation size. The valve size is measured by the shell boundary definition with Instance Segmentation tool: Instance segmentation (via Mask R-CNN tool) delineates exact shell shapes, enabling accurate area evaluation, which is crucial for morphological comparisons.
Step IV: Object classification. Two approaches have been considered: "shell" classification and "left-right" classification.

Step V: Object pairing. Implementation of a method for pairing images of left with right valves recognised as a same individual bivalve is still in progress.

RESULTS. The current results consist in: 1) objects classification; 2) objects segmentation masks and 3) objects area. SHELL: The model achieves high precision (AP = 81.6%) with perfect accuracy at both AP50 and AP75. LEFT-RIGHT: The model's precision decreases to 44% in the two-class setup, likely due to the increased difficulty in distinguishing between L and R shells.

Figure 1: Inferred segmentation for shell classification (left) and inferred segmentation for Left and Right shell classification (right)

DISCUSSION. The integration of ML techniques into the analysis of archaeological marine shell assemblages allows processing large and complex datasets of images that can be quickly collected, as photographing specimens can be easily done in the archaeological storehouses. This methodological approach not only streamlines the time-consuming process of manually matching right and left valves but also enhances the resolution and informativeness of archaeological shell studies. By automating the crucial tasks of valve size estimation and classification, the proposed protocol offers a more efficient and accurate means of analysing shellfish midden remains. The ongoing implementation of a method for pairing images of left and right valves (Step V) will benefit from the estimation of valve sizes and classification, as those will allow automatic selection of potential pair candidates.
The use of the Detectron2 platform has demonstrated promising results in automating the initial stages of shell analysis. While the results for valve size estimation are promising, the automatic labelling of left and right valves remains a significant challenge. On top of the automatic identification and segmentation of the object (the shell), one major challenge is uniforming the computed areas. Each shell appears in different pictures (back and front, oriented or not), however the computed area of the same shell is different, as slight tilts in the shell result in different masks computed to identify the object. Current work is ongoing to align those areas and provide a threshold based approach to compute the error in measurements. The implementation of this ML-based approach for archaeological research significantly reduces the time and labour required for shellfish midden remains analysis, allowing archaeologists to process larger datasets more efficiently. This increased efficiency can lead to more comprehensive and detailed studies of prehistoric hunter-fisher societies, providing deeper insights into their exploitation practices and environmental interactions, as well as allowing reconstruction of dietary habits and resource management practices. This can provide valuable information about the social and economic structures of these societies, as well as their adaptability to environmental changes.

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395. When prehistoric insects meet 3D reconstruction

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I- Introduction

Amber is a fossilised resin from ancient conifers. Found in many places, it may contain relics of the past embedded inside. Whether plants or insects, these fossils are millions of years old. At a time when the evolution of the living world around us is being studied, entomologists would like to be able to study these insects in detail so that they can be linked to the insects of today. Microscopy is routinely used to analyse them, providing a 3D model of these insects would ease their observation and provide precise measurements, but observations are distorted by refraction. This work investigates 3D reconstruction methods of objects immersed in refractive media, hoping to address the complex case of amber in the future. It integrates geometric and photometric methods, to develop robust and precise 3D reconstruction pipelines. Assuming the medium shape known, the first work was then carried out on adapting multi-view stereo to refraction. The second work is an adaptation of photometric stereo in the case of a refractive planar interface between the camera and the object.

II- Methods

Aiming at providing methods that are user-friendly and affordable for everyone, we have chosen to adapt classical photographic reconstruction methods to refraction, demonstrating that it is possible, in a controlled environment, to recover the geometry of objects encased in a refractive medium.

Assuming calibrated cameras and a triangular mesh representation of the refractive medium, we adapted multiview stereo (MVS) methods, by incorporating refraction laws and proposed a refracted MVS pipeline to reconstruct the insect inside the refractive medium. We do it by modelling the light paths according to Snell's equations for projection, and back projection through the medium within the MVS method. This work also includes the refinement and robustification of the existing approach by adding reconstruction of polyhedral media with more complex geometry, as well as studies on the determination of the refractive index of the medium. Finally, we also studied the consequences of the usage of different levels of precision in the definition of the shape of the medium (number of faces).

Our adaptation of a geometric method (MVS) to refraction has shown positive results when it comes to the use of Snell's laws to adapt 3D reconstruction methods. We also investigated a second important family for 3D reconstruction, photometric methods. Fan et al. (Fan et al. 2022) explored the case of an underwater camera, with refraction caused by the encasing of the camera. In this work, we focus on a different situation: a refractive photometric stereo method with an (infinite) planar refractive interface. In this contribution, the aim is to adapt the model of PS to refraction by taking into account an infinite plane separating two homogeneous media. The difference with the work (Fan et al. 2022) lies in the use of a plane that is not necessarily fronto-parallel, in the presence of an orthographic camera model instead of a perspective one, and in the absence of a laser to calibrate depth.

This work shows how to modify the directions of both the camera and the directional lights according to Snell's laws, as well as the intensity of the lights by applying Fresnel's laws. Following these principles, we create a new virtual scene, this time without refraction, enabling us to solve a classic photometric stereo problem.

III- Results & Discussion

Our first reconstruction with the adaptation of the MVS methods to refraction provides decent results with details, as illustrated in Figure 1, across three application cases (two synthetic and one real). The real case appears noisier than the synthetic cases, likely due to cracks observed on the back face of the medium and errors in the camera parameters, medium geometry, and refractive index, which were estimated rather than being exact as in the synthetic cases. The main constraint of this method is the computation time: restricted to polyhedral refractive media, the results can be obtained within 10 to 24 hours, depending on the precision required. In the smooth curved case, the medium surface is approximated by a very large number of faces, and despite a greedy optimisation approach, this time evolves from one day to one week (though acceleration is possible as parts of the algorithm are easily parallelizable).

The results of our adaptation of PS to refraction show that taking refraction into account provides higher-quality 3D reconstructions, while ignoring it leads to much flatter results. We can also note that the depth ambiguity of PS prevents us from using Beer-Lambert's law, because of the unknown length l, causing the impossibility of modelling the colour absorbance in our model.

The impact of this work was to demonstrate the feasibility of 3D reconstruction of objects trapped in a refractive medium. We were able to show that it is possible to adapt traditional methods, enabling us to obtain results that respected the geometry of the objects. We were also able to use it. This work has shown that the initial project of reconstructing insects in amber is certainly achievable. There are still many challenges ahead before we can achieve even the first microscopic-scale reconstructions, but current work on refraction, different materials, detail reconstruction and fine structures will eventually make it possible to reconstruct insects with a high degree of fidelity and then do the same for versions embedded in amber.

Figure 1. From left to right, a reference image and two views of our reconstruction. From top to bottom, a synthetic cuboid case, a synthetic smooth case and a cuboid real case.

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Fan, Hao, Lin Qi, Changhao Chen, Yuan Rao, Linghui Kong, Junyu Dong, and Hui Yu. 2022. "Underwater Optical 3-D Reconstruction of Photometric Stereo Considering Light Refraction and Attenuation." IEEE Journal of Oceanic Engineering 47 (1): 46–58.

518. From the material to the immaterial: digital comparative anatomy for archaeological ungulates

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Context
The identification of faunal remains (bones and teeth) found in archaeological contexts is based on a visual comparison of the shape and size of the bones with their modern counterparts. This comparative anatomy work draws on several morphological criteria identified for given species in present-day environments. However, the application of anatomical criteria by archaeozoologists presents two significant challenges. Firstly, while most of the criteria can be used to identify species, some are present in other species within the same genus or family, which limits identification and results in a significant loss of information. Secondly, there are discrepancies between the anatomical description of the criterion and its observation on the archaeological find. These discrepancies may be due to imprecise vocabulary, a lack of anatomical knowledge or subjectivity in the anatomical representation. This can lead to errors in anatomical identification.

Main argument
In light of these considerations, we sought to ascertain how these anatomical shapes could be described and observed using 3D imaging and supervised learning algorithms. The objective is to create a reliable and reproducible digital reference database based on expert knowledge. While the combination of topological data analysis and kernel matrices has yielded promising results in differentiating between wild and domestic species with similar morphological characteristics (Vuillien et al., 2024), the lack of a defined benchmark hinders the interpretation of the results from a morphological perspective. Furthermore, the construction of a digital database necessitates the utilisation of numerically discernible anatomical criteria. This prompted us to ask the following questions: We would like to ascertain whether the anatomical criteria observed on the bones are identical to those observed on the 3D scanned part (Figure 1). Are there specific criteria that apply only to the 3D object? If so, can these newly identified criteria be considered reliable identification keys?

Applications
To address these questions, we collaborated with archaeozoologists and mathematicians on a data set comprising 150 bones from five ungulate species with similar morphological characteristics: ibex, goat, sheep, roe deer and gazelle. While some of these species, such as sheep and goats, have a substantial literature supporting their identification, others, such as roe deer and gazelle, lack sufficient evidence. This work has enabled us to update the available anatomical criteria and to identify and test numerical criteria that are not visible on physical bones. This work forms the basis of future machine learning analyses that will enable us to consolidate the identifications of animals found in archaeological contexts with the help of the expert and to propose new identification criteria that are more mathematically robust.

Reference:

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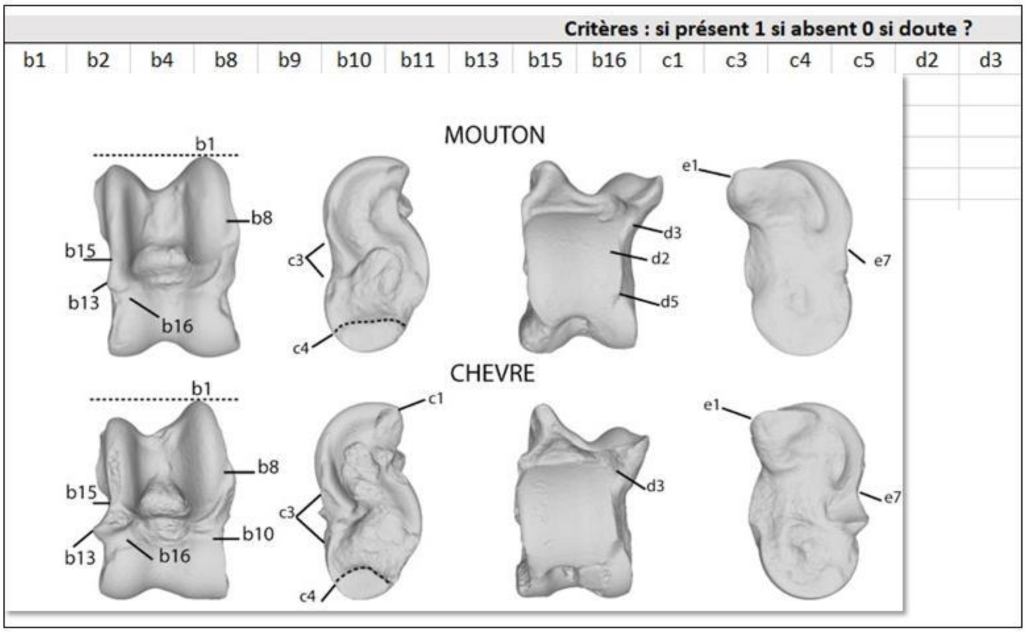

Figure 1: A simplified presentation of part of the protocol showing the list of criteria for sheep and goats on their respective 3D models.

77. Tracking the morphological evolution of small ruminants through Wasserstein barycenters

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Context

In archaeological sites, it is common to find bones of small ruminants, that were part of the subsistence economies of these sites and a major source of food. The study of these animals and in particular the domestic sheep and goats, is fundamental to the understanding of human cultural evolution over time. Their study provides information on domestication process, selection, environmental adaptations and exchanges between past communities. However, the identification of these species from archaeological remains is often complicated due to the significant morphological similarities between closely related species. For instance, sheep and goats exhibit overlapping anatomical characteristics, which makes distinguishing between them a real challenge (Sipilä et al. 2023). Moreover, intraspecific diversity further complicates the analysis, making it difficult to differentiate between natural evolutionary changes and those brought about by human intervention, such as selective breeding.

Traditionally, archaeozoologists rely on visual comparisons and manual measurements to analyze bone morphology. These methods can be time-consuming and subject to interpretational bias, especially when dealing with morphologically similar species. With the advent of 3D scanning technologies, bones can now be digitized and represented as point clouds or meshes, opening new avenues for quantitative analysis. In this context, optimal transport theory (Villani, 2009) offers a mathematically robust framework to tackle the problem of comparing and interpreting bone shapes.

In this work we address these challenges by focusing directly on 3D models of astragali (ankle bone), belonging to archaeological and modern specimens. Our aim is to highlight the morphological evolution over time, hence the transition from archaeological to modern, by directly comparing these 3D representations. We approach the problem by defining a distance between two-point clouds. We then reinterpret the problem of tracking the morphological evolution as the search for weighted barycenters between the input bones. The evolutionary trajectory between the bones can be captured as the model's hyper-parameters vary, offering a novel quantitative perspective on species evolution.

Main argument (Discrete optimal transport)

Optimal transport (OT) was originally formulated to describe how to move one distribution of mass to another distribution in the most efficient way, minimizing the transportation cost. By interpreting the point clouds from 3D bone scans as discrete distributions of points in space, OT allows us to compute meaningful distances between these shapes. We directly compare 3D scans of bones without needing to rely on traditional morphological landmarks or manual measurements using the Wasserstein distance. This distance provides a natural metric for assessing shape similarity between bones, offering a quantitative measure of how much one bone must be "morphed" into another to achieve the closest possible match.

Let $X\in\mathbb{R}^{N\times3}$ and $Y\in\mathbb{R}^{M\times3}$ be two point clouds representing for example an archaeological and a modern bone, respectively, from a given specie. X and Y can be interpreted as discrete measures (or distributions) μ and ν over the 3D space. Specifically, $\mu=\sum_{i=1}^{N}{a_i\delta_{x_i}}$ and $\nu=\sum_{j=1}^{M}{b_j\delta_{y_j}}$, where a_i and b_j are weights corresponding to each point x_i and y_j of X and Y, and δ_{x_i} is the Dirac measure centers at x_i.

In order to compare the similarity between X and Y, we apply the 2-dimensional Wasserstein distance, defined by
W_2\left(\mu,\nu\right)=\left({min}\below{\gamma\in\Gamma\left(\mu,\nu\right)}{\sum_{i,j=1}^{N,M}{\gamma_{ij}d\left(x_i,y_j\right)^2}}\right)^\frac{1}{2},
where \gamma_{ij} represents the transport plan (how much mass is moved between x_i and y_j), \Gamma\left(\mu,\nu\right) is the set of all admissible transport plans, and d\left(\cdot,\cdot\right) denote the standard Euclidean distance.
However, we aim to study the evolution between bones X and Y, e.g. how the shape changes from X to Y over time. To address this challenge we solve the Wasserstein barycenter problem (Cuturi and Doucet, 2014). The Wasserstein barycenter allows us to find an intermediate or “mean” shape (still representing a bone’s structure) that interpolates between X and Y.
In a general framework, the barycenter B\left(\mu_1,\ldots,\mu_k\right) for a set of k discrete measures \mu_1,\ldots,\mu_k is the solution of
B\left(\mu_1,\ldots,\mu_k\right)=arg{{min}\below\nu{\sum_{i=1}^{k}{{\lambda_iW}_2^2\left(\nu,\mu_i\right)}}},\ (2)
where \lambda_i are positive weights assigned to each distribution \mu_i that must sum up to one (e.g. \sum_{i=1}^{k}\lambda_i=1), and W_2^2\left(\nu,\mu_i\right) represents the squared Wasserstein distance between the barycenter \nu and each measure \mu_i.
Considering the input clouds, X and Y, and assigning weights \lambda_1 and \lambda_2 respectively, the barycenter B\left(\mu,\nu\right) defines a new point cloud that minimizes the Wasserstein distance between itself and the input clouds. By varying the weights \lambda_1 and \lambda_2, while ensuring their sum still equals one, we can iterate problem (2) and model the intermediate stages of morphological changes between two bones, enabling the study of evolutionary trajectories and species transformations over “time”.

Applications

The proposed approach allows us to trace the evolutionary trajectories of species by interpolating between 3D input bone shapes. This method provides archaeozoologists with a powerful quantitative tool to infer how species adapted, evolved, or were selectively bred by humans. For example, by calculating the Wasserstein barycenter between an archaeological sheep astragalus and a modern one, we can visualize the intermediate cloud that may capture the morphological changes (Figure 1). Furthermore, the same technique could be used to compute a “mean” bone shape for species with no well-defined morphological criteria, offering a new approach to studying species where morphological characteristics are limited.
A key a priori step in this methodology is the global registration of the data. Since the Wasserstein distance operates directly in the feature space (in our case the 3D space), it is crucial to ensure that the input point clouds are optimally aligned beforehand. This can be accomplished through different machine learning techniques such as ICP (Iterative Closest Point) or PCD-based alignment (Point Coherent Drift), ensuring that the bones are correctly registered. User-guided methods (through software like MeshLab, etc.) can also be applied for more complex cases. Accurate registration is essential for reliable analysis, as it improves the comparability between samples.
In conclusion, by directly working on 3D models, this approach offers a robust solution that aim to avoid the subjectivity inherent in traditional morphological analysis. The use of the Wasserstein distance and Wasserstein barycenter introduce a rigorous, quantitative framework for analyzing 3D shapes while offering to archaeologists a detailed and objective tool for interpreting species evolution, domestication patterns, and morphological diversity, ultimately enhancing our understanding of the past.

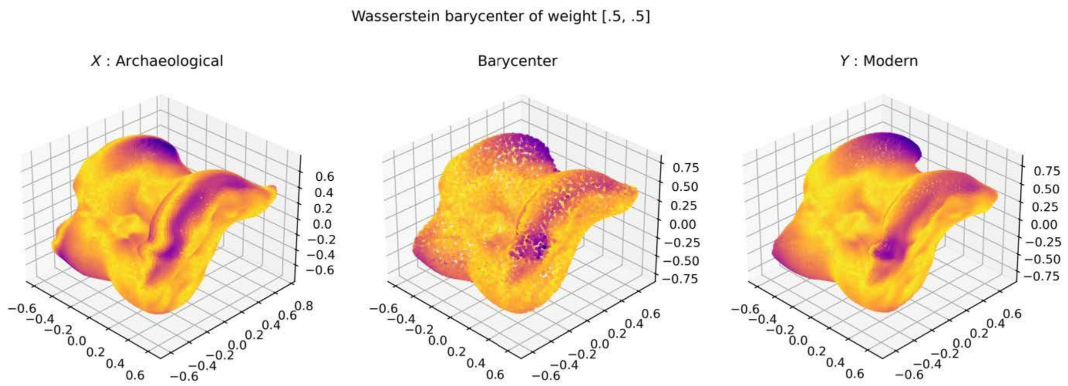

Figure 1. In this motivational illustration, we show the Wasserstein barycenter of two input 3D point clouds describing an archaeological (X, left) and a modern (Y, right) astragalus of sheep's specie. The resulting barycenter (in the middle) has 10k vertices and is computed in order to represent the "mean" shape between bones X and Y (e.g. weights $\lambda($, $\lambda+ = 0.5)$, such as that cloud that minimize the Wasserstein distance between itself and bones X and Y.

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228. Integrating Digital Methods in Archaeology: The Case Study of Posta Rivolta's Hut 1

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Introduction:
This research investigates domestic structures in Southern Italy dating between the late third and early second millennium BCE through an integrated methodology based on digital reconstruction. The study focuses on the archaeological site of Posta Rivolta, which serves as an ideal case study due to its wellpreserved post-hole patterns from multiple hut structures. The site, excavated between 2010 and 2016, has garnered significant scientific interest as a production-oriented village settlement associated with the Palma Campania cultural horizon.

Methods and Materials:
The methodology employs an integrated approach combining:
• Digital modeling using open-source software (Blender)
• AI-powered generation of Physically Based Rendering (PBR) materials
• Archaeological documentation and site plans for precise architectural modeling
• Comparative analysis with well-preserved culturally affiliated contexts
• Anthropological and ethnographic comparative data
• Experimental archaeology reference materials
The research focuses on "Hut 1," a substantial structure measuring 20.50 x 7.80 meters, located in the eastern sector of the excavation area with a northwest-southeast orientation. The reconstruction process incorporates archaeological evidence, including post-hole patterns, and draws comparisons with similar structures from the Palma Campania cultural context.

Results:
The digital reconstruction has enabled:
1. Detailed analysis of architectural elements and structural volumes
2. Volumetric calculations for assessing ecological impact and energy expenditure
3. Computational fluid dynamics testing to evaluate wind resistance and aerodynamic properties
4. Enhanced understanding of technological solutions employed in prehistoric domestic architecture

The methodology's reliance on open-source and freely available tools ensures research sustainability and reproducibility, making it accessible for broader application in archaeological reconstruction.

Discussion:
This digital approach to archaeological reconstruction offers new insights into prehistoric domestic architecture while providing quantifiable data for understanding construction methods, resource utilization, and architectural adaptations to environmental conditions. The research demonstrates the potential of integrated digital methodologies in archaeological interpretation, particularly for studying prehistoric built environments.

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178. More than Meets the Eye: GIS Tool to Identify Building Plans of a Multi-Phased Neolithic Settlement (Naters-Breiten, Switzerland)

Raphaëlle Javet (University of Zurich)*; Aurèle Pignolet (InSitu Archéologie SA); Ileina Colaizzi (InSitu Archéologie SA); Laura Tordeur Champagne (InSitu Archéologie SA); Corentin Bondi (InSitu Archéologie SA); Lauriane Vieli (Archeodunum Investigations Archéologiques SA); Samuel van Willigen (InSitu Archéologie SA)

Introduction

Between 2020 and 2022, under the mandate of the Office cantonal d'archéologie (OCA) of the State of Valais (Switzerland), a team of archaeologists from InSitu Archéologie SA conducted a preventive excavation at the Naters-Breiten site. This excavation uncovered several domestic occupations from the Middle Neolithic (early 5th millennium to mid-4th millennium BC) across more than 3,000 square meters (van Willigen et al. 2023). This terrestrial settlement is unique in the Alpine region, as most known Neolithic settlements in the area appear later and consist of pile dwellings. The site is expected to significantly contribute to the understanding of the lifestyle of the first farming societies in the Alps, particularly in terms of house architecture.

However, the architectural traces of these successive settlements form a complex set of features, mainly postholes, creating a grid that is challenging to interpret. Faced with the considerable challenge of interpreting this dense layout, innovative methods are to be explored. A PhD project at the University of Zurich will complement the post-excavation work with research on building plans from a methodological and technical perspective. This approach is inspired by ideas proposed in the early 1980s by Stephen Cogbill (Cogbill 1980) and by the methodological reflections of Peter Trebsche (Trebsche 2018).

Methods and Materials

Recorded descriptions during excavations are often heterogeneous. To standardize the data, extensive preliminary work was undertaken to formally identify the postholes at Naters-Breiten, treat them systematically and individually, position them stratigraphically, and assign them to a phase (or a range of phases) of possible occupation. The result is a standardized corpus of 2,520 postholes with harmonized intrinsic data.

The method involves developing a computational tool (a QGIS plugin) to help identify building plans by detection of postholes clusters. We chose an approach based on the spatial relationships between each posthole and its neighbours, focusing on recurring distances and angles between the centroids of each structure. The tool will also incorporate standardized descriptions of each posthole: the detection process will be guided by a preselection of each entity according to its archaeological attributes (possible stratigraphic phasing, fill type, dimensions, etc.). Additionally, the detection of regular spacing could also be refined by specifying preferred orientations.

Simultaneously, a catalogue of previously published buildings plans from the Middle Neolithic in the Alpine region and surrounding areas is being compiled. This corpus is intended to facilitate the experimental validation of the tool on proven plans. By metrically describing these previously published plans, we hope to identify their typical posthole spacings, recurring angles (e. g., for apsidal formations), and other characteristics to guide research on the Naters-Breiten plan.

First results

As of fall 2024, the first phase of work, involving the standardization and phasing of the Naters-Breiten posthole corpus, has been completed. The QGIS plugin is under development. Initial tests are promising and already allow the identification of relatively simple alignments that were not visible by eye. Once the QGIS extension is fully operational, manually formulated queries will be able to integrate variables derived from the comparative building corpus for the Middle Neolithic, which is also being compiled.

Discussion

At this stage, several points can already be highlighted. A key challenge, common to many disciplines, lies in the contingencies of field data acquisition. Field observations are often subjective and context-dependent. Despite efforts to objectify the interpretation process, it is essential to remain aware of the inherent subjectivity of archaeological data as a necessary precaution.

Regarding the QGIS extension specifically, one of the main challenges is managing tolerance margins. For instance, setting overly strict criteria for regular spacing may result in detecting very few (or no) alignments (false negatives), while overly loose criteria could identify too many alignments (false positives), making the results as unclear as the original features plan. We are particularly mindful of this issue, as it will be critical to the tool's effectiveness.

Finally, we emphasize the importance of assembling a chronologically, culturally, and geographically relevant buildings comparison corpus alongside the site analysis. This corpus must include rigorously only well-documented and convincingly argued cases from the literature, to avoid the risk of perpetuating interpretative errors and false patterns. We also hope that this tool will help challenge certain preconceived notions about building shapes and propose new types of architectural layouts.

Despite these challenges, we believe that finding solutions to make the most of posthole plans from dense, multiphase sites is essential, as these are often underused in architectural reconstructions. We hope that the methodology and computational solution we propose, tailored to the specific case of Naters-Breiten, can be applied to other similar cases.

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94. Hole Line Project, a QGIS plugin tool to help interpretation of postholes

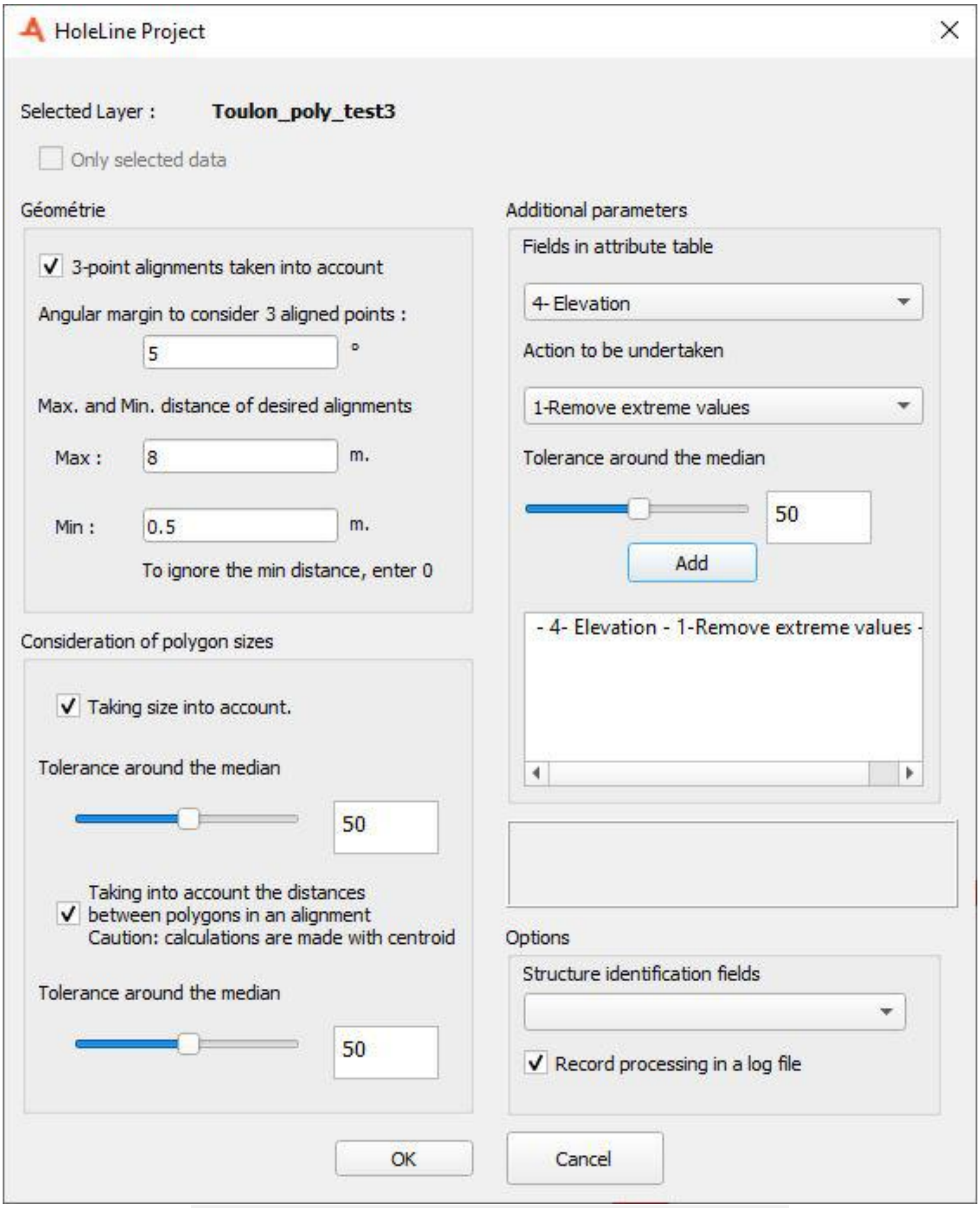
Guilhem Turgis (Archeodunum)*; Bertrand Bonaventure (Archeodunum); Agata Poirot (Archeodunum)

Introduction
From the Neolithic to the medieval period, archaeologists are often faced with a recurring challenge: how to interpret fields of postholes, the last remains of wooden structures that succeeded each other over centuries on the same site? Most of the time, the approach is empirical: archaeologists search for alignments by cross-referencing, where possible, the phasing of the structures with data such as the depth of the postholes, their size, the regularity of distances between them, and other attributes recorded in a database. This process is time-consuming, which becomes even more problematic in the context of preventive archaeology.
The goals of preventive archaeology are the same as those of planned academic archaeology: to excavate and process information to enrich our understanding of the past. What sets them apart are the legal frameworks and economic contexts. In preventive archaeology, because the land must be cleared for construction and civil engineering projects, time is limited. This affects the methods and tools used, not only during excavation itself but also in post-excavation work.

Methods and Materials
In 2021, a 10-hectares preventive excavation of an Early Medieval site in Toulon-sur-Allier (Allier, France) delivered a particularly complex plan with more than 1200 postholes scattered erratically and sparked the development of a tool to assist in the interpretation of postholes fields. This led to the creation of the Hole Line Project, whose goal is more modest than its name suggests: it is a QGIS plugin developed in Python to detect and, if needed, filter and categorize alignments based on parameters that the user can adjust.
Currently, the tool detects alignments in a polygonal layer and applies various settings that the user can modify. Some are geometric (angles and distances, regularity of the structures), while others, optional, use numeric fields in the layer's attribute table (such as elevation, depth of the structures, etc.).

Results
The output is a new linear layer made up of the identified alignments. For each entry, the attribute table provides information such as the axis orientation between the first and last points of the alignment, the standard deviation of the size and distance between structures (if these options were selected), and any additional fields based on the options chosen by the user.

Discussion
This tool does not replace the archaeologist's analysis. It is not a magic wand that automatically detects building plans. Rather, it is a tool that helps archaeologists save time by automating and systematizing tasks that were previously done manually and, as much as possible, try to process a mass of information the human eye could not handle. The tool was developed in response to field archaeologists' needs.
In the future, we plan to complement this approach with machine learning to detect building plans, focusing not only on alignments but also on more complex patterns.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Taking into account the distances between polygons in an alignment
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Record processing in a log file
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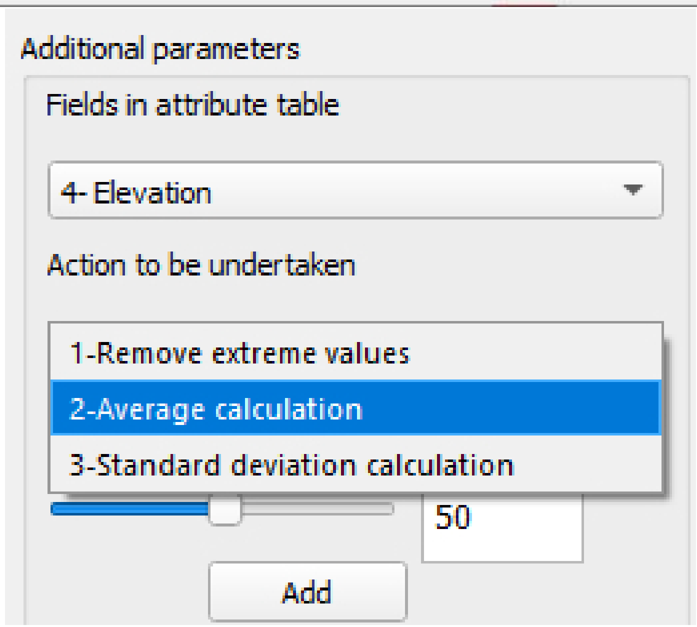
Additional parameters
Fields in attribute table
4- Elevation
Action to be undertaken
1-Remove extreme values
2-Average calculation
3-Standard deviation calculation
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528. Pile Field Analysis: A Critical Review of the Current State of the Art and Computational Approaches

Jonas Blum (University of Zurich)*

During the Neolithic and Bronze Age, the circumalpine region was characterised by a considerable number of lakeside settlements, the preservation conditions of which were exceptionally favourable due to the water-saturated soils. The most outstanding findings are undoubtedly the large pile fields, some of which can be dated to the exact year using dendrochronology. They therefore form a promising basis for modelling settlement structures.

Nevertheless, in many cases, dendrochronological dating is insufficient for a reliable interpretation of architectural units, as it is often challenging to prove that multiple piles belong to a single structure. While most investigations do analyse the pile fields carefully and consider all archaeological features, no reliable methodological framework has yet been proposed to address this issue. Computer-based quantitative methods may offer a promising solution to this problem.

The apparently disorganised character of the pile fields is the consequence of repeated settlement activities, which have occurred over periods of several decades or even centuries. The application of dendrochronological dating enables the attribution of piles to a particular settlement phase, thereby elucidating their structural characteristics.

Since the beginning of systematic pile field analysis in the 1980s, archaeologists have typically examined the distribution of contemporaneously dated piles in order to identify patterns. Pile alignments, parallel rows and regularly spaced piles are still being grouped together almost axiomatically to form units and interpreted as concrete structures, such as houses or palisades. The interpretations presented in recent research are additionally supported by dendrotypological considerations: In addition to the dating of the piles, other characteristics, such as the age of the tree, the start of growth, the progression of growth, or the similarity of the dendro-curve, are also taken into account. It is an ideal situation when the dendroarchaeological interpretations can be supported and made plausible by archaeological findings, such as in-situ hearths. In many instances, however, the available evidence is not optimally preserved, or only a limited number of piles can be dated, which considerably complicates the process of drawing conclusions about the structure of the settlements in question.

In general, it is reasonable to situate piles that appear to have a clear spatial relationship to each other in a common context. Nevertheless, despite the methodological innovations that have been introduced, there has been no fundamental methodological debate regarding the procedure for analysing pile fields or the plausibility of the affiliation of piles to presumed units. Only a small number of scientific publications even address this issue (Bleicher and Burger 2015). The established analysis practice is lacking not only a robust theoretical foundation but also the possibility of revision. This makes the approach susceptible to less critical adaptations and sometimes leads to circular reasoning, whereby pile rows are addressed as architectural units (houses) on the basis of expectations, despite the lack of findings and an insufficient number of dated piles (Leuzinger u. a. 2020).

The recognition of potential spatial relationships within a pile field continues to be contingent upon the expertise and experience of the dendroarchaeologist engaged in the investigation. Nevertheless, even if linear and parallel structures are regarded as evidently belonging together, the deduction remains arbitrary and is not reproducible in the true sense of the word. The application of computational quantitative methods represents a promising approach to the systematic organisation of these analytical processes.

The objective of conducting a systematic and reproducible analysis of the spatial relationships between piles using quantitative approaches has yet to be achieved. The question of whether piles are installed randomly or non-randomly in rows, alignments or at regular intervals represents a valuable addition to the methodological toolkit of dendrochronology and dendrotypology. Furthermore, it would facilitate the development of a stable conceptual framework.

The aim of this paper is twofold: firstly, to introduce the subject of pile field analysis to a wider audience and, secondly, to facilitate interdisciplinary debate on the use of computational techniques for modelling settlement structures.

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290. Innovative Approaches to Reconstructing Pile-Dwelling Settlements: Integrating Structural Analysis and Interdisciplinary Data

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1. Introduction
With their extraordinary preservation, wetland sites provide unmatched glimpse into material remains from past lifeways. This has allowed for the recovery of a broad range of information about the structural components of these settlements. To date, this information has been majorly used to hypothesize or reconstruct building locations, foundation types and planimetric reconstructions: often focusing on raised vs. ground-level floors and above water vs. above tidal/land space.
Nevertheless, advancements—no longer so recent—suggest that combining methodologies, like dendrochronology and paleoenvironmental data on lakeshore fluctuations, may oGer a deeper understanding of these settlements.
These insights can be further enriched by integrating engineering-based structural calculations with archaeological data. Although these methods were designed for modern applications, they have the potential to lay the groundwork for studying ancient construction techniques and the social and technological contexts in which these structures were built. We cannot claim precise calculations but can outline structural possibilities to support reconstructions.

2. Materials and Method
2.1 Creation of Database and Site Catalogue
To adopt a new method, it was necessary to select an initial focus area from which to gather the most comprehensive information possible. Given the greater availability of bibliographic resources and the authors' familiarity with the region, Italy was chosen within its modern geographical boundaries, taking account of the entire territory, from north to south. Information was collected on wetland contexts from the Neolithic to the Early Iron Age (5800–750 BCE) and organized into an Access database and GIS Project. As a result, one of the most complete catalogues of Italian wetland sites to date was created, with a total of 312 sites and 125 recognized structures.

2.2 Typology of Structural Elements and “Bonifiche” (Fill Reclamations)
The typology of structural elements and bonifiche (the term used in Italy for fill reclamation, generating an insulated floor for buildings) was updated, starting from the classification proposed by Balista and Leonardi (Balista & Leonardi 1996, 199-228).

2.3 Structural Calculations: Critical Pile Height and Wind Impact on Structural Stability
Once all relevant data and information on structural elements were gathered, calculations of the critical height for piles were carried out for contexts where the necessary structural data were available.
Critical height means the maximum height a pile -with certain characteristics and on a certain substratum- can reach before failure, which allows for estimating the maximum height of a structure. This measurement includes the height from the point where the pile raises from the ground up to its maximum height. To perform this calculation, the cross-sectional area of the pile is required (although in most cases, the diameter suGices, if precise data are unavailable), as well

as the wood species. Other values are derived from the Italian Technical Standard NTC 2018, EuroCode 5 and UNI EN338:2016.

This analysis resulted in the calculation of the critical height for 71 structures across Italy. For two of these sites, the analysis of the spatial distribution of the piles was also possible: Lucone D (Brescia, Italy, dating to the Early Bronze Age) and Fiavé VI (Trento, Italy, dating to the Middle Bronze Age).

The recent finding at Lucone D site of two multi-hole timber beams 8 m long, suggested that they could be adopted as wall plates in the roof structure. In order to check the feasibility of this hypothesis, the eGect in terms of deflection and displacement has been carried out, considering the wind forces as reported in the Italian Technical Standard NTC2018.

Additionally, thanks to collaboration with the University of Bern, the sites of Lattringen VIRiedstation (Bern Canton, Switzerland, dating in the passage between Middle Neolithic and Late Neolithic), Zürich-Parkhaus Opéra (Canton Zurich, Switzerland, dating Late Neolithic) and Greifensee-Böschen (Canton Zurich, Switzerland, dating to the Late Bronze Age), were also included in the study.

3. Results

The results are still a work in progress and have yet to be thoroughly discussed. However, preliminary data highlight that critical pile height yields interesting insights, especially when merged with available dendrochronological data.

In cases where dendrochronological data does not allow for a precise identification of the perimeter and structural elements—due to similar dating results or closely spaced structures, where it is unclear whether they represent a single larger structure or multiple smaller ones—critical height can help distinguish which piles likely served as load-bearing elements. It can also clarify whether the central row of piles within the structure was tall enough to support the ridge beam of the roof or determine the function of piles found within the perimeter, such as supporting walls, lofts, or only the raised floor. Moreover, the initial results demonstrate structures with greater elevations, which could highlight a three-dimensionality of the various structural elements within the sites and, consequently, propose insights into the social dynamics within the settlement.

Regarding the impact of wind on the multiforated wooden beams found at Lucone D, hypothesized to function as edge beams, once the maximum heights achievable by the piles at the site were estimated, it was possible to confirm this hypothesis as plausible, as it would not destabilize the structure even when the wind action is considered in the calculation.

4. Discussion

This newly applied method still requires validation across a wider range of data and study contexts but seems to hold the potential to provide a fresh perspective on both past and future datasets. Achieving this, however, depends on a detailed understanding of the existing constrictions, particularly in the upper section of the piles—a factor that is not always accessible as often one has to rely on assumptions drawn from the archaeological record concerning the constrictions of the lower part, which may diGer significantly.

A significant limitation for research lies in the lack of precisely published data on pile diameters and their spatial distribution in archaeological reports. Addressing this gap is a key priority for future studies.

Having access to such information could enable the identification of previously unclear construction techniques distributed across various contexts. This, in turn, could shed light on connections and exchanges that have yet to be fully understood, oGering a deeper insight into the technological and cultural interactions of these communities, bringing forward a proper techno-typological approach.

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453. Berezov: Defensive And Civil Architecture Of The Late 16th - 18th Centuries (3d Reconstruction Based On A Comprehensive Research)

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Introduction

The urban-type settlement of Berezovo is the northernmost district center of the Khanty-Mansi Autonomous Okrug - Yugra. It remained a small settlement and preserved its historical layout and part of the buildings. As a result, at the end of the 20th century, only Berezovo could claim the status of a historical settlement of Yugra. Founded in 1593 by the governor N. V. Trakhaniotov, the town of Berezov became the main base for the development of the North of Siberia.

A real treasure for historians was the plan of the Berezov town dated by the end of the 17th century, compiled on the basis of a plan and map of the area that has not survived to this day. By the end of the 18th century, the architect I. Lyapin drew up a project for the reconstruction of Berezov, replacing the disorderly layout with a “regular” one with straight streets and blocks.

However, the opportunity to clearly illuminate the life of the residents of Berezov is provided by archaeological research conducted by the expedition of the Scientific and Production Association “Northern Archeology - 1” over several field seasons, starting in 2006. During the the reconstruction of the planigraphy of the town fortifications, 4 main stages of development were identified: the fortress in 1593; before 1610; 1610-1642 (according to the description of 1636); after 1668 (according to the description of 1691).

Methods and Materials

In the excavation area of 424 square meters, the remains of 38 buildings lying on seven construction tiers were identified and investigated, 30 of them were parts of eight courtyards-estates of the 17th-18th centuries. Of the four estates that were completely excavated, two are most suitable for reconstruction: Estate No. 7 (1618 - 1642-1650) and Estate No. 3 (1674-1718). Based on the materials of the archaeological excavations and ethnographic data, an 3D architectural reconstruction of these buildings and the settlement in general was made.

The relief was obtained in the.dxf format, one of the popular vector drawing formats, and was a height map of 8 geological sections with a step of 0.5 m. Geometric sections were represented by a contour, a vector line, and were not suitable for working in polygonal modeling. It was decided to import a dxf file with geometric sections into the Rhinoceros CAD modeling program. This program needed the Grasshopper* plugin, with which a simulation of a 3D relief model can be made. Then the relief was converted into a volumetric plane (surface) format and imported into the Blender program in fbx format for further work.

During the importing of materials into Blender program, it is important to monitor the location and scale of imported objects, because if the default units of measurement in Rhinoceros were millimeters, and in Blender - meters, then the model can be imported at a scale of 1:100 or vice versa, if the planes of the imported model are inverted. Therefore, it is necessary to determine the overall dimensions of the model in Rhinoceros and recheck them after importing into Blender. There is a need of retopology since the resulting relief model has been imported into Blender. The towers’ drawings were converted to dxf format to import into Blender and were divided into the main orthogonal views: top view, front view and side view

Results

In Berezov, a stable development of posad estates with a street layout can be traced from the beginning of the 17th century. All the posad estates in excavation pit 2 were built in three lines parallel to each other and perpendicular to the street, which was directed parallel to the main bank of the Northern Sosva River. Despite the fires, this street layout remained unchanged for two centuries. The most difficult issue in the reconstruction of estates based on archaeological materials was connected with determining the number of storeys of buildings. For archaeologists, reliable signs of two-storey buildings are the discovery of the remains of stairs and supporting pillars of the porch.

The data obtained during the archaeological work of 2008-2021 made it possible to restore the planning structure of Berezov with a greater degree of probability: a description of the Kremlin, the posad, the two well-preserved estates, and also provided material for reconstruction of the height characteristics of the buildings.

Thus, the city of Berezov consisted of several parts: the “town fortress” (Kremlin) had an almost square structure with walls made of gorodnya (a wooden and earthen structure, part of a fortification, usually consisted of a separate, closed log house, most often filled with soil). Four towers adjoined the walls at the corners. The main tower, Spasskaya, stood at the south-eastern corner. It was a “driveway” with a gate. Permskaya Tower stood at the south-western corner, Vymskaya tower - at the north-western corner (the names of these two towers were probably given in memory of their builders - the Permichi and Vymichi), and the Round Tower with “small gates” stood at the north-eastern corner. This is the first experience of 3D reconstruction of wooden architecture of the north of Western Siberia and this experiment will be continued and comparisons with examples of Russian wooden architecture of other territories will be conducted.

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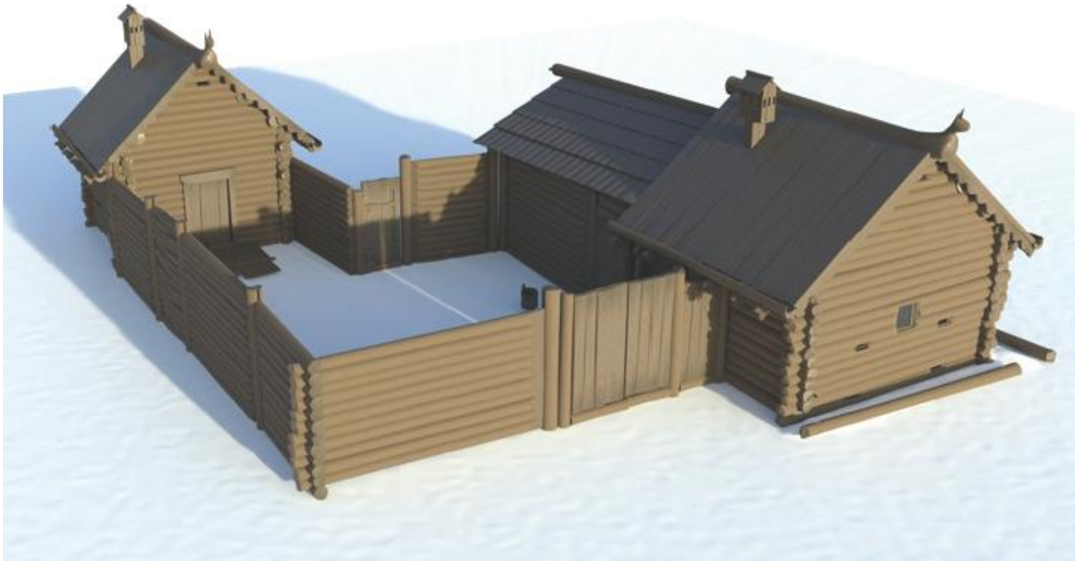


169. Image Data for Neural Networks: Insights from Existing Archaeology Research

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In 2012, the ImageNet Large Scale Visual Recognition Challenge, which consisted in the classification of one million images into 1000 classes (1000 images per class), was won with an accuracy more than ten percentage points higher than the next best model by a deep artificial neural network now commonly known as AlexNet (named after the first author of Krizhevsky, Sutskever and Hinton 2017). This was arguably a watershed moment in the recent history of machine learning, marking the explosion in performance and number of applications of all kinds of artificial neural networks, but especially those dealing with image data. In archaeological research, an explosion of machine learning applications is also visible starting from the year 2018 (Bellat et al. in prep), with artificial neural networks slowly growing to become the overwhelming majority of models used in publications in the year 2022 (Bellat et al. in prep).

The use of images as input data for models is not restricted to artificial neural networks. Random forest, another very popular machine learning model in archaeology (Bellat et al. in prep) is well-suited for many image-based classification problems. However, neural networks have been applied to numerous tasks dealing with image data across a great number of areas of science, technology, and modern life, often to great publicity. It is therefore no surprise that their application has also been explored in archaeological research.

However, the use of image inputs for artificial neural networks is not straightforward. For example, during training of the model, the neural network may use certain features as important for classification even though they are not meant to be diagnostic or are incidental to the actual feature intended for classification, leading to false positives (an important problem in e.g. machine learning-assisted medical diagnosis; see Varoquaux and Cheplygina 2022). Furthermore, image datasets available for certain specific archaeological tasks or applications can be very small or contain (sometimes heavily) imbalanced classes (Bellat et al. in prep; cf. in medical imaging: Varoquaux and Cheplygina 2022) with no changes applied to the methods used in order to correct or ameliorate the aforementioned issues (if there is any way to address these issues at all, that is). In some cases, the methods used are not described in enough detail (or the code used not available) to know whether issues like those described earlier truly exist or not (Bellat et al. in prep).

Such methodological issues must be brought to light and addressed if researchers are to obtain and report significant results, and if these results are to be replicable, a foundational requirement for scientific research. We thus present here a brief summary of important methodological considerations (and what they imply for reporting results and conclusions) when using image data for neural networks based on insights gained from existing applications of neural networks in archaeology, providing also some suggestions for best practices for using image data for neural networks based on the broad types of tasks to solve. Through this, we seek to provide researchers with a better understanding of the possible issues present with the use of image data, but also possible ways of overcoming these challenges. Our hope is that this can lead to improvements in the methods used, in how they are reported, and in the validity of the conclusions drawn from the results obtained from not only image-based artificial neural network applications in archaeology, but also from machine learning models in general.

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60. An application of neural networks to identifying cellular bone growth processes

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Identifying the two main cellular processes of bone growth, bone formation and bone resorption, on the surface of dry bones is fundamental for our understanding of the ontogenetic processes behind morphological evolution in fossil hominins (Bromage 1989). Bone modeling studies require the use of quantitative data to assess the intra- and interspecific variability, which have long been lacking. Despite substantial methodological progress, it remains time consuming to manually identify and quantify patterns of bone modeling on dry bone surfaces. Schuh et al. (2019) developed a workflow that involves manually selecting bone resorption on images of the bone surface captured via confocal or digital microscopy. Bone resorption is distinguishable from its opposite cellular activity, bone formation, as it can be identified through the presence of Howship's lacunae, i.e. small depressions indicating that the bone is being broken down. Depending on its state (aggressive or "skimming" (McCollum 2008)), bone resorption can take different aspects, from respectively deep, rounded depressions to elongated, superficial marks.

Here we present the first steps towards a fully automated workflow for image segmentation of bone formation and resorption using machine learning, which is at its infancy in our field (Courtenay et al. 2019, Navega et al. 2022). We compare different machine learning architectures based on a dataset of 100s of standardized images, which were manually segmented by a single observer (AS). The most basic of these was a U-Net model — a convolutional network that has proven effective for segmenting biomedical images. The source image is first downsampled through a series of convolutional layers which each pass through a rectified linear unit (ReLU) and max pooling. The images are then upsampled to the original image resolution through a series of up-convolution layers and concatenations. In the final step, the pixels are passed through a sigmoid function to pull the values towards 0 or 1 to create masks. These masks are then compared to the original segmentation mask for this image to measure the accuracy of the model. We had our greatest success when training the model on a reduced set of images with clearly delimited areas of bone resorption (i.e., with the "aggressive" state), but more work needs to be done on images with the skimming state. We then used semi-supervised learning to add images and fine tune the model.

In a separate attempt, we adapted both Meta's publicly accessible Segment Anything Model (SAM) and the YOLOv8 model to our purposes. SAM is trained on 11 million images consisting of 1.1 billion masks. However, this out of the box functionality did not perform well on our bone images. Thus, we added our own training images to the existing model in a type of transfer learning. We then applied this augmented SAM to test images. When given prior information (bounding boxes) on where the bone modeling might be in the test images, this augmented SAM performed extremely well at segmenting our images. Similarly, we augmented the YOLOv8 model. Overall this model performed better than the U-Net models; however, when it failed, it did so catastrophically, yielding very poor results.

Thus far these results suggest that with some modifications to the workflow, machine learning can speed the process of segmenting these images. However, currently the results do not allow for an automated workflow. More work needs to be done to fine tune these models and to augment the training datasets to improve the accuracy of the segmentations.

The use of machine learning thus represents a promising avenue for the identification and quantification of features on dry bone surfaces. Such methods open up new possibilities for analyzing bone surfaces by improving the study of large datasets in a significantly reduced amount of time. Here we show that neural networks can have broad applications to the field of paleoanthropology.

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119. Classifying Polish in Use-Wear Analysis with Neural Networks: Investigating the Effects of Magnification and Material Variations

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Introduction

Lithic use-wear analysis examines the micro- and macroscopic traces on tool surfaces that result from the wear produced by human use. One of the most extensively studied traces is polish, which forms through the physical abrasion of the stone surface during contact with worked materials. The formation of polish is known to be the result of a dynamic process, influenced by the tool material, contact material, and duration of use (Ibáñez and Mazzucco 2021). To identify and classify polish, researchers have been applying quantitative methods to achieve more accurate, standardized and replicable results, with the most recent addition being machine learning (e.g., Pedergnana et al. 2020).

Polish classification studies using machine learning focus on two key axes. The first addresses methodological questions, such as examining how the intensity of tool use affects the formation and development of polish, as well as identifying the optimal magnifications for its analysis (Ibáñez and Mazzucco 2021). The second axis explores archaeological questions, including the distinction between used and unused tools and the classification of contact materials in relation to the hardness (e.g., soft or hard), type (e.g., bone or hide), and condition (e.g., dry or fresh) of the contact material (Pedergnana et al. 2020).

As research questions become more complex, developing high-performance models becomes increasingly challenging due to factors such as image quality, sample size, and equifinality. This paper aims to integrate both research axes and use a pre-trained neural network model to determine the best microscopic magnification (optical objective) for polish classification and assess whether it can classify polish based on the hardness and type of contact material.

Methods

The dataset consists of 75 grey-scale images of polish created by contact with wood, hide, and bone from 43 flint tools created using controlled experimental protocols. The images were acquired using a a reflected light microscope (ZEISS Axio Scope.A1 MAT, objective EC Epiplan 10x/0.25 M27, Objective EC Epiplan 20x/0.4 M27. All analyses were conducted using Python scripts, ensuring reproducibility and transparency in processing and model evaluation. Images were resized to 512x512 pixels, and their values normalized between 0 and 255. To ensure consistent brightness and contrast across the images, Contrast Limited Adaptive Histogram Equalization (CLAHE) was applied. Images were cropped to eliminate unfocused areas through Sobel edge detection and Otsu thresholding, resulting in binary images with polished areas represented as polygons. Two parameters were extracted: the spatial distribution and the size of the polygons, encoded as color values. The classification was performed using a pre-trained ResNet50 CNN model with the colour-coded images as input. The data was split into training, validation, and test sets, with augmentation applied to the training data. Finally, the model was evaluated using metrics such as accuracy, loss, ROC-AUC curves, and confusion matrices.

Results

The model exhibited varying performance depending on the magnification of the input images. Images captured at 20x optical objective achieved an accuracy of 60%, while those at 10x optical objective reached 80%. The model effectively distinguished between hard and soft materials, achieving an accuracy of 90%. The classification of polish based on the type of contact material yielded an accuracy of 80% and loss of 0.9, indicating strong overall model performance. When analysing the identification of materials individually, bone polish was recognized with high accuracy, achieving a precision of 0.84, recall of 0.96, and an F1-score of 0.90. The identification of wood polish was satisfactory, showing an increase in false positives and false negatives, with a precision of 0.83, recall of 0.56, and F1-score of 0.69. Hide polish exhibited the lowest classification performance, with a precision of 0.50, recall of 0.67, and F1-score of 0.57. Based on the learning curves, we observe that the model's learning rate is smooth and stable across epochs for both training and validation loss and accuracy. A slight gap emerges between the curves after epoch 5, however, due to its small magnitude, this is not a concern for overfitting. Consequently, early stopping was applied to conclude the training.

Discussion

Our results indicate that samples within the same hardness category—whether hard or soft—can be classified accurately. In terms of different contact materials, hide did not yield satisfactory results, either due to form of the polish or the lack of optimal descriptive parameters. The observation that the algorithm performs better at 10x optical objective compared to 10x is likely due to the fact that the information captured in higher magnifications is not adequate for the polish patterns studied.

The results agree with previous machine learning studies on classifying polish. In line with Zhang and colleagues (2024), our results indicate that transfer learning is advantageous, as it does not require excessively large datasets for model training. Our findings suggest that a lower optical objective captures the characteristics of polish more effectively, contrasting with Zhang and colleagues (2024); however, differences in microscopes, contact materials, and models prevent direct comparisons and highlight the need for further research. A novel aspect of this paper is the use of parameters that focus on the extent and distribution of polish as input data, going beyond raw images, ISO parameters, and texture analysis.

Despite employing data augmentation, stratified splitting, and class weights to address the small and imbalanced dataset, these methods can mitigate but not fully eliminate classification issues. Moderate accuracy for hide classification and the slight distance between training and validation curves may stem from these factors. Additionally, eliminating unfocused areas from images may have resulted in significant information loss, limiting the creation of more classification parameters.

The development of robust models that achieve high accuracy across different datasets is closely related to the quality and availability of data. Therefore, the systematic and controlled acquisition of data, along with its subsequent sharing, should be integral to use-wear analysis workflows. Moreover, researchers employing machine learning methodologies should acknowledge the imperfections of their datasets (experimental reference collections) and adapt their approaches to meet their specific research questions.

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486. Improving archaeological artifact classification with modern transfer learning architectures

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Introduction:
With the rapid growth in the size and complexity of deep neural networks, the big models have achieved remarkable TOP-1 accuracy (>90%) in natural image classification on ImageNet [1]. This high performance ensures reliable transfer learning capabilities for downstream tasks, particularly when applied to smaller, domain-specific datasets. In archaeological artifact classification, recent studies have demonstrated the success of pre-trained networks, like EfficientNet-B3, Inception-V3, and ResNet-50, which classified an artifact image set collected from the Israel Antiquities Authority (IAA-Set), ranging from the early Paleolithic to the late Islamic periods [2-3].
Despite the success of these methods, there remain challenges in artifact classification that could be addressed through dataset organization, image quality control, and model architectures. This study aims to update and improve the IAA-Set in [2] by incorporating recently published artifacts and leveraging the latest foundation model for segmentation. Moreover, we upgrade the backbone networks in [2] with state-of-the-art (SOTA) pre-trained models, utilizing either convolutional neural networks (CNNs) or transformer-based architectures. This work also introduces a novel multi-input network architecture designed to handle multiple photos of the same artifact, taken from different angles. The comprehensive ablation experiments quantitatively illustrate how the proposed modifications significantly improve artifact classification performance.

Methods and Materials:
Dataset: The primary dataset used in this study is the updated IAA-Set, which has been expanded to include newly published artifact photos available online. To enhance the quality of the images, background removal is performed using the Segment-Anything-Model (SAM), a foundation model for segmentation. This segmentation step is essential to ensure that the model can focus on the artifacts themselves, without being distracted by irrelevant background details.
Preprocessing and Augmentation: Prior to model training, each segmented artifact is placed onto a square white background and resized to 224x224 pixels for input into pre-trained models. Standard data augmentation techniques, including random rotation, scaling, and flipping, are applied to increase the diversity of training samples and reduce overfitting. These augmentations expose the model to various variations of the same artifact, helping it generalize better and become more robust.
Model Architecture: Several SOTA models for classification were investigated for the backbone networks. In terms of traditional CNN-based architectures, we tested VGG-19, ResNet-50, EfficientNet-B3, and Inception-V3 for a direct comparison with previous work [2-3]. In addition, we incorporated transformer-based models, such as Vision Transformers (ViT), which have demonstrated significant success in image recognition tasks due to their ability to capture long-range dependencies and global context within the image.
Multi-input Network Design: A novel multi-input network architecture is introduced. Many artifacts in the IAA-Set were photographed from multiple angles, providing valuable structural and detailed information. Rather than treating each image as an individual input, we designed a multi-input system that combines features from multiple images of the same artifact. This

architecture is specifically designed to handle multi-view inputs, enabling the model to extract more meaningful and comprehensive representations of each artifact. The features extracted from each input are fused at an intermediate stage, allowing the network to learn more robust and enriched representations, ultimately improving classification accuracy.
Training and Validation: The models were trained using the Adam optimizer with an initial learning rate of 0.0001. The dataset was randomly split into 75% training and 25% validation sets, with this split repeated five times. Model performance was evaluated based on classification accuracy, specifically TOP-1, TOP-3, and TOP-5 accuracies, which measure the percentage of test samples for which the correct label appears in the top 1, top 3, or top 5 predictions, respectively. To evaluate the impact of different components of the system, including the choice of loss function, backbone architecture, and the multi-input network design, we conducted a series of ablation experiments. These experiments were designed to isolate the contributions of each modification and assess their individual effects on model performance.

Results:
The experiments conducted in this study resulted in significant improvements in artifact classification accuracy compared to previous approaches [2-3]. Using the updated IAA-Set, we observed a marked increase in performance, particularly when the new background removal technique was applied. By eliminating irrelevant background information, the models were able to focus more effectively on the artifacts themselves, leading to higher accuracy.
When comparing different backbone networks, the transformer-based Vision Transformer (ViT) architecture outperformed the CNN-based models in terms of overall classification accuracy. However, the combination of CNN and transformer architectures in the multi-input network yielded the best results, demonstrating the advantages of utilizing both spatial and global context features. Additionally, the multi-input architecture significantly outperformed the single-image approaches, underscoring the importance of using multiple views of the same artifact to enhance classification accuracy.

Discussion:
The findings of this study underscore the potential of using SOTA deep learning models for artifact classification tasks. The significant improvements in classification accuracy can be attributed to several key factors. First, the updated IAA-Set, which includes newly published artifacts and incorporates background removal techniques, provided a more reliable and informative dataset for training. Second, the exploration of CNN and transformer-based architectures demonstrated how leveraging both local and global features enhances the classification of similar artifacts. Lastly, the novel multi-input network architecture proved highly effective in utilizing multiple photos taken from different angles, resulting in a more comprehensive representation of each artifact. This study illustrates that thoughtful consideration of dataset organization, model architecture, and input strategies can lead to substantial improvements in artifact classification. Future work could expand the dataset to include artifacts from other regions and time periods, further enhancing the model's generalization capabilities and making it more applicable to complex classification challenges.

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209. Supporting a Celtic coin die study with image matching and hierarchical clustering for creating a social networks analysis

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Introduction
For numismatists, carrying out a coin and die study is a very time-consuming task. They have to compare numerous coins or coin photos by hand and identify possible dies. The effort required for this grows exponentially with the number of coins available and can hardly be managed by one or even several people within a reasonable period of time. As coins were produced in large quantities in antiquity and many have been preserved, coins and their dies have great potential for researching local or supra-regional economic areas.
In our new project „De Retibus Nummorum" (DeReNum) we want to support a coin die study on Celtic coinage and a social network analysis (SNA) with different AI and non-AI approaches. Celtic coins differ in their characteristics from Greek or Roman coins (e.g. hardly any legends). However, the coins can help to explore the Celtic area in Central Europe and its trade networks by means of a social network analysis using identified dies and their couplings, which are often caused by the higher wear of the upper die and the need to replace it in the minting process.

Methods and materials
In order to carry out the die study and the social network analysis, data sets are needed that are regionally diversified and contain a sufficient number of coins. Therefore, one of our most important goals at the beginning will be to compile these coin datasets, which are spread across different institutions such as museums, universities and archaeological offices. Due to the easy availability for us, we would like to start with the so-called Bushel series (already acquired) and the Kaletedouquinars (approval still to be granted), which are available as a data set with at least 2000 coins each. The data sets will then be pre-sorted according to the state of preservation of the coins using the unsupervised ML approach Deepcluster, which we also used in the previous project (ClaReNet) that are stored in a Dédalo database.
Our pipeline for supporting the die study was also developed in this project. It consists of the following steps: We start by pre-processing the coin images to minimize possible biases such as color, damage, corrosion and irregular coin edges. To do this, the images are converted to gray scale, processed with a blur filter and cut out in a circular shape (circle crop). Afterwards, we use a keypoint detection and matching algorithm in the processed images and compare them in pairs for all images in the dataset (like a numismatist does). The result is an n x n (n = number of coins) matrix containing the keypoint matches of each image pair. Each row represents a vector with matches for a coin image. The distances between these vectors are determined using the Spearman distance in the Orange Data Mining App and then analyzed using hierarchical clustering. In the end, we obtain a dendrogram of all coins as a visualization of the results. In this dendrogram very similar coins, which may have been produced with the same die, can be found in the same subtrees. These sub-trees can then be selected by our numismatists and the coin images they contain can be compared directly. In the course of his master's thesis, Markus Fiedler was able to improve this pipeline by testing and comparing various keypoint detection and matching algorithms as well as other distance functions.
In order to evaluate the results of the pipeline, data sets with a ground truth, i.e. a manually performed die study on a subset of a data set, are required. We would then like to carry out the social network analysis, which is based on graph theory. The coin locations serve as nodes. If we

find the same die in different locations, an edge is added between these locations. The aim here is to find trade networks in this Celtic area and to be able to investigate them more closely.

Results

We were able to achieve initial results for the application of our pipeline in the ClaReNet project. This evaluation was carried out on class VI of the hoard find of Le Câtillion II, for which a die study by the numismatist Philip de Jersey with approx. 1300 coins and more than 30 dies was available. Our approach produced 256 clusters of which 208 had at least 70% coins of the same die (based on ORB - Oriented FAST and rotated BRIEF) for the keypoint detection and brute-force matching. Furthermore, 194 clusters only contained coins that were produced with the same die according to the ground truth. In our opinion, this shows the potential of this pipeline. In his Master thesis, Markus Fiedler was able to significantly improve these values as shown in the table below, mainly by alternative detection and matching algorithms.

	>70%	100%
previous system (based on ORB)	208 (81,25%)	194 (75,78%)
optimized system (work of Markus Fiedler)	239 (93,35%)	230 (89,84%)

Table 1: Comparison of original system by the ClaReNet project with the improved system developed by Markus Fiedler based on 256 clusters.

Discussion

Based on the results we have achieved on the Le Câtillion coins, we are confident that we can also achieve good results on other Celtic coins of the Central European area and thus effectively support our numismatists in the preparation of die studies. Of course, the results of our pipeline must be checked on other coin data from this geographic area. For this we need data sets that have already been (partially) subjected to a die study. One of our challenges here is access to the coin data distributed across various archaeological institutions. In addition to authorizations to use the data, different states of preservation, data formats and the type of photographs taken can also play a role in this process.

We will continue to look for ways to incorporate Machine Learning-based methods into our work. It is possible that transformer-based approaches may offer ways to effectively identify coin dies, thus facilitating the work of numismatists.

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106. Arkindex, an open-source platform for document image recognition applied to archeology

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Introduction

Computer vision and machine learning have found many applications to assist archaeologists in their fieldwork (Bickler 2021). However, these techniques can also be useful for the exploitation of archaeological documentation, be it traditional scientific publications (articles, monographs, catalogues) or grey literature (internal reports, excavation notebooks, dissertations, plans, sketches, photos). Recent advances in artificial intelligence, in particular multimodal generative artificial intelligence, open up great prospects for the exploitation of this textual and iconographic data. This resource is abundant but often poorly catalogued and only available in its original form: on paper or, after digitization, as an image of the document. The PictorIA consortium brings together 47 partners - museums, archives and academic laboratories - from the French-speaking humanities, arts and social sciences (HASS). Its aim is to study and develop AI based methods and tools to extract and structure textual and iconographic information from image corpora in the HASS, particularly in the field of archaeology.

The exploitation of digitized archaeological documents presents three challenges: first, the volume of these documents is often substantial. Secondly, the content and format of these documents is very diverse, ranging from handwritten notes to photographs. Finally, the configuration of the extraction of information requires the professional expertise of those who produced the documents or will use the data. For these reasons, it is necessary to develop tools that are scalable to mass processing, adaptable to many types of documents and information to be extracted, and directly usable by end users. As part of its goal to evaluate tools, the PictorIA consortium evaluated the open-source Arkindex platform for extracting information from archaeological documents.

Methods

Arkindex is a digital document processing platform designed with three objectives: to integrate any type of document and processing method, to process up to millions of documents, and to adapt to the needs of users.

In order to adapt to any type of project and information, Arkindex does not require the use of predefined document structure types. The structure of the project can be customised, from the organisation of the corpus down to the smallest textual or visual element, by specializing a generic type for each desired level. These types can then be organised hierarchically to reflect the overall structure of the project. Secondly, Arkindex does not restrict the type of information that can be extracted from these elements. Each element can be enriched with an orientation, classes, transcripts and metadata. All these enrichments can be preconfigured, constrained (for classes) or free (for metadata).

Arkindex enables the integration of any type of processing algorithm with an API that covers the full functionality of the platform and a modular design that separates data processing and storage. All processing is integrated into Docker containers that run on independent compute nodes and interact with the platform through the API. This architecture makes it possible to take advantage of the rapid improvement of algorithms by easily integrating and training them into the platform. Arkindex's distributed processing architecture enables scaling by distributing

processing across many compute nodes, whether on local servers, in the cloud or using supercomputing resources through the SLURM system.
Finally, Arkindex offers a graphical web interface that allows users and business experts to contribute to the definition of the data structure, configure the processing and verify the results. The source code of Arkindex is open-source, which allows the community to either develop new features or fund developments.

Results

In this section, we will present 2 use cases to illustrate how Arkindex's generic and modular design allows it to process very different documents in the field of archaeology.
The first use case is the textual and visual indexing of the handwritten excavation journals of the French archaeologist Bernard Bruyère, preserved at the French Institute of Oriental Archaeology in Cairo. A corpus of 4 notebooks (892 pages) was organised and processed in Arkindex in order to obtain an index of text lines, hieroglyphic lines, plans and illustrations.
The hieroglyphs, plans and illustrations were localised and manually enriched with the date and location of find, inventory number, other names and owner metadata. The illustrations were manually enriched with 62 classes describing the type of object or motif. All lines of handwritten text were automatically transcribed using a handwritten text recognition system (Maarand et al. 2022). The result of this semi-automatic text-image indexing will be published on the IFAO website.
The second use case concerns the analysis of wheel decorations on Argonne pottery (Bakker et al. 2018). For a preliminary study, 212 photographs of fragments of Argonne pottery were selected and imported into Arkindex. These images of fragments were manually annotated to locate and identify the different decorations present according to a side / fragment / wheel / motif hierarchy. A classification was then added to the patterns to categorise them into 9 pre-defined classes. This set of annotated images was then used to train a pattern detection and classification model using the YOLO open-source library integrated into the Arkindex platform. This preliminary study has enabled rapid validation of the automatic wheel pattern detection approach using the YOLO library, paving the way for a larger project.

Discussion

Since the 2010s and the rise of deep learning algorithms, two fundamental trends in the machine learning community have enabled the adoption of these artificial intelligence technologies in many application areas: on the one hand, the development of state-of-the-art open source software libraries and, on the other hand, a methodological convergence that makes it possible to solve many problems with the same models, namely deep neural networks, whether for images or text. The "last mile" is to make these tools accessible to end users through simple, adaptable and efficient interfaces. Arkindex aims to achieve this by providing an open-source platform for processing scanned documents, both text and images, that allows the integration of best-in-class AI models as they are developed and
provides scalable processing capacity. The PictorIA consortium will continue to evaluate Arkindex through other use cases, contribute to its development to adapt it to the needs of archaeologists, and provide an instance and computing resources to partners.

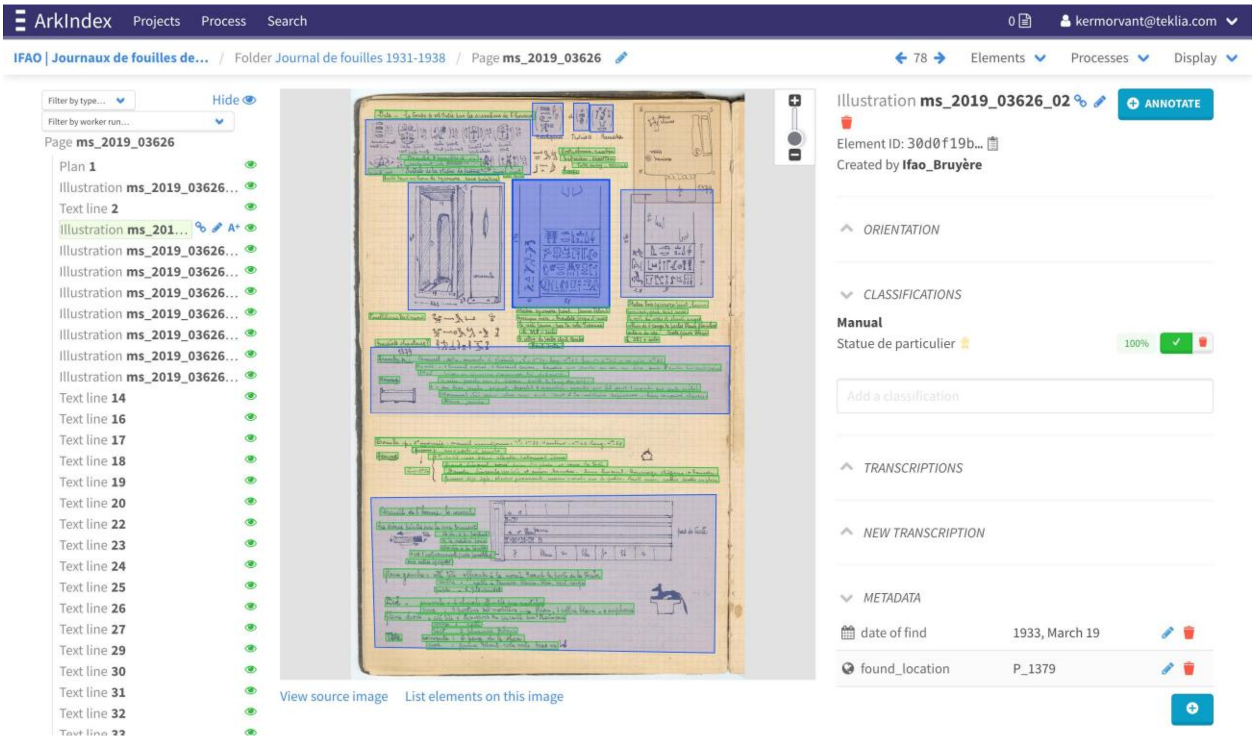

Figure 1: Text and illustration indexing of B. Bruyère’s handwritten excavation journal using Arkindex.

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487. Deep-learning based Detection and Segmentation in Archaeology

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1 Introduction

Modern archaeology benefits from a convergence between traditional excavation methods and technological advancements, particularly those stemming from computer vision.

Among these technologies, image segmentation plays a central role. It involves dividing an image into multiple meaningful regions to isolate specific elements, such as artifacts, architectural structures, or traces of ancient carvings. This task is crucial for extracting, analyzing, and interpreting visual information from archaeological surveys. However, segmentation in the archaeological context poses specific challenges. Images often come from complex scenes where objects of interest may be partially buried, degraded, or blended into their surroundings. Varied textures, shadows, and overlapping elements make it difficult to accurately identify shapes and contours. Despite these challenges, modern approaches, particularly those based on deep learning, have significantly improved segmentation capabilities.

In this work, we propose applying two state-of-the-art segmentation methods to two archaeological problems. We will focus, on the one hand, on the detection and segmentation of petroglyphs, and on the other hand, on the segmentation of mosaics into tesserae.

2 Methods and Materials

Petroglyphs Detection with YOLOv9 Petroglyphs serve as immutable spatio-temporal markers that hold crucial information about the history of local settlements. The study of these archaeological sites (Danielyan 2020) often requires cataloging all the petroglyphs present. This process traditionally involves photographing the rocks of interest and subsequently analyzing the images, manually detecting and outlining each petroglyph — a labor-intensive task. Using YOLOv9, we propose automating this demanding step.

YOLO (You Only Look Once) is a family of real-time object detection models renowned for their speed and efficiency. Designed to simultaneously localize and classify objects in an image in a single step, these networks have evolved over successive versions to deliver increasingly impressive performance.

With YOLOv9 (Wang, Yeh, and Mark Liao 2025), the latest iteration in the series, significant improvements have been introduced. This version leverages advancements in network architecture, optimization, and data processing to enhance accuracy while maintaining exceptional speed. YOLOv9 incorporates optimized modules such as advanced attention mechanisms, adaptive anchoring strategies, and better balancing for detecting objects of various sizes.

We trained YOLOv9 with annotated images provided by archaeologists. Due to the limited availability of data, data augmentation was essential. Additionally, the images originated from only a few sites, influencing various factors such as rock color. Training was automatically halted after 379 epochs, demonstrating YOLOv9's capability to adapt to this specialized archaeological dataset.

Segmenting Mosaics with Segment Anything

Another aspect of our work focuses on the segmentation of tesserae that compose mosaics. These tesserae exhibit varying shapes and sizes, often irregular, and are separated by mortar arranged in a non-uniform manner. Furthermore, the tesserae typically have muted colors and low contrast, making it difficult to distinguish them from the mortar. Automatic segmentation of tesserae thus represents a significant challenge.

The goal of this study is to develop a segmentation method specifically tailored to mosaics, concentrating on extracting tesserae as distinct entities. Such an approach would allow archaeologists to analyze the tesserae directly, facilitating their digitization.

The detected tesserae would form the basis for deeper analysis, aiding in the interpretation and utilization of the extracted information. While machine learning approaches like Segment Anything (Kirillov et al. 2023) outperform traditional methods, they are not without limitations. When applied to the full image of a mosaic, Segment Anything tends to detect broader shapes, such as characters or decorative elements on the mosaic, rather than focusing on individual tesserae. To counter this, we apply Segment Anything to smaller, localized sections of the image devoid of identifiable forms. This adjustment allows for the generation of more precise masks.

This approach, however, requires post-processing. Issues such as duplicate masks and overlaps can arise. To address these, statistical analysis of tesserae sizes and a selection algorithm for the masks are employed to eliminate undesirable duplicates and guarantee segmentation accuracy.

3 Results and Discussion

For petroglyphs, our algorithm delivers satisfactory results, particularly when petroglyphs from the same site are included in the training data. However, due to the vast variability in features (e.g., petroglyph shapes, rock types), some elements may go undetected. To address this, an executable application has been developed, allowing archaeologists to manually refine the results produced by the network. This tool will be released as open-source software. Figure 1 illustrates an example of petroglyph segmentation before and after archaeologist intervention.

Similarly, the tesserae segmentation will also be integrated into an open-source application. This tool will support the use of various input image types, such as those enhanced through gradient emphasis or captured under different lighting conditions for the same scene. This application has already been employed to conduct a statistical study on the tesserae of Saint-Romain-en-Gal (France), analyzing their size, color, and roughness. This study enabled the tesserae to be grouped based on these characteristics, marking the beginning of an investigation into the materials used in their construction.

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Figure 1: Results of both our approaches. Top row: two outputs on the same petroglyph from the site of Ughtasar (Armeny), provided by our segmentation network, before (left) and after (right) manual intervention. It was observed that the petroglyphs were generally detected successfully, but manual post-processing was sometime necessary to refine the results, such in this case as separating the two horns of an ibex, to ensure greater precision in the segmentation. Bottom row: automatic tesserae segmentation of a mosaic from Saint-Romain-en-Gal (France).

237. Machine Learning in Archaeological Fortification Studies: A CNN-Based Approach for the Caria Region

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Fortifications represent some of the most significant and complex architectural achievements of ancient societies. In regions such as Caria, these structures not only embody defensive and architectural ingenuity but also provide valuable insights into cultural, economic, and political dynamics. Despite their importance, the study of ancient fortifications faces a persistent challenge: the overwhelming scale of data generated during documentation and the lack of efficient, standardized tools for its analysis. This PhD project aims to address these challenges by applying image-based machine learning to ancient fortifications, focusing initially on Carian walls. It introduces a tailored convolutional neural network (CNN) pipeline designed to streamline the documentation and analysis of fortification walls, offering an efficient, reproducible, and adaptable workflow for the archaeological community.

The methodological foundation of this research lies in the integration of photogrammetry and machine learning. High-resolution orthomosaics generated from drone-based photogrammetric surveys provide a detailed and comprehensive dataset. This project has documented roughly 2 kilometers of fortifications in Halicarnassus and the Caria region using drones and RTK-GPS to ensure geometric accuracy and high-quality data acquisition. These orthomosaics are systematically processed, segmented, and annotated to create a robust training dataset for the CNN model. Training data is organized into four categories of stonework—ashlar, polygonal, trapezoid, and quarry stones—reflecting the diversity of construction techniques found in Carian walls. The CNN architecture, based on the U-Net model, has been specifically tailored to archaeological datasets, addressing the limitations of pre-trained models such as the Segment Anything Model (SAM), which failed to handle the complexity and specificity of ancient wall features.

The project’s primary output is a two-part pipeline. The first component involves an automated segmentation and classification tool that identifies and categorizes features in orthomosaics with a high degree of accuracy. By eliminating the need for time-intensive manual segmentation, this tool allows archaeologists to process large datasets efficiently. The second component focuses on the statistical analysis of the segmented data. Using advanced statistical techniques, such as Shapiro-Wilk tests, Kruskal-Wallis tests, and clustering algorithms, this component enables researchers to identify patterns and trends within the walls. Questions addressed include: “Which block types are used where?” “How do seam widths vary across the structure?” and “Can clusters in block usage reveal information about construction phases or architects?” These analyses provide insights that go beyond traditional manual interpretation, uncovering construction methods and stylistic nuances that are not immediately visible to the human eye.

This research aligns closely with the session's focus on data acquisition and analysis challenges in archaeological machine learning. A critical aspect of the project has been the development of a systematic data acquisition and annotation process, ensuring reproducibility and high data quality. The creation of annotated training datasets from orthomosaics involved both domain expertise and a rigorous workflow to ensure that the CNN model is both accurate and adaptable. This project demonstrates how tailored CNN architectures can bridge the gap between data acquisition and research questions, enabling archaeologists to extract meaningful insights from complex datasets.

The broader relevance of this project lies in its adaptability. While the initial focus is on fortifications in Caria, the pipeline is designed to be flexible and applicable to other ancient city walls, irrespective of region or period. By standardizing workflows for segmentation and analysis, the project offers a scalable solution to one of archaeology's most pressing challenges: handling large-scale architectural datasets in a systematic, reproducible, and objective manner. Open access to the code and tools, alongside a user-friendly interface, ensures that this pipeline will be accessible to archaeologists with varying levels of technical expertise, fostering broader adoption and collaboration across the field.

Several key challenges have emerged during the development of this project, offering valuable lessons for the application of image-based machine learning in archaeology. The first major hurdle was the setup of the CNN model and the creation of annotated training datasets, which required significant effort in data preparation and validation. Pre-trained models, though widely available, were ill-suited to the unique features of ancient fortification walls, underscoring the importance of domain-specific model design. Another anticipated challenge lies in the second component of the pipeline: developing statistical methods that can handle the complexities of archaeological data while generating meaningful insights. This involves careful selection and testing of methods to ensure they align with research questions and data characteristics.

While ethical concerns are minimal in this specific context—focusing on architectural features rather than sensitive human or cultural data—this project is guided by principles of transparency, reproducibility, and accessibility. By making tools and data openly available, this research contributes to ongoing efforts to promote responsible AI use in archaeology, ensuring that the benefits of these technologies are widely shared.

The implications of this project extend beyond the immediate scope of fortification studies. By automating segmentation and enabling large-scale statistical analysis, this workflow has the potential to transform how archaeologists engage with architectural datasets. It allows researchers to move beyond descriptive analysis and explore broader questions about construction practices, regional variation, and cultural exchange. Moreover, it offers a model for integrating image-based machine learning into archaeological workflows, highlighting the importance of interdisciplinary collaboration and tailored approaches.

In conclusion, this PhD project represents a significant step forward in applying machine learning to archaeological research. By focusing on ancient fortifications in Caria, it demonstrates how CNN-based models can address longstanding challenges in data management and analysis. At the same time, it emphasizes the broader applicability of these methods, offering tools and workflows that can be adapted to diverse archaeological contexts. This research invites dialogue on several key issues, including the integration of domain knowledge into machine learning models, the challenges of working with limited datasets, and the potential for standardized workflows to enhance reproducibility and cross-site comparisons. By contributing to the session's goals of advancing image-based machine learning in archaeology, this project highlights both the opportunities and challenges of adopting AI-driven methods in the discipline.

329. End-To-End Deep Learning to Assess Archaeological Potential from Multimodal Data

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We propose a novel deep learning-based workflow to predict the Archaeological potential in the hinterland of ancient Sagalassos in South- west Turkey. Our approach concerns a convolutional architecture trained on a semantic segmentation task with self-supervised pretraining. Our experimental results demonstrate the potential for end-to-end learning techniques in assessing archaeological potential using multimodal data sources.

1 Introduction

Archaeological fieldwork is time-consuming and requires many resources to drive the campaigns. Archaeological predictive modeling (APM) (Willett 2022) provides means to estimate the potential of archaeological sites in landscapes to aid the archaeological research by increasing the effectiveness of data usage. Willett 2022 recently proposed LAMAP (Locally-Adaptive Model of Archaeological Potential) to estimate area suitability for human activity in the Sagalassos Study Area (Turkey) during specific periods. The algorithm relies on spatial distributions built on features derived from Geographic Information Systems (GIS) data using known-site locations. The algorithm performs well with limited data but requires exponentially increasing computation time as unique sites grow, due to its use of the inclusion-exclusion principle in probability calculations (Chen 2014). A downside of LAMAP is its neglect of non-site data, solely using known- site data for its predictions. Furthermore, the algorithm relies on manually or mechanically derived GIS features, introducing inherent bias.

In this work, we propose a novel end-to-end deep-learning workflow to estimate the archaeological potential and drastically accelerate predictions using data-driven feature extraction utilizing the entire dataset. Our contributions introduce faster predictive algorithms as viable alternatives to existing methods. Specifically, we train our model to classify patches extracted from the GIS images. Then, we evaluate our model by predicting the archaeological potential of the entire Sagalassos area. We compare our results to the LAMAP reliability survey results that, for each period, extensively examined cells and compared the on-site examination results to LAMAP's corresponding predictions (Willett 2022).

2 Methods and Materials

The Sagalassos area in Turkey presents a unique landscape characterized by the Taurus mountains. This region has geographically unique properties (Poblome 2023), such as narrow river valleys, badlands, and cliffs. The study area's 2000-meter elevation range supports diverse vegetation, from semi-arid steppes to deciduous woodlands and Mediterranean zones at higher altitudes. (Poblome 2023). The data captured in the Sagalassos Site Database results from 30 years of archaeological surveying (Vandam et al. 2019). Sites are dated using architectural standards, inscriptions, and tool industries, commonly through pottery determination based on cross-dating methods. Although earlier sites are present in the study area, only sites from the Late Neolithic (6500 – 6100 BCE) onward have been incorporated, as that is when the first sufficient settlement data becomes available. In total, the dataset covers seven different periods during which demonstrated occupation in the study area: Late Prehistory (6500–2500 BCE), Iron Age-Archaic (1150 – 546 BCE), Achaemenid-Hellenistic (546 – 25 BCE), Roman Imperial (25 BCE–300 CE), Late Antique (300 – 700 CE), Byzan- tine (700 – 1200 AD), and Late Ottoman (1700 – 1921 CE). Among them, we distinguish occupations from different periods by demonstrable

differences in settlement patterns and material culture (Willett 2022). The dataset contains 704 sites at 289 locations, over an area of about 1200km2, defining sites through observed archaeological activity. GIS data complements existing site data by introducing a geospatial component. Using a digital elevation model, Willett 2022 derive additional features that help to characterize the landscape. Following the authors, these features are elevation, aspect, slope, convexity, distance to drainage, distance to water resources, distance to roads, and distance to city centers. Each feature maps the original input across 1515x3302 pixels of the study region.
We consider three methods: LAMAP, Naive Bayesian classifier (NBC), and convolutional neural network (CNN).
LAMAP, proposed by Carleton et al. 2012, classifies sites' archaeological potential by comparing input data to known sites via frequency distributions of landscape variables, without using parameters (Willett 2022). Together with these frequency distributions, we can estimate the probability for unseen data points given an input vector xi = (x(1), x(2), . . . , x(m)) as
P (xi|s) = Πnj=1P (x(j)|s)K(s, xi) (1) i
where m denotes the number of features, s is a vector of known archaeological sites, and P(x(j)|s) the probability that the j-th variable at of data point xi
resembles the known archaeological sites. Further, K (s, x) = exp(− ||s−x||2) 2σ2
is an exponential kernel that computes the proximity from the data point to the known sites using euclidean norm, ||s − x||, between the sites s and the data points x assigning higher values to sites in proximity given a length scale of σ. Because pixels occur in multiple known site areas (Willett 2022), the estimations are corrected with the law of total probability and the inclusion- exclusion principle to output a class value T .
The NBC is a probabilistic machine learning technique that efficiently learns to classify data under the naive assumption of conditional feature importance. Using Bayes rule, we can predict the probability of a data point xi to belong to target T, i.e., P(T|xi), by decomposing the probability calculation into:
P(T|xi) = P(T)P(x(1)|T)P(x(2)|T)...P(x(m)|T) (2) iii
for features x(j) where j = 1 . . . m. While NBC offers a fast maximum-likelihood
alternative to LAMAP, it assumes feature independence and may overlook important feature correlations. We train NBC on the same set of features as LAMAP.
CNNs are deep learning models primed with a spatial bias toward grid-like structures capable of detecting local features and combining them hierarchically to find correlations on a global scale based on the convolution operation, using a trainable kernel of size kxk to slide over an input image X ∈ RHxWxC, producing feature maps Y ∈ Rhxwxc. Here, H,W and h,w are the input and output dimensions, and C,c are the input and output channels. In GIS data, each band corresponds to a channel. CNNs are built with multiple convolutional layers combined with nonlinear activation functions. In contrast to LAMAP and NBC, CNNs work directly on GIS image data to learn the relationship between bands to detect spatial and hierarchical dependencies. The data presents learning challenges; as it consists of: a) large GIS images with few labels (site data), and b) non-site data that not automatically constitutes negative data. To mitigate, we first divide the image into tiles of fixed sizes P xP that cover the entire study area. Secondly, we use pseudolabels provided by a teacher model. Additionally, we use data augmentations like normalization, random rotation, and horizontal flips to reduce noise in model predictions. We implement LAMAP in R, the NBC in Python, and the neural network using TorchGeo (Stewart et al. 2022).

3 Conclusion

Our preliminary experimental results demonstrate the potential for end-to-end learning techniques to assess archaeological potential using multimodal data sources.

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500. Investigating the Archaeological and Cultural Landscapes of the Levant through Digitized Historical Maps and Machine Learning

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Digitized historical maps have provided, and continue to provide, interesting and unique insights into archaeological research that contextually historicize areas of archaeological interest. In recent years, studies have emerged that utilize digitized historical maps to showcase the practical use of historical maps in current archaeological research, yet there is a distinct area in which archaeologists have not given enough critical engagement when using digitized historical maps: evaluating the maps themselves as objects of archaeological interest within a historical context. With historical maps digitally available now more than ever before, it is time to start critically evaluating historical map series and their relationship to Archaeology.

This doctoral research employs a digital methodology utilizing open-source computer visualization and OCR software specifically for digitized historical maps, such as MapReader (Hosseini et.al 2022; Wood 2024) and Strabo (Chiang 2013), on digitized Imperial maps of Lebanon, Syria, and Jordan from the early twentieth century to track the depiction, introduction, and evolution of archaeological information between successive map series. MapReader's ability to analyze pixelated images for specifically defined symbology, and then train a model to analyze further maps (Hosseini et.al 2022; Wood 2024), along with Strabo's ability to read text on digitized maps (Chiang 2013) lend themselves well to studying key aspects to maps that were informed by historical archaeological research: symbology, text, and toponyms. Identifying these aspects, and studying how they changed over time, grants us a snapshot into the development of Archaeology in the Levant through the lens of Cartography amid rising globalization.

Specifically, this paper outlines the doctoral project and introduces the initial digital analyses done on early twentieth century historical maps of Lebanon, Syria, and Jordan from various archives and libraries using MapReader (Hosseini et.al 2022; Wood 2024) and Strabo (Chiang 2013). This is done to identify how information from historical archaeological research in the early 1900s made its way into these cartographic images and how archaeological information changed over successive map series of the region as World Wars, governmental changes, and national borders were imposed upon the regional landscape. Being able to contextualize archaeological information in this fashion not only demonstrates the cyclical relationship between Archaeology and Cartography, but can only be done through digital means due to time constraints and scope. Thus, this paper will ultimately illustrate how digitally investigating historical map series can be useful in digital archaeological research.

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215. Creating a controlled vocabulary and an ontology for Pacific ceramic vessels to understand past cultural connections.

Kristine Hardy (ANU)*; Mathieu Leclerc (ANU); Terhi Nurmikko-Fuller (Australian National University); Robert Henderson (ANU)

Ceramic material culture has played an important role in understanding the history of Pacific peoples, most markedly in its support for characterising the Austronesian culture, with their 'Lapita' style pottery, and their expansion into the region over 3000 years ago. Following this initial spread of characteristically red-slipped and dentate stamped pottery, techniques and customs for making and decorating pottery changed in different ways in the various Pacific communities. This occurred in response to internal factors and inter-community cultural exchange across the Pacific and Island South East Asia. Some communities, including those in areas of Papua New Guinea (PNG), Solomons, Vanuatu and Fiji, continued to create pottery after European contact, and there is extensive ethnographical literature on the varied pottery chaînes opératoires of the different 'ceramic industries'. Utilising both archaeological and ethnographical data, cross-Pacific temporal and spatial comparisons of the different industries, has the potential to provide information on how communication and cultural exchange varied throughout Pacific history.

Comparisons of Pacific ceramic industries, would be greatly facilitated by a standardised vocabulary for describing properties including, ceramic building methods, morphological features and decorative techniques. As part of our Kuden Pacific pottery project, we are producing an illustrated glossary web page of such features, and each feature will have a Uniform Resource Identifier. We are using this vocabulary to characterise the different (predominantly) past ceramic industries (aka 'types', 'technologies') and their vessels, across space and time.

A major reason for creating such a web resource was to give temporal context to the ceramic pottery fabrics in our image database (kudenfabrics.anu.edu.au). In the study of Pacific pottery often different research techniques are applied to different sherds from an industry and we are interested in inter-linking these different types of information via web pages on each industry and/or sites. Thus, the Kuden project has 'industries' as its central focus instead of particular vessels (or sherds). This resulted in challenges in designing the model schema and differences from schemata of databases for museum or other vessel collections.

As part of our research we are examining whether mapping the information as a linked open data (LOD) ontology would be feasible and worthwhile for our (and potentially others) research. Ontologies are a type of reference model for a subject that utilise controlled vocabularies and define the relationships between the different subject concepts and the restrictions on these relationships. They can be used within linked data to create computer navigable knowledge graphs. Ontologies, such as, TAO, Lekythos, Ontoceramic, CeraTyOnt and GREYWARE have been created for Chinese vase, Greek and Roman vessels and medieval greyware pottery. These can be used to describe particular sherds and/or vessels and have facilitated the characterisation of vessels in databases such as the Beazley archive pottery database.

For evaluating a LOD implementation we are focusing on the ceramic industries of Eastern PNG (Eastern Highlands, Morobe and Madang regions). Possible queries include, which features are shared between the different industries and in particular those shared with the Agarabi, who are the only highlanders who made pots. We will also see how well queries can be constructed to suggest where surface sherds from Tami Island, a trading centre off the eastern coast (Abramson 1969, 83-90), are likely to derive from. If the latter case works well, a full LOD implementation of Pacific pottery industries could be used by archaeologists to help identify the source of non-local sherds, or to suggest cultural links between communities for local sherds.

In designing the ontology we begun with outlining relationships between classes such as "potter group", "ceramic industry", "ceramic piece" and "ceramic feature", and then altering the relationships to fit the The International Committee for Documentation conceptual reference model (CIDOC-crm) activity based philosophy. This involved re-centering the model primarily around 'pot creation' (Figure 1). While performing this translation we are finding that CIDOC-CRM predicates are able to describe the class inter-relationships, and that its classes can be used or extended to encompass our classes.

Our ontology has classes for potter group, ceramic industry, ceramic piece (with subclasses, sherd and vessel) and ceramic feature (Figure 1). Example instances of these include the Adzera potters, who make (and decorate) gur, of which the sherd NLO5 has been attributed to (Hardy et al. 2024, 1-10). The sherd NLO5 has an everted rim, a triangular notched lip, and impression stamping, which are instances of the ceramic feature class. Potters speaking Adzera, have existed in at least 15 different villages in the Markham Valley, Morobe, and their pottery has been found in locations from the Markham and Eastern Highlands to New Britain.

While the referenced data, especially ethnographic information, often derives from Pacific communities including authored works by researchers with Pacific heritage, their access to and control of the data is often limited. The possibility of including WikiData identifiers for the industries could allow for increased community input into, at least the naming (or alternative labelling) of industries.

Our current plans for our dataset only include adding vessel and sherd examples that help describe the industry. However, the ontology with its defined ceramic features could be used by others, to catalogue sherds in an assemblage or a vessel collection in a museum or other research institute. Having collection vessels identified by 'industry' may help community members and researchers find where examples are currently located.

If the use of LOD with Pacific pottery data proves useful, this ontology should provide a guide for the creation of similar -or extended ones, for other material culture, such as adzes. If the use of LOD grows, LOD from inside and outside archaeology, particularly linguistic, geological, geochemical and paleoenvironmental, could potentially be interlinked with LOD Pacific material culture datasets to examine questions on trade (via sherd province) and the possible causes of cultural change. There is a clear need for improved organisation and indexing of archaeological reports and datasets. This research will help determine whether LOD is an effective method to do this.

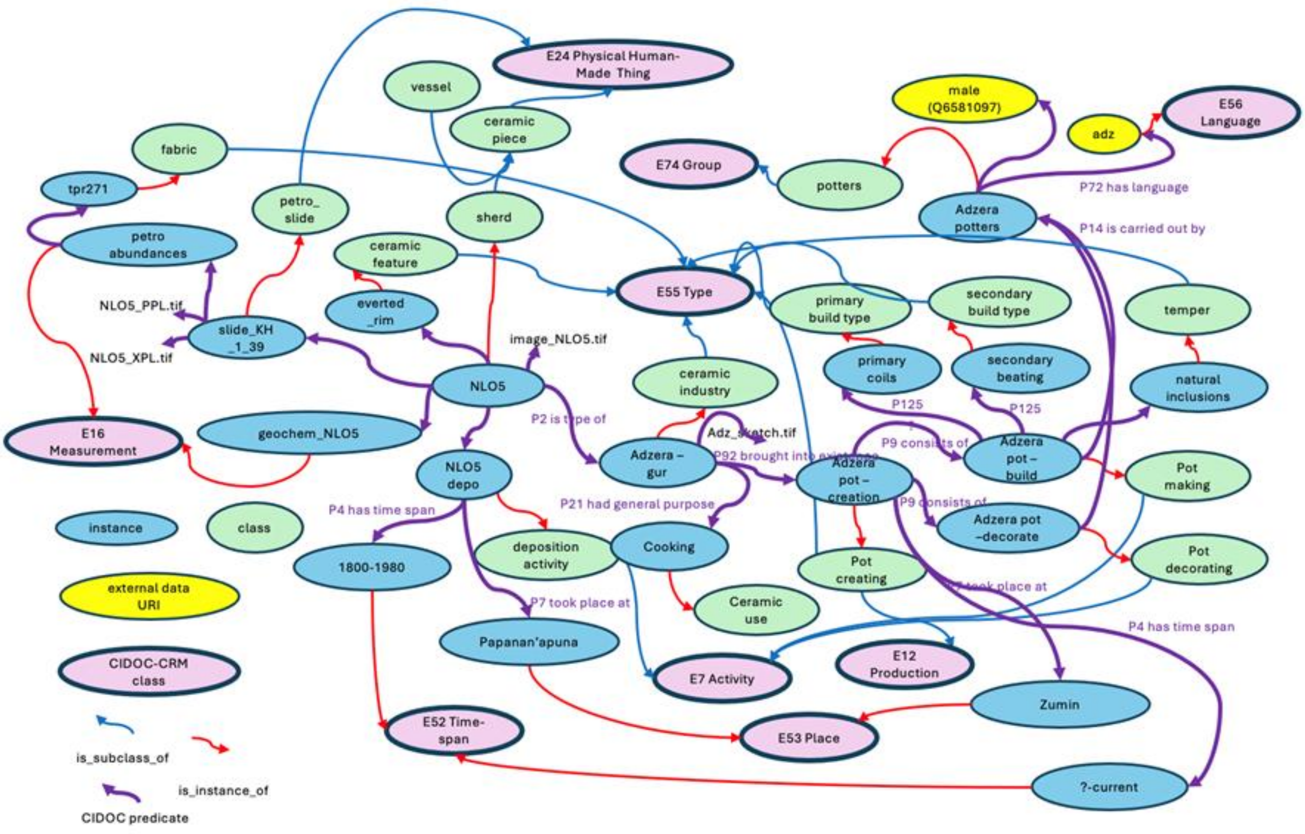

Figure 1: Some of the classes and instances in the kuden vocabulary. Instances are identified by their label instead of id for clarity. The graph shows how sherd NLO5, found in Arona, PNG, is attributed to Adzera speaking Markham Valley potters. crm is http://erlangen-crm.org

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114. Cross-platform publication of monograms on ancient coins

Ethan Gruber (American Numismatic Society)*; Ulrike Peter (Berlin-Brandenburg Academy of Sciences and Humanities); Karsten Tolle (Goethe-University); Peter van Alfen (American Numismatic Society)

The administration of ancient (Greek) coin production is generally not well understood. A sovereign authority, such as a monarch, oligarchic council, or assembly of citizens (democracy), likely made the ultimate decisions about coin production, including whether to mint or not, but appear to have then delegated the production to lesser authorities, such as magistrates and overseers of mints. Aspects of this hierarchy were increasingly recorded on coins themselves it would seem from the late Archaic period onward. For example, Hellenistic royal coins are remarkably “chatty”; the reverses of the coins typically carry not just the name of the king, the sovereign authority, but also numerous additional monograms and symbols. These are not well understood. Some we know indicate the place (the “mint”) where the coin was produced; others may indicate additional administrative information, such as the magistrate directly responsible for the coinage. These marks are often our sole clue for deducing where and when a coin was struck. Until recently, there had been no attempt to collate the thousands of marks known from the individual series of ancient coins into a universal, searchable repository.

The primary obstacle in conducting new forms of scholarly research on these marks was the lack of interoperability between two major Greek typology projects, Corpus Nummorum, published by the Berlin-Brandenburg Academy of Sciences and Humanities (BBAW), and Hellenistic Royal Coinages, undertaken by the American Numismatic Society (ANS). These projects both publish monograms following the principles of Linked Open Data, in which monograms are represented as concepts defined by URIs and machine-readable Resource Description Framework (RDF). However, identical monogram forms were not interlinked between these projects. Furthermore, the Hellenistic Royal Coinages project is an umbrella of several typology sub-projects, and identical forms were not co-referenced between, for example, the coin types of the Seleucid and Ptolemaic Empires. As a result, the same monogram form might be represented by four or five different URIs across multiple typologies, limiting the query possibilities only within a given typology. The first step in overcoming this limitation was to identify the same monograms across these disparate datasets.

Each published monogram itself represents an abstraction of the original monogram found on the coins, since the idea is to group coins together having the same (similar enough form) monogram. Similar to a coin type definition, this is to some extent depending on the domain expert. However, with a rising number of monograms it is getting more and more difficult for a human to see if a similar/identical monogram exists already. We therefore set up a pipeline that supports the human by sorting the monograms based on their visual representation. In order to do so, the original SVG files were transformed into JPEG files and by using the open source tool Orange Data Mining (https://orangedatamining.com/). We defined a pipeline (as shown in the figure below) that takes the JPEG files as input, calculates so called embeddings (vectors) for each image based on SqueezeNet, calculates the distances of these vectors (we used the Cosine distance) and on these distances a hierarchical clustering was performed. By selecting a subtree, the corresponding images can be shown in an image viewer.

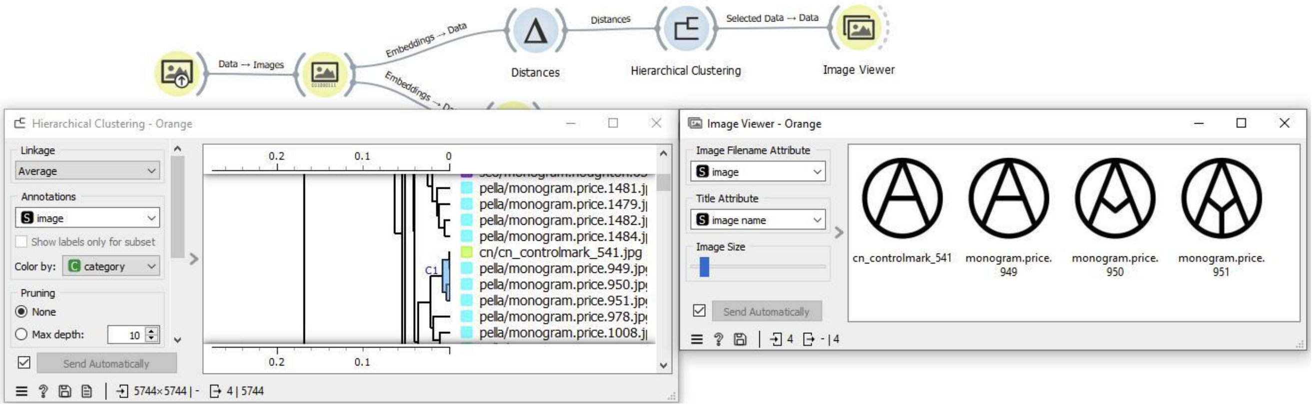

Figure: Showing the pipeline defined in Orange together with the visualization of the hierarchical clustering and the image viewer of a selected subtree with four monograms.

By clicking on the scale above or below in the hierarchical clustering window (see figure), one can define clusters based on this distance value. The resulting clusters can be downloaded as a CSV file. We used this to reduce the time-consuming effort to have a look at all of the roughly 4,500 monograms we had. By removing the clusters of just one monogram, we generated a list containing possible duplicates with only 1,360 monograms, sorted based on the distance as done by the hierarchical clustering.

The vetting by the subject specialists was much easier with a reduced list. Sometimes small differences require a new monogram, in other cases a similar monogram could be deleted because a better-preserved example made the monogram more clearly identifiable.

Following the vetting of monogram forms, approximately 4,000 new URIs were minted in Nomisma.org, under a new namespace for iconographic symbols, a reduction from the original number of ca. 4,500 glyphs published by Corpus Nummorum and Hellenistic Royal Coinages. These Nomisma.org monogram URIs implement the exactMatch property from the Simple Knowledge Organization System (SKOS) ontology in order to link to one or more URIs in the source projects. Using Nomisma.org as a ‘bridge’ between disparate typology databases enables joining them together via SPARQL to create queries and visualizations on a broader scale than had previously been possible in a more siloed digital environment. Additionally, the RDF for monograms captures individual Greek or Latin letters which comprise the monogram, making it possible to query monograms by selecting one or more characters from different alphabets. Such queries can be used to display the mints, hoards, or archaeological findspots associated with the monograms, generate network graphs of relationships between monograms appearing together on coins, or other kinds of statistical analyses related to coin types or associated concepts (places of production, ruling entities, denominations, etc.).

This paper will expand upon the underlying data models and queries for constructing various data visualizations. Mapping the distribution of monograms is only a starting point. Now functional, our resource immediately allows deductions about attributions and dating to be verified or corrected, and gives insight into the extent to which the marks were reused across time and space, which could help to resolve the purpose of some marks. Our information system can handle queries such as "show all monograms produced by a specific mint, ordered by date" or "show all monograms issued under Seleucus I, organized by mint and by the volume of types produced." Linked Open Data methodologies enable new forms of research questions that could not have previously been asked of this material.

208. Fuzziness and Wobbliness in Numismatics and Ceramology: Examples from the NFDI4Objects Knowledge Graph

Karsten Tolle (Goethe-University)*; Florian Thiery (LEIZA); Sebastian Gampe (Goethe-Universität Frankfurt am Main)

The NFDI4Objects consortium, part of Germany's National Research Data Infrastructure (NFDI) initiative, encompasses a broad scholarly community focused on studying material remains spanning approximately 2.6 million years of human history. It draws from various disciplines, including the humanities, cultural studies, and natural sciences, emphasising archaeological and historical research. The objects of study range from common pottery sherds and mass-produced items like coins to organic remains such as wood, bones, and pollen, as well as inscribed artefacts like clay tablets, papyri, and stones. These objects and their associated relationships are dynamic, undergoing transformations reflecting their life cycles through documentation, collection, analysis, preservation, storage, and dissemination processes. As such, NFDI4Objects focuses on several key objectives: (a) representing physical objects as research data, (b) contextualising them within their historical and cultural frameworks, (c) appropriately translating them into digital formats, and (d) curating them following domain-specific standards (Thiery et al. 2023).

Within a so-called TRAIL (Task Related Activities for Implementation and Launch of Services) – 2.2: Evaluation of fuzziness and wobbliness in numismatics and ceramology – within NFDI4Objects, the authors of this paper intend to collect and represent use cases from those two domains. The goal is to drill down in some of them and to explore them in more detail.

The concepts of vagueness and uncertainty can be found anywhere in archaeology. Vague statements per se are certain, e.g., the object A is dated between 100 and 200 AD. Nothing is uncertain about it (as far as we can see here). In case the dating of object A represents the production date of a coin or a ceramic vessel (produced within a very short time), a range of 100 years is vague. The preservation status of the object might only allow an approximation. In this case, the expressed vagueness is due to uncertainty. It could also be that whoever stated the statement was not interested in the exact dating, and his range reflects the granularity he needed for his research question. Our understanding is that the habits and best practices in the various disciplines can also change over time. This already illustrates that we are confronted with a rather huge problem. Identifying the situation and understanding why uncertain or vague information is given is already a challenge in itself. We use the terms fuzziness and wobbliness to reflect that these concepts of vagueness and uncertainty, which could be distinguished in theory, overlap in many practical cases.

In the context of TRAIL 2.2 and within this paper, we will present some of the use cases from Numismatics and Ceramology, ways to model them in RDF or RDF-Star, and possibilities to entail new information from them.
Most of the current data in both disciplines is generated by humans. This means experts look at the object and, based on expertise (and sometimes mood or depending on many other things), enter the information about it into a database. Asking experts to include a likelihood value of how sure it is would (a) cost quite some time, (b) raise the question of what a likelihood of 53% exactly means, and (c) would again vary depending on the current circumstances. Since we are now in a phase in which information is also entered by AI systems that (depending on the system) can provide a likelihood value that can at least be reproduced in case the model stays stable. It

becomes important to (a) understand the potential for having the exact likelihood values of AI Systems and (b) indicate what needs to be stored as additional context information to avoid problems later. Based on such given likelihoods, reasoners can be used to entail new triples with an accordingly calculated likelihood for them (Weigel 2024).

We have developed different use cases for Numismatics and Ceramology, intending to show the potential, compare different approaches and lay the ground for future decisions. This includes the following questions: (a) What is important to store? (b) What are possible ways to model it? and (c) What can be achieved by making this effort? Since we are in a transition phase (as things are constantly changing), the combination of data modelled without such details needs to be addressed.

In a Samian Ware use case, as an example, about 21% of the Samian Ware dataset relating to potters and kiln sites, as well as potsherds attributed to these kiln sites, include strings with expressions containing the keywords AND or OR, indicating vagueness; AND statements combined with a question mark indicate uncertainty. Vagueness and uncertainties also occur in determining vessel fragments (e.g. when only a base fragment of a vessel is preserved), which may be attributable to different possible types of pot forms. In this case, the vagueness is modelled using the Academic Meta Tool (AMT) by creating a semantically modelled knowledge network using nodes (concepts) and weighted edges roles representing a "normalised degree of connection" between 0 and 1 (Thiery et al. 2022). The vagueness and uncertainty expressed in string statements - depending on the keywords AND and OR, as well as a question mark - are transformed into the vagueness-based AMT logic as a degree of connection: for OR statements, the total count of possibilities results in the count of entities between the OR statements. For example (Fig. 1), the Information Carrier 118117 can be represented by the Dragendorff pot forms 18 OR 15/17 OR 18/31, resulting in a degree of 0.33 for 18. This dataset and the AMT modelling are part of the NFDI4Objects Knowledge Graph, mainly based on CIDOC CRM.

A significant challenge for the TRAIL 2.2 will be how to integrate the different concepts of fuzzy and wobbly data modelling, that exist parallel to the Samian way of doing it, into the N4O-ObjectsOntology, which serves as a common ontology to make data within NFDI4Objects and the NFDI exchangeable and interoperable.

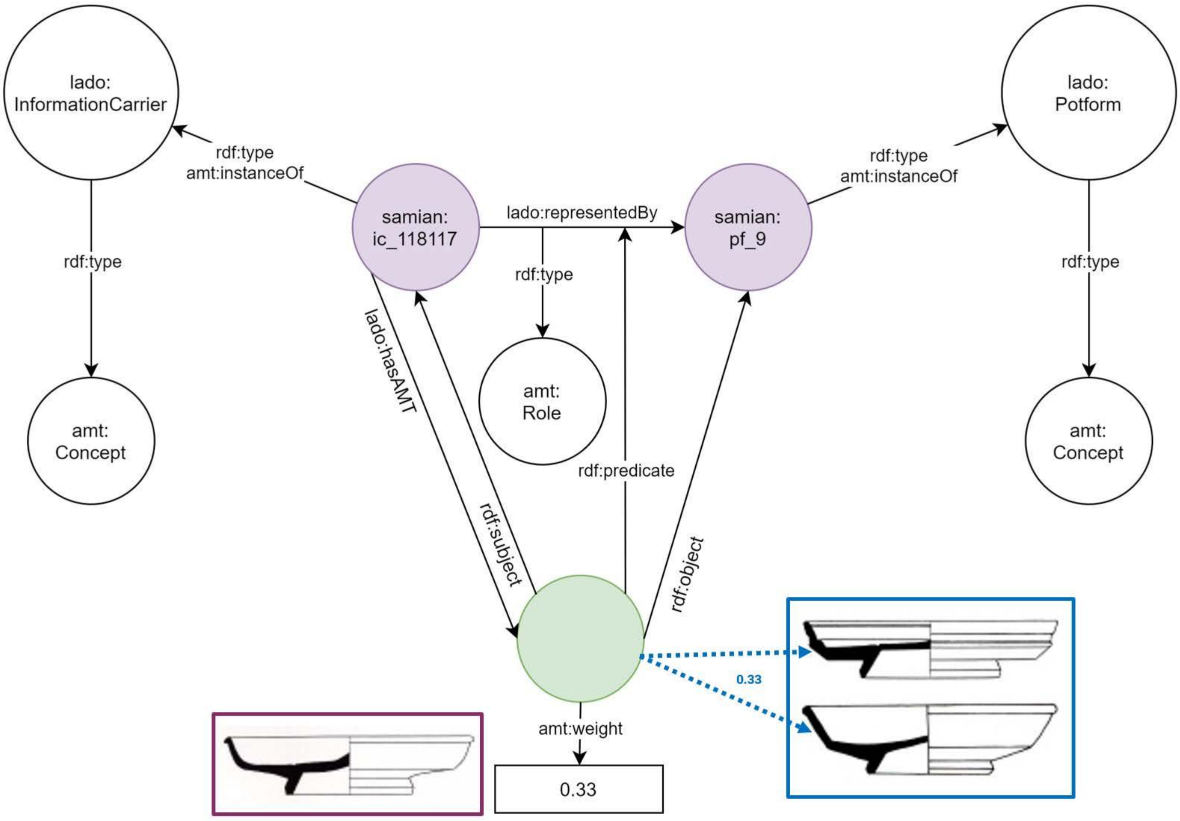

Fig. 1. Exemplary schematic representation with the AMT tool, *anonymous*, CC BY 4.0.

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465. Taming the Space: Semantic Modelling using Linked Open Data of Fuzzy Wobbling Geospatial Data from the Archaeological and Geosciences domains

Florian Thiery (LEIZA)*; Sophie C. Schmidt (FU Berlin); Chiara G.M. Girotto (Arch Pro Beratungsgesellschaft mbH); Fabian Fricke (German Archaeological Institute); Fiona Schenk (JGU Mainz); Stefanie Baars (SPK Berlin); Allard Mees (LEIZA)

Archaeological and geoscientific research often encounters challenges in data modelling, particularly in addressing vagueness, uncertainty, and ambiguities in georeferencing sites and spatial locations (Figure 1). Ensuring high-quality, reusable, and comprehensible data requires explicit modelling of these uncertainties, essential for practical analysis and alignment with FAIR principles, as promoted by initiatives like the German National Research Data Infrastructure (NFDI). Linked Open Data (LOD), as proposed by Berners-Lee, offers a robust graph-based framework to tackle these issues, but achieving interdisciplinary coherence in modelling spatial uncertainty remains a significant challenge.

This paper explores semantic modelling of vague and uncertain geospatial data through interdisciplinary use cases in archaeology and geosciences, focusing on uncertain site georeferences represented as LOD. Frameworks such as SUFF (cf. https://w3id.org/suff/spec) and the "Fuzzy Spatial Locations Ontology" (FSL-O) (Thiery, Schenk, and Baars 2023) provide mechanisms for documenting geoinformation origins, the methods used, and the nature of uncertainty. These approaches also emphasise the role of human interpretation, argumentation, and observation in data creation.

Semantic descriptions of geospatial metadata, particularly for coordinates, are foundational to FAIRification. Effective visualisation techniques mitigate impractical geometries, including significant decimal places, buffers, and bounding boxes. Tools like ChronOntology and Wikidata illustrate methods for representing uncertainty, although challenges such as elliptical distortions in WGS84 coordinates highlight the need for user-focused solutions that balance precision and usability.

The methodology employed in this paper draws on Linked Open Data (LOD) principles, explicitly using the Fuzzy Spatial Locations Ontology (FSL-O), Wikibase instances, and Wikidata. In FSL-O, based on PROV-O, an entity, such as an archaeological site, is linked to its geometry (spatial representation), the method used to create this spatial information, and the person or agent responsible for the data collection or interpretation. In Wikidata, entities containing fuzzy geospatial information can be annotated with coordinates (P625). These coordinates often carry inherent uncertainty, which can be modelled and further specified using Wikidata qualifiers and references. This structure is extended by integrating Geolocation Metadata (GLM) and Coordinate Metadata (CM). GLM includes key statements such as locationOfDiscovery (P189), exactMatch (P2888), and OSMnodeID (P11693) to identify relevant locations, while CM qualifiers — such as determinationMethodOrStandard (P459), statedIn (P248), and location (P276) — provide further contextual information about the precision, origin, and sources of the coordinates, especially in the context of archaeological findspots and sites under study.

For the fuzzy-sl Wikibase, entities can be modelled similarly to represent geospatial information.

Coordinate Metadata (CM) for fuzzy-sl Wikibase incorporates ten key properties, including precision (P23), certaintyLevel (P5), certaintyDescription (P13), and methodUsed (P7), all of which help model the uncertainty and level of confidence associated with geospatial data. Further properties, such as actingPerson (P14), sourceTypeGeneric (P6), sourceTypeDetail (P16), and pointType (P33), enrich the data by providing metadata about the origin of the coordinates, their source, and the type of geospatial point represented.

This structured approach enables the effective modelling of uncertain and vague geospatial data, ensuring that the coordinates' origin, accuracy, and derivation methods are transparently documented. It also facilitates the integration of such data into Linked Open Data ecosystems, enhancing the interoperability and FAIRness of geospatial information in archaeology and geosciences.

The data sources utilised in this study span diverse archaeological and geoscientific domains, providing a robust foundation for the analysis of fuzzy geospatial information. These include (i) Ogham Stones, e.g. the cluster at Ballinrannig (CIIC 148-154), (ii) Campanian Ignimbrite Findspots, e.g. maar-associated locations (AU3, AU4, DE3, by Schenk et al. (2024) and caves containing archaeological evidence, such as Crvena Stiljena Cave, (iii) Sites of Croton's Silver Coinage, (iv) Samian Research Database Sites, e.g. “London / No. 1 Poultry”, (v) archaeometallic sites in the Eastern hemisphere, e.g. of the Seima-Turbino Transcultural Phenomenon as they were published by the Institute of Archaeology of the Academy of Sciences of the Soviet Union, (vi) sites in Brandenburg (5th mill BC), e.g. Seelow 20, and (vii) mapping Urnfield Horizon cultural geographies and especially their spatial uncertainties by visualsing them through aggregation techniques, bounding boxes, and buffers as an extension of the work previously published in Girotto (2020).

The first selection of modelling results includes Linked Open Data (LOD), entries in Wikidata, and records in the fuzzy-sl Wikibase, which focuses on archaeological and geoscientific datasets.

In Wikidata, examples of Ogham stone inscriptions include CIIC 81 (Q130529871), the Ogham Stone at Dunmore Head (Q126503090), and the Ballinrannig Group (Q130602255, Q130602277, Q130602052, Q130602118, Q130602227, Q130601908, Q130602089). As LOD, FSL-O represents Campanian Ignimbrite findspots, such as the Crvena Stiljena Cave (fsl:cisite_51). In the fuzzy-sl Wikibase, geoscientific findspots related to the Campanian Ignimbrite are represented through entries such as Auel Maar AU3 (Q70), Auel Maar AU4 (Q84), and Dehner Maar DE3 (Q85). Additional examples of caves with archaeological significance include Crvena Stiljena Cave (Q89) and Franchthi Cave (Q111). Archaeological sites from the Samian Research Database include, e.g., London / No. 1 Poultry (Q95), Southwark / London Bridge (Q108), Colchester / Culver Street (Q96), and Llanfair-ar-y-bryn (Q121). These entries demonstrate the effectiveness of semantic modelling for recording diverse types of archaeological data with spatial and historical dimensions.

The proposed methodology demonstrates functionality and promise but requires further detailing and refinement through application to diverse use cases. Key areas for discussion include identifying additional properties necessary to augment coordinate data and determining the most effective geometries for visualising spatial uncertainties, such as buffers, convex or concave hulls, and bounding boxes. Integration and visualisation of these structures in modelling approaches like RDF or Wikibase instances must also be addressed, ensuring both technical compatibility and clarity of communication. An extended metadata set for spatial data should be designed to include qualitative information about the origin of coordinates, such as GPS measurements, total station data, or extraction from literature. Additionally, the typification of geodata and its outputs is essential, capturing spatial representations' generative origin and meaning. For example, a point with a buffer could symbolise spatial uncertainty, while a central point with an enclosing polygon might represent the extent of a site. Georeferencing semantic approaches like GeoSPARQL could further enrich these datasets, linking geometries like central points and polygons. These refinements will enhance the usability and interpretability of geospatial data, supporting interdisciplinary applications and FAIR principles.

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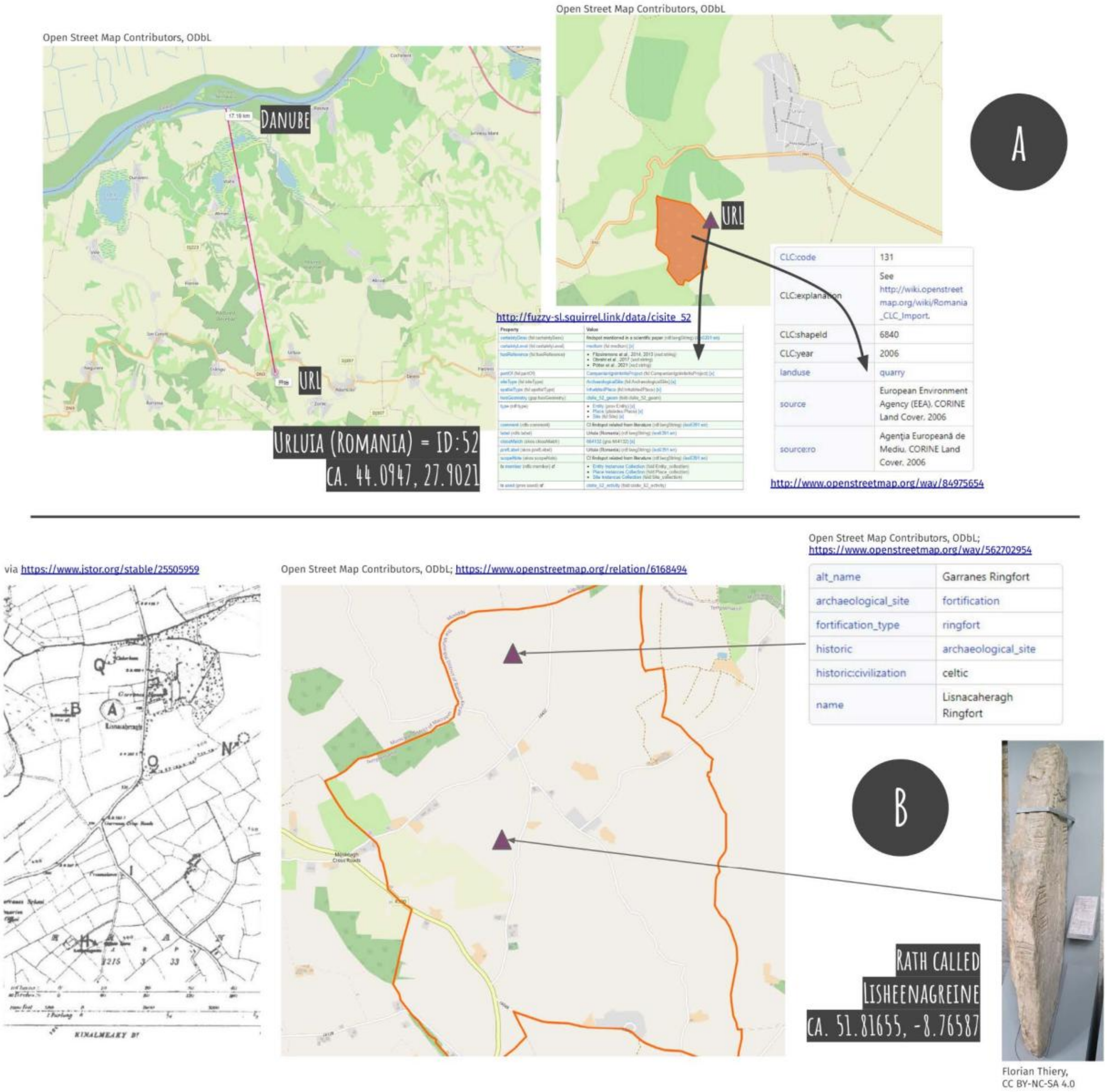

Fig. 1. A: xyz; B: xyz. *anonymous*, CC BY 4.0 with images from Open Street Map (Open Street Map Contributors, ODbL), Seán P. Ó Ríordáin and J. Ryan, via https://www.jstor.org/stable/25505959 and Florian Thiery, CC BY-NC-SA 4.0 (Ogham Stone at UCC).

118. Using CatMapper to Reconcile and Organize Time Periods across PeriodO and Wikidata

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Introduction Archaeologists have increasingly used Linked Open Data (LOD) to connect dispersed datasets, improve discoverability, and facilitate integration of data across platforms and disciplines. By following standardized web technologies like the Resource Description Framework (RDF) and using platforms such as Wikidata, LOD has enabled archaeologists to link legacy data, digital resources, and external databases across a range of domains, including Neolithic ceramics, Roman terra sigillata, and Early Medieval inscribed stones, thereby contributing to a more connected and open archaeological knowledge system (Schmidt et al. 2022). Despite its great promise for facilitating new research, implementing LOD faces several challenges in the archaeological context. Data quality is often inconsistent, with legacy datasets fragmented or poorly documented. Different projects and regions use varying standards and vocabularies, making integration and interoperability difficult. Additionally, data sensitivity—such as protecting exact archaeological site locations—limits the openness of certain datasets.
ArchaMap. CatMapper's (https://www.catmapper.org) ArchaMap tool aims to facilitate LOD in archaeology by assisting users in integrating complex categories like artifact types, lithics, ceramics, time periods and site contexts from diverse datasets (Hruschka et al., 2022). ArchaMap provides tools for efficiently and transparently translating and reconciling differing encodings across datasets, thereby ensuring consistent data integration and mapping how datasets can be linked across platforms. ArchaMap also allows users to document and share the details of the merges they have used for published papers, supporting transparency and reusability, which are core to LOD principles. Importantly, ArchaMap does not store observational data. Rather the platform points to diverse, external datasets that store data on comparable categories and also catalogues the keys that permit linking data across those datasets. In this way, it focuses on the task of linking datasets, while delegating issues of licensing, ownership, and human subjects approval to users based on the specific datasets they plan to use.
ArchaMap uses a graph database to organize complex, hierarchically-structured categories, from diverse datasets. It represents each unique category (e.g., the time period "Warring States-China") and dataset (e.g., PeriodO) as a node. A "Uses" tie from a dataset node to a category node captures all of the claims that specific dataset makes about the category (e.g., alternative names, start date, end date, region/country, geospatial coordinates, url from that dataset for the specific category). To facilitate linking categories across datasets, each "Uses" tie also stores the key used by the data source to uniquely identify that category. This structure permits: (1) efficient, bulk matching of categories from new data sources, by leveraging alternative names integrated from multiple sources (2) detecting errors by permitting comparison of contextual information across different datasets pointing to the same node, and (3) transparently indicating provenance of all claims about categories.
Methods and Materials. In this paper, we illustrate how ArchaMap can be used to reconcile and organize one kind of archeological category—time periods—within and across two prominent linked open data repositories—periodO and wikidata (Rabinowitz et al. 2015). In October 2024, PeriodO included 8741 time period records and wikidata included 871 unique pages classified as either archaeological or historical periods. PeriodO has many records that refer to the same time period category (e.g., 'Warring States, 403-221 B.C" and "Warring States Period") as well as records with similar names that actually refer to different categories (e.g., "Warring States period"

refers to two completely different time periods in Japan and China). We first consolidated records in PeriodO based on similar names, time spans, and regions into unique time period categories (e.g., all Chinese Warring State records assigned to one category). For each unique time period from PeriodO, we created a new node in ArchaMap and "Uses" ties to that node for all relevant PeriodO records. We then used ArchMap's translate tool to propose matches to Wikidata time periods, limiting by country and time period.
Results. Consolidating period records from PeriodO into unique categories. Of the 8741 records in PeriodO, 27% were near-perfect duplicates in terms of time, name and place, and 20% were samples from the same general period in different locales (Flavian period in Scotland vs. England). Thus, roughly half of all PeriodO records were consolidated with other records into a unique category.
Accuracy and Error Detection. Comparing records assigned to the same category permitted identifying errors and inconsistencies, permitting us to identify 29 cases of metadata errors in PeriodO. As an example, one of four records labelled "Year of the Four Emperors" had a much different time span (193 CE vs. 68-69 CE) than the other three, indicating it should have been labelled "Year of the Five Emperors" instead. This same approach facilitated differentiating different categories with similar names (e.g. "Warring States" in 1400-1600 CE Japan vs. 480-220 BCE China).
Improved searches and matching. Consolidating records into common categories and integrating the names across those categories can also improve searches for future matching. For example, searching for "Flavians" in PeriodO identifies some examples of the Flavian period (e.g., Flavians, 69-96, The Flavians), but misses others (e.g. Flavische Dynastie and Flavian dynasty (Roman Noricum). In ArchaMap, searching for any of these names (or names similar to them) produces the full list of Flavian records.
Matching Wikidata with PeriodO. Only 47 time periods were already linked across Wikidata and PeriodO Using bulk lexical matches constrained by contextual information (e.g. location, time), ArchaMap assisted in efficiently identifying 10 times more matches across the two repositories. We did not do a formal time use study of matching Wikidata and PeriodO. However, a recent effort to match over 6,500 library of congress call numbers for ethnic groups to over 1000 ethnicites in the Ethnographic Atlas using ArchaMap's companion app, SocioMap showed a > 70% reduction in effort.
Discussion. CatMapper/ArchaMap provides tools for overcoming key bottlenecks in achieving linked open data in archaeology—including identifying and verifying matching categories across different repositories, integrating and comparing diverse claims made about the same categories in different repositories, and storing and sharing past decisions about matches to support reuse and replication of prior data synthesis efforts.

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213. How do we integrate community data from Wikidata, FactGrid and the fuzzy-sl Wikibase into a cultural heritage knowledge graph? First examples using SPARQL Unicorns, CIDOC CRM and Linked Open Data

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Community-driven repositories, databases, and knowledge bases — such as Wikidata, FactGrid, and the fuzzy-sl Wikibase — offer a wealth of cultural heritage (CH) and archaeology-related data. Volunteers, Citizen Scientists, and independent researchers working outside publicly funded projects often curate these platforms. Their contributions complement traditional research initiatives by addressing gaps in existing datasets, thereby enriching the overall knowledge ecosystem (Schmidt, Thiery, and Trognitz 2022). Meanwhile, large-scale infrastructure initiatives like the German National Research Data Infrastructure (NFDI), DARIAH, and ARIADNE are advancing the development of knowledge graphs. These graphs, typically constructed using semantic frameworks such as RDF, OWL, and CIDOC CRM or graph database systems like Neo4J, aim to harmonise heterogeneous data into interoperable, accessible, and reusable hubs. The challenge lies in effectively integrating community-driven platforms with these expansive knowledge infrastructures, including the archaeology-related consortia of the NFDI, particularly NFDI4Objects, NFDI4Memory, and NFDI4Culture.

NFDI4Objects (N4O) represents an interdisciplinary consortium dedicated to archaeology and cultural heritage research, with a scope encompassing 2.6 million years of human history. Its focus spans a wide variety of objects, including archaeological artefacts such as potsherds, sculptures, jewellery, and coins; organic remains like wood, bones, and pollen; inscribed artefacts such as clay tablets and papyri; and architectural remnants and anthropogenic landscapes. The NFDI4Objects Knowledge Graph (Voß et al. 2024) currently integrates 13 datasets, including Linked Open Ogham, African Red Slip Ware, and KENOM. Its structure, based on CIDOC CRM RDF models and extended with ontologies like CRMdig and CRMarchaeo, exemplifies the potential of Linked Open Data (LOD) for advancing cultural heritage research.

Integrating community-driven data sources such as Wikidata, FactGrid, and fuzzy-sl into infrastructure knowledge graphs is essential for ensuring comprehensive, accurate, and globally applicable datasets. These platforms contain a wealth of volunteered data, often addressing critical gaps left by traditional research approaches. However, the integration process poses significant challenges, including semantic alignment, data quality assurance, and achieving interoperability between datasets. To address these challenges, it is necessary to identify cultural heritage-related entities within these platforms, map them to CIDOC CRM or its extensions, and publish the aligned datasets as RDF via repositories like Zenodo. Semi-automated workflows play a pivotal role, allowing periodic updates and regeneration of datasets to ensure their currency and adherence to FAIR principles (Findability, Accessibility, Interoperability, and Reusability). This integration enriches the NFDI4Objects Knowledge Graph, bridging the contributions of community-driven platforms with institutional and international research efforts.

Wikibase instances — including Wikidata, FactGrid, and the fuzzy-sl Wikibase — form the basis of this approach. Wikidata is a community-driven, multilingual, and freely accessible knowledge base providing structured data across various domains, including cultural heritage and archaeology. It acts as a central hub for linked data, enabling the alignment and integration of diverse datasets through semantic modelling while adhering to FAIR principles. FactGrid is a collaborative knowledge base tailored to humanities research, offering archaeologists a versatile platform for interlinking excavation records, historical data, and other materials. In contrast, the fuzzy-sl Wikibase (Fuzzy Spatial Locations) explicitly addresses uncertainties and ambiguities in findspot locations, using metadata qualifiers to manage spatial imprecision.

Our proposed semi-automatic workflow consists of six key steps. Firstly, Wikibase instances such as Wikidata, FactGrid, and fuzzy-sl identify and evaluate cultural heritage entities. Examples include archaeological sites and artefacts such as Ogham Stone sites, Holy Wells, Roman amphitheatres, Limes castra, and Campanian Ignimbrite findspots, which are often archaeological findspots as well (e.g. caves). FactGrid datasets, including the Cuneiform Project, Mapping Koblenz, and Early Modern Practical Books, also contribute valuable data. Secondly, an ontology is developed based on the classes and properties of these entities, which are mapped to CIDOC CRM to ensure semantic alignment and interoperability. Thirdly, SPARQL Unicorn scripts are developed using Python libraries, such as “rdflib”, to transform SPARQL queries from Wikidata, FactGrid, and fuzzy-sl into Linked Open Data (LOD) while leveraging the ontology. Fourthly, these scripts and the resulting datasets are published on GitHub and linked to Zenodo for version control and citation via Digital Object Identifiers (DOIs). Fifthly, regular releases of these datasets are made publicly accessible on Zenodo to ensure long-term availability and compliance with FAIR principles. Finally, the datasets are integrated into the NFDI4Objects Knowledge Graph using semi-automated scripts, streamlining the process and enhancing interoperability.

The application of this method will result in a comprehensive list of CH-related classes and properties derived from Wikidata, FactGrid, and the fuzzy-sl Wikibase, systematically mapped to an ontology aligned with CIDOC CRM. This ontology will serve as the basis for scripts that transform these datasets into Linked Open Data, hosted on GitHub for open access. Periodic releases will be published on Zenodo and integrated into the N4O Knowledge Graph, ensuring the datasets are accessible and queryable through tools like the SPARQLing Unicorn QGIS Plugin. This functionality builds upon existing capabilities provided directly by Wikidata (cf. Fig. 1), offering enhanced querying and visualisation opportunities.

The paper will also address critical questions regarding Wikidata, FactGrid, and fuzzy-sl modelling approaches, exploring their commonalities, differences, and alignment with CIDOC CRM and Linked Open Data community standards. Special attention will be given to identifying the "least common denominator" — the shared core elements facilitating interoperability while respecting each knowledge base's unique characteristics and functionalities. This analysis will provide valuable insights into optimising integration workflows, improving semantic consistency, and enhancing the usability of datasets within the broader cultural heritage knowledge graph ecosystem. By bridging community contributions with institutional and international initiatives, the proposed approach advances FAIR principles, fosters interdisciplinary collaboration, and supports developing sustainable and accessible research infrastructures for cultural heritage and archaeology.

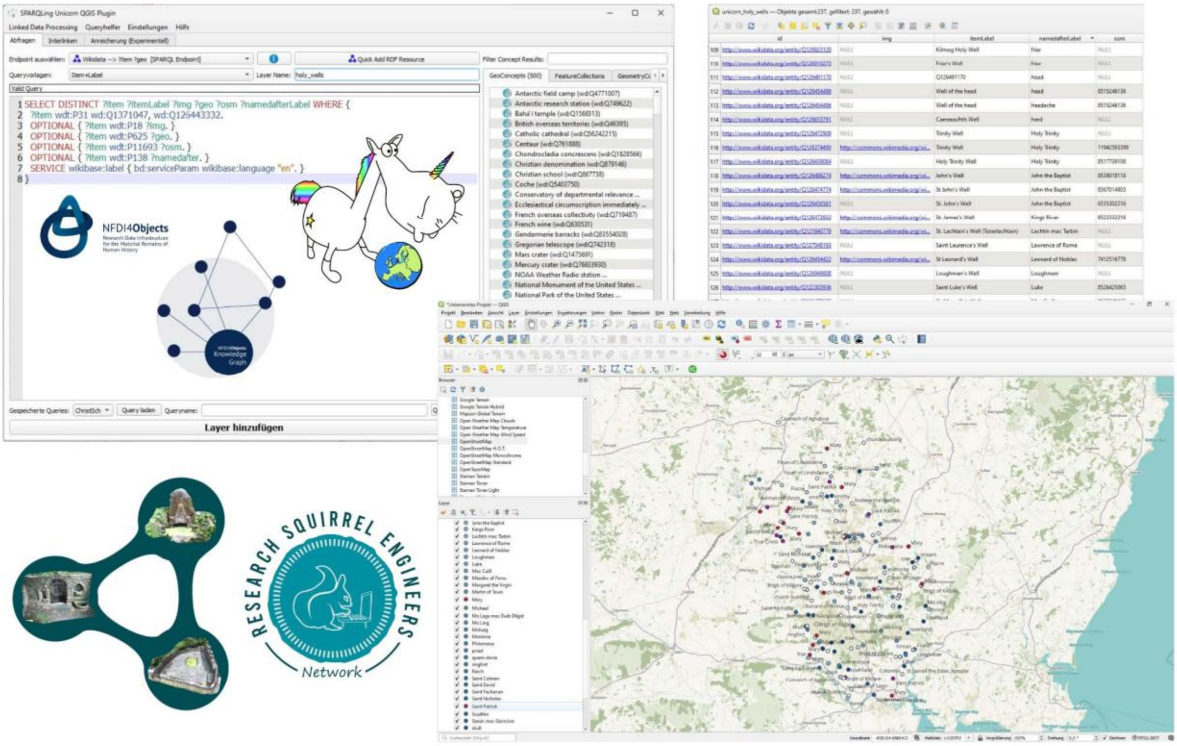

Fig. 1. Top: SPARQL query on Wikidata using the SPARQLing Unicorn QGIS Plugin to get Irish Holy Wells by etymology; bottom: Result as a map in QGIS using the SPARQLing Unicorn QGIS Plugin. *anonymous*, CC BY 4.0.

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502. A wiki base for active excavation? A debate on maya excavations in Belize

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The Maya Research Program (MRP) has documented and protected Maya sites in, e.g., northwestern Belize for over three decades, generating a wealth of archaeological and ethnographic data, an excerpt of which can be found in the publication list on the website (http://www.mayaresearchprogram.org/styled-3/MRP%20publications.html). However, these datasets are often scattered across diverse platforms, making them difficult to integrate and analyse collectively. With the Maya Wikibase we aim to address this challenge by serving as a Linked Open Data (LOD) hub, fostering the principles of FAIR (Findable, Accessible, Interoperable, Reusable) data sharing and Open Science. By adopting the Wikibase flexible data model and infrastructure, the project offers a robust framework to link, organise, and disseminate diverse data related to Maya archaeology.

The Wikibase platform's dynamic model, based on items, statements, qualifiers, and references, allows for the structured representation of rich metadata, making it ideal for handling the complexity of archaeological datasets. The Maya Wikibase aims to incorporate the CIDOC CRM (Conceptual Reference Model) and extensions to ensure semantic consistency and interoperability with global archaeological standards. Spatial information, a cornerstone of Maya research, is integrated using the GeoSPARQL standard, enabling the representation of complex geographic data such as fuzzy coordinates, polygons, and other spatial relationships. These technologies position the Maya Wikibase as a central metadata hub that connects to external LOD repositories, including Wikidata, FactGrid, and the NFDI4Objects Knowledge Graph.

The Maya Wikibase also leverages existing tools to automate and simplify data workflows. Scripts for data ingestion and transformation, including the generation of QuickStatements for batch uploads, are provided to ensure efficient integration of datasets. These scripts align with FAIR4RS (Lamprecht et al., 2019) principles, offering compatibility with popular data science environments such as Python, R, and Jupyter Notebooks. By enabling researchers to work with structured data efficiently, the project empowers users to perform advanced analyses and visualisations while ensuring the provenance and quality of the data.

The creation of the Maya Wikibase involves a semi-automated workflow designed to produce a flexible and extensible data model. The core of this process is data alignment with the CIDOC CRM and standards like GeoSPARQL, ensuring that the information is interoperable with large-scale knowledge graphs. Integrating thesauri helps standardise terminologies for data exchange, while spatial data is enhanced with fuzzy geographic representations using tools such as the fuzzy-sl Wikibase. This approach enables the representation of complex spatial features, including points, polygons, and buffers, in formats like GeoJSON, thereby ensuring that the platform supports a wide range of spatial queries and visualisations.

In addition to data modelling, the Maya Wikibase aims to connect to other repositories and the NFDI4Objects Knowledge Graph, facilitating interoperability and cross-referencing of data. This interconnected infrastructure should not only improves data accessibility and usability but also foster collaboration between researchers from various disciplines. The Wikibase instance is hosted on wikibase.cloud, providing a scalable platform for storing, linking, and disseminating archaeological data. The resulting metadata hub offers citable, persistent URIs for each dataset, promoting reproducibility and encouraging reuse in diverse archaeological contexts.

At the moment, the Maya Wikibase is still being developed. It is initiated by the Maya Research Program of the University of Texas at Tyler and has triggered a wide discussion on the potential implications of opening the data of mainly ongoing excavations. More than most countries, Belize struggles to protect its cultural heritage from looters and tomb raiders. Fact is that almost all sites in Belize have been subject to looting already and making their presence known prior to concluding their excavation bears the risk of intensifying looting activities.

On the other hand, there is a growing interest of tourists in visiting excavation sites, seeing the active work of identifying and recreating the site, as well as getting insights into how these areas could have looked like. A wikibase will not only help making this knowledge accessible, but also to ensure that all information is current and aligned with scientific insights.

The first implementation efforts of the Maya Wikibase will focus on areas of less criticality, i.e. that have already been excavated thoroughly. Its effectiveness will be assessed on the one hand in terms of its ability to integrate heterogeneous datasets, support FAIR principles, and enhance researchers' usability. And on the other hand in terms of usage by tourists and related interested parties.

In this presentation we want to discuss the benefits and drawbacks of a Wikibase for archaeological finds, covering, but not being excluded to, effort, scientific benefits, tourism, potential looting, ethical concerns etc.

The Maya Wikibase aims to significantly contribute to the application of Linked Open Data in archaeology. It could demonstrate how distributed datasets can be integrated into a cohesive framework while promoting innovation, collaboration, and reproducible research. As a central metadata hub, the Maya Wikibase will set a precedent for future initiatives to make archaeological data FAIR and support Open Science practices. If, of course, we can agree that the benefits outweigh the risks.

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249. Examining Changes in Preplanned Lithic Technologies Through Cutting Edge Angles Using a Digital 3D Approach: A Case Study of Tabun Cave, Israel

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The application of predetermined technologies by Middle Pleistocene hominins plays a pivotal role in understanding the evolution of human cognitive capabilities. During the Lower and Middle Paleolithic periods, advancements in lithic technology marked significant milestones, with the widespread use of Levallois technology in the Middle Paleolithic (MP) representing a notable leap in the complexity of core reduction processes. Previous studies have examined the evolution of predetermination through various aspects, including core reduction sequences and the characteristics of end and waste products. This study addresses it through a different aspect, the cutting edge angles of the produced blanks, a highly informative feature given its functional significance and visual prominence.

Cutting edge angles of lithic implements have long been regarded as critical for understanding technological behaviors and cognitive capacities. However, accurately recording and analyzing these angles presents considerable challenges. Angles are geometrically defined between two straight lines or planes, yet lithic cutting edges are inherently non-planar surfaces. Over the years, numerous methods have been devised to address this issue. However, the reliance on 2D measurements for 3D artifacts has often resulted in low accuracy and replicability, undermining the reliability of conclusions.

To address this methodological gap, this study employs a recently developed, advanced methodology for measuring edge angles on lithic artifacts (Grosman et al., 2022; Valletta et al., 2020). This approach analyzes the geometry of the surfaces forming the edge using 3D digital models, categorizing vertices into dorsal and ventral groups based on their normal unit vectors and defining the angle bisector vector. The mean edge angle is computed as the supplementary angle to the arccosine of the dot product of the mean normal vectors of the two surfaces. To enhance precision, the algorithm identifies the most consistent portions of the surfaces using iterative shell analysis, optimizing measurements by minimizing angle variability across multiple subsections.

The study hypothesizes that Levallois technology, prevalent in the MP, enabled the production of more standardized cutting angles compared to other lithic technologies from the Lower Paleolithic (LP). To test this, a protocol was developed to divide lateral cutting edges into ten sections and measure the mean edge angle for each section. Four variables were calculated to assess standardization: the mean edge angle, the standard deviation of mean section angles across the edge, the number of sequential sections with absolute angle differences ≤5°, and the absolute difference between the left and right cutting edges of a single artifact. These analyses were applied to lithic artifacts excavated by A. Jelinek at Tabun Cave, Israel (Jelinek 1982). The sample was divided into two temporal groups: (1) Late LP, represented by Acheulo-Yabrudian artifacts (ca. 400–250 ka), and (2) MP (ca. 250–160 ka). Artifacts were further categorized into two morpho-technological groups: blades and flakes.

The results reveal statistically significant differences in cutting edge angle properties between MP and LP artifacts. MP blades and flakes consistently exhibited more acute cutting edge angles compared to LP artifacts, with mean edge angles in MP artifacts being significantly different from those of LP artifacts. Additionally, MP flake artifacts demonstrated lower standard deviations in cutting edge angles and a higher number of sequential cutting edge segments with absolute angle differences ≤5°, indicating reduced variability. These patterns were not observed in the blade

category, and no significant differences were found in the symmetry of cutting edge angles between MP and LP artifacts.
These findings highlight the transformative impact of Levallois technology on lithic production. The observed reduction in variability and increased sequential consistency of cutting edge angles in some MP artifacts supports the hypothesis that this standardization may have supported the widespread adoption of Levallois technology, known for its technical and cognitive complexity. However, the results also underscore the mosaic and multifaceted nature of hominin technological evolution, demonstrating that it cannot be fully understood through a singular lens. Finally, this research underscores the value of integrating 3D digital models and formal geometric computational analysis into prehistoric studies. By enabling the formation of testable hypotheses with unprecedented accuracy, such methodologies represent a critical advancement in our efforts to reconstruct and understand human behavior in the distant past.

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351. Reducing Time and Data: A Method for Documenting Large Ceramic Assemblages through Photogrammetry

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This paper presents an approach used for documenting a large amount of ceramic material from the Iron Age settlement of Dzedzvebi in the Kvemo Kartli region of Georgia. Analysing large quantities of pottery often encounters the problem of insufficient time for documentation. The main focus of this method is to reduce the time required for this process when the material is available for study for a limited time.

Years of research at the site resulted in the collection of thousands of pottery pieces that needed to be documented. Limited time and resources have made this goal unattainable until now. To address this quantitative challenge, a method of photogrammetry was applied during the last year of research. By utilizing a custom-built framework to hold a set of 10 or more pottery pieces in place, a single batch of photographs is sufficient to document the entire assemblage. The innovation in this approach lies in the fact that the sherds do not need to be reattached to the frame. The minimal surface of the pottery fragment is covered by thin nails in two places. Since this area is usually the broken part of the sherd and only fem millimeters wide, this imperfection can be neglected in the upcoming analysis of the material. To ensure the highest accuracy, several sets of markers on the framework are used to create high-precision alignment for the photos. One set of around 250 photos is sufficient to create an entire 3D model. The photos are taken with a mobile tower holding two cameras that can also be adjusted at different angles. This advantage of the setup is further evident when the photos are processed in programs such as Agisoft Metashape. The entire model with multiple sherds can be processed in a single chunk and then separated into individual models of the sherds. From each sherd profile sections can be exported into a vector drawing and combined with the frontal photo of the model sherd.

Similar approaches have already been presented in different publications, where the whole process of collecting photos and processing them is separated into 2 sets/chunks. In comparison, the method applied to the material from Dzedzvebi is quicker and generates less data for processing. By reducing the number of photos required and minimizing the data generated, this method not only speeds up the documentation process but also ensures that the post-processing of the models is faster.

The advantage of this method is that it can be applied to most of the sherds available. While almost complete and complete vessels cannot be attached to the frame, they can still be photographed using a turntable.

This method enables more efficient and accurate documentation of pottery, which can be valuable for long-term preservation. The creation of 3D models allows virtual storage of ceramic collections, minimizing the risks associated with physical handling and providing an opportunity for future researchers to revisit and reanalyse the material.

By integrating photogrammetry the time spent on manual documentation tasks such as photographing and drawing can be drastically reduced. This makes the process scalable, enabling archaeological teams to handle larger datasets, which is especially important in large-scale excavations such as research where this method was applied.

The 3D models generated through photogrammetry can be used to perform precise measurements and quantitative analysis, such as determining the size, shape, and decorative patterns of ceramic vessels. This can contribute to more accurate classification and typological studies of ceramic assemblages. The ability to digitize pottery also allows for easy comparison between different sites or excavation periods.

This method bridges the work between archaeologists, computer scientists, and engineers. The use of photogrammetry and 3D modeling can be further developed through machine learning algorithms that automatically classify pottery sherds or predict their function, making the process more efficient and improving the quality of the final analysis.
One of the major implications of this approach is its potential to reduce the costs associated with traditional documentation methods.
If we do not limit ourselves only to using models for determining the thickness of the fragment, shape, or typological classification, we use models to extract additional information that would not be so easy to extract from the original object at first. This way of gathering information opens the door for future analyses of archaeological material.

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545. Computational 3D analysis of Middle Stone Age Lithic Technology

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Three-dimensional scans of artefacts are increasingly being incorporated into analytical workflows in archaeology. Yet, most uses of these scans centre on overall artefact morphology. Lithic artefacts possess much complex variability beyond their overall shape, including specific techno-typological attributes. These attributes, which were previously visually classified into discrete qualitative categories, can now be precisely quantified using their volumetric and surficial geometries. Here, 3D computational methods are applied to Middle Stone Age prepared cores – a particularly skilful and cognitively intensive lithic technology where preparatory core shaping is aimed at producing standardized flake blanks. First, flake scar boundaries were automatically identified using an existing method that identifies contiguous areas of high surface curvature. Then, flake scar surface area proportions were used to quantify the extent to which these cores are preferential or recurrent. The typical criteria for identifying Levallois cores were then quantified: the planarity of the plane of intersection was estimated as the mean distance of the outline coordinates from the plane; the hierarchy of the surfaces was computed as the ratio of the volume either side of this plane; the lateral and distal convexities were estimated via their volume and distribution around the periphery of the cores; and the parallel fracture plane was quantified according to how perpendicular the normal vectors of the flaking surface was to the plane of intersection. Lastly, the direction of the flake scars' normal vectors also identifies step, hinge, and plunging flake terminations, helping to quantifying the severity of knapping mistakes. This set of bespoke computational and automated methods are applied to a pilot sample of 124 3D scans of cores from five MSA sites in eastern and northern Africa. These methods establish continua of prepared core preparation, recurrence, and exhaustion.

157. From mapping to fruition: the use of 3D acoustic remote sensing data in seabed archaeology. Insights from the Underwater Archaeological Park of Baia (south Italy).

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Introduction
The documentation and study of underwater cultural heritage is a complex process that requires the integration of innovative technologies and interdisciplinary research that combine physical and anthropic factors, spatial elements and social filters to describe, interpret and communicate the traces of human activities in the marine environment. These aspects are strongly connected to the use of appropriate planning tools and economic, cultural and environmental characterization also in relation to climate change impacts. From a socio-cultural point of view, the main issue concerns the human perception of underwater landscapes. Moreover, only a few people have the opportunity to observe such landscapes in situ.
Among the methods currently used for the characterization and mapping of the seabed archaeology, acoustic remote sensing techniques based on latest generation of Ultra-High Resolution (UHR) multibeam echo-sounder (MBES) systems represent an important tool not only for the documentation and monitoring, but also for the valorization and communication of the Underwater Cultural Heritage (Violante, 2018). The high degree of resolution and accuracy of such systems offers new opportunities for the development of detailed 3D reconstructions of the underwater historical-archaeological heritage and of the morphological-sedimentological characteristics of the seabed, significantly contributing to the assessment of the impact of environmental and anthropic stress factors. Furthermore, the integration of remotely sensed bathymetric data with direct visual seafloor inspections provides an advanced information base from which to extract information and build models for archaeological research, and develop applications for the reconstruction and conservation of underwater artefacts and cultural landscapes (Violante, 2020).
The present study concerns the use of UHR multibeam echo-sounder data to map seabed archeology in the Underwater Park of Baia (south Italy). These activities were carried out as part of a research agreement with the Campi Flegrei Archaeological Park) with the aim to implement a highly specialized remote sensing methodology for archaeological research in the underwater environment (Violante et al, 2023).

Methods and materials
In the marine environment acoustic waves are the most efficient means of investigation due to their ability to propagate through water (up to several km) without significant attenuation. The level of attenuation depends on frequency and is higher for high frequencies. The acoustic energy transported during propagation can be used to make measurements of the medium traversed.
In the study area, for the bathymetric survey was used a MBES system NORBIT WINGHEAD® i77h with working frequencies of 400 kHz and 700 kHz. This system operate in a bathymetric range from a minimum of 0.5 m up to approximately 300 m. It is an integrated system consisting of three elements: a curved transducer, a small Sonar Interface Unit (SIU) and a pair of GNSS receivers. The processing of the seabed survey takes place inside the sonar head, which also integrates a very high-performance Applanix OceanMaster inertial navigation system. This configuration enables precise georeferencing of the survey by providing latitude, longitude, elevation, roll, pitch, heading, heave and time synchronization information. This system is also compatible with RTK (Real Time Kinematic) real-time correction, which guarantees centimeter accuracy of

horizontal positioning. The measured depths are corrected in real time to compensate for the movement of the boat and variations in the speed of sound in the water. This configuration allows for bathymetric measurements with an accuracy of 2 cm and a resolution of approximately 1 cm. The survey took place in November 2021 in the Zone A of the Baia underwater Park, on seabed depths between 1 and 11 m. The survey covered a total area of 2 km2. During the survey, sound velocity measurements were taken in the water column using the Sound Velocity Profiler probe. The sound velocity data were entered into the acquisition software for the correct depth calculation.

QINSy (Quality Integrated Navigation System) software from QPS (Quality Positioning Services) was used for the acquisition and processing of bathymetric data. The processing module of this software allows a complete assessment of the data according to three basic steps: position correction, depth correction and statistical control of the data. The processed and filtered bathymetric data were than grided to obtain a very high resolution Digital Bathymetric Model (DBM) with a cell size of 0.1 m. Bathymetric data were further processed with 3D modeling techniques. The bathymetric survey was computed by specific algorithms and the point cloud were triangulated to obtain a mesh model with centimeter-level resolution.

Discussion

Bathymetric measurements with the UHR multibeam echosounder enabled the production of very high-resolution thematic maps that illustrate the archaeological, sedimentological and geomorphological features of the study area. The main results concern the 3D modelling of the seabed and the mapping of underwater archaeological features with unprecedented detail. In particular, it was possible to identify and map new architectural elements belonging to the residential complex of the Villa dei Pisoni. The UHR multibeam survey confirmed the general shape and dimensions of the Villa derived from previous archaeological investigations, and revealed hitherto unknown details and structures such as the presence of a large fishpond complex along the end of the Villa and mooring areas in the northern area. Moreover, the dense point cloud of the multibeam survey was processed with 3D modelling techniques for implementation in advanced spatial data visualization platforms, also in a web environment. This has enabled the design of immersive installations for communication and access to the wide public, including through the creation of 3D prints of the digital bathymetric model.

Future developments envisage the implementation of the methodological approach described above within the MOLAB (MObile LABoratory) platform of the European Research Infrastructure on Cultural Heritage Science (E-RIHS - www.erihs.eu), with the creation of an open-access underwater acoustic remote sensing laboratory for researchers, scholars and professionals.

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496. Incorporating shape data from 3D models of artefacts into phylogenetic analyses as continuous traits

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The recent rise in the 3D digitisation of artefacts has enabled the adoption of innovative new methods to explore and analyse material culture. One method of interest to my own research is 3D shape analysis via geometric morphometrics (GMM), which quantifies morphological shape using geometric coordinates. GMM is commonly used in the field of evolutionary biology to explore variation in biological organisms and structures. Earlier approaches to GMM focused predominantly on two-dimensional representations of shape, which do not require 3D models, but can be generated from static photographic images. However, with the increased accessibility of 3D modelling technologies, including CT scanning, laser scanning and photogrammetry, the application of GMM in three dimensions has become more common and well-developed in biological research.

GMM has also been embraced in archaeological studies, where it is most commonly utilised in lithic research, generally in two dimensions. However, 3D GMM has recently begun to generate some interest, again linked to an increase in 3D modelling, and has expanded to artefacts beyond stone tools, such as northwest European ships (Dhoop et al. 2020). However, the scope of these GMM analyses remains limited, with discussions almost solely focusing on principal components analysis (PCA) or canonical variates analysis (CVA) plots to discuss standardisation or variation in shape of specific artefacts and structures through space and time. Contrastingly, in evolutionary biology, there has been a notable uptick in studies incorporating GMM data into broader analyses, particular those using phylogenetics.

Phylogenetics involves the study of the evolutionary history of entities, by encoding their heritable traits, and reconstructing their relationships using tree diagrams. Many biological studies rely on DNA or RNA, but it is also common to use the morphological traits of organisms as inputs in cases where genetic material is not available. Typically, this morphological data is encoded as discrete traits, for example, feather types, or the presence or absence of a foramen. It has been suggested that such an approach is subjective, coloured by the interpretations of individual researchers (Parins-Fukuchi 2018). Furthermore, it causes issues with numeric data (such as dimensions), which must be split into arbitrary bandings to conform to such a system. This reliance on discrete data has been a software limitation until recently, with some applications now supporting the incorporation of continuous data, particularly those developed for the Bayesian method of phylogenetics, such as BEAST or RevBayes.

Similar to GMM, phylogenetics was initially developed as a technique by evolutionary biologists, but has subsequently been utilised by archaeologists to explore the evolution of material culture. Given that phylogenetics and GMM both provide pathways to exploring and understanding variation in morphology, biologists have argued since the early 1990s that it makes sense to combine the two techniques, and recent developments have now made this possible from a software perspective, as noted above. As such, the incorporation of continuous shape data into phylogenetic analyses been increasingly adopted in recent biological studies. It is suggested that the use of continuous traits, which are entirely quantitative, may help overcome the aforementioned problems of subjectivity attached to discrete coding practices, and create more robust phylogenetic studies (Parins-Fukuchi 2018).

The use of either 2D or 3D shape data in the phylogenetic analyses of artefacts has been entirely absent in archaeological research, until a recent preprint article released by Marwick et al. (2023). The authors conduct a Bayesian phylogenetic analysis of Late Neolithic and Early Bronze Age arrowheads from Northwestern Europe, using two-dimensional artefact shape coefficients from an outline GMM analysis as continuous traits. This work shows promising results in its ability to identify a statistically significant phylogenetic signal in the dataset, indicating the potential of shape data to help researchers identify and understand patterns of cultural evolution over time.

However, there is still room to expand on Marwick et al.'s work further, with the use of 3D GMM data, rather than 2D. Shape is an incredibly important feature of many archaeological artefacts, with discernible trends in form that change over time and across space. However, to reduce discussions of shape to two dimensions is to miss essential parts of the story. Given the relative ease and speed with which we can now make accurate 3D representations of artefacts, there is prime opportunity to use 3D GMM data in novel ways, including as an input to phylogenetic analyses.

This is what I am currently aiming to do in my own PhD research. My dissertation focuses on the application of quantitative, data-driven approaches to understand and compare the different administrative systems used during the Bronze Age period in the Aegean, a region that comprises modern-day Greece, Crete and their surrounding islands. A number of different administrative systems were in use throughout the region during this period, each with a specific repertoire of administrative devices (various types of tablets, labels, dockets and sealings). Many of these device types have a very distinctive shape, which appears to have acted as a visual marker for their respective functions. Several researchers have discussed these shapes, and other features of the devices, in order to highlight potential parallels or differences between the different administrative systems, many of which have wider implications for the history of the Aegean at this time. However, this has been done in a relatively qualitative, and arguably subjective way, until now.

In this paper, I will present the initial results of incorporating continuous shape data into my own phylogenetic analysis of these artefacts. This data has been extracted from 3D models of these devices, captured via photogrammetry techniques. I will be trialling using the GMM data as the only input to the model, as was done in the aforementioned study by Marwick et al., as well as including it alongside a set of discrete traits, in order to compare the outcomes, and assess the overall phylogenetic signal achieved with each method. Regardless of the outcomes, a major aim of this research is to develop a robust, easy-to-follow protocol for future archaeologists wanting to combine both Bayesian phylogenetics and 3D shape data in their own projects.

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9. Corrective Hybrid 3D Digitization

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Problem statement

The application of accurate 3D acquisition technologies in cultural heritage has proven to be beneficial in many aspects, such as data collection, analysis, preservation, and education. There are several 3D scanning methods available, each with its own set of strengths and limitations. The effectiveness of a method often relies on the object's characteristics. When it comes to 3D digitizing intricate, structurally complex and delicate objects, a number of challenges may arise. Factors such as size, geometric complexity, thickness, reflectance, occlusion and transparency or translucence can all influence the effectiveness of a method and can introduce severe errors in the process. Zooarchaeological finds, such as animal bones or seashells typically exhibit at least one of the above problematic characteristics, making them challenging to digitize (Spyrou et al., 2022).

In this work, we propose a methodology, based on proven algorithms to combine multiple 3D models of the same physical object acquired with different digitization approaches, in order to take advantage of the merits of each method and rectify problematic scans by selectively combining and fusing surfaces.

Methodology

The proposed pipeline is presented in the following figure. Below we briefly outline the steps involved.

Input. The pipeline takes as input two or more meshes of the same object, digitized with different approaches and proceeds with the detection of mismatched regions on their surfaces. In our case study, we used the two most popular approaches, i.e. structured light scanning and structure from motion.

Output. The result of the process is a mesh with texture (depending on the input), where problematic surface areas have been replaced using the best candidate surface from the alternative digital versions to the original (defective) scan.

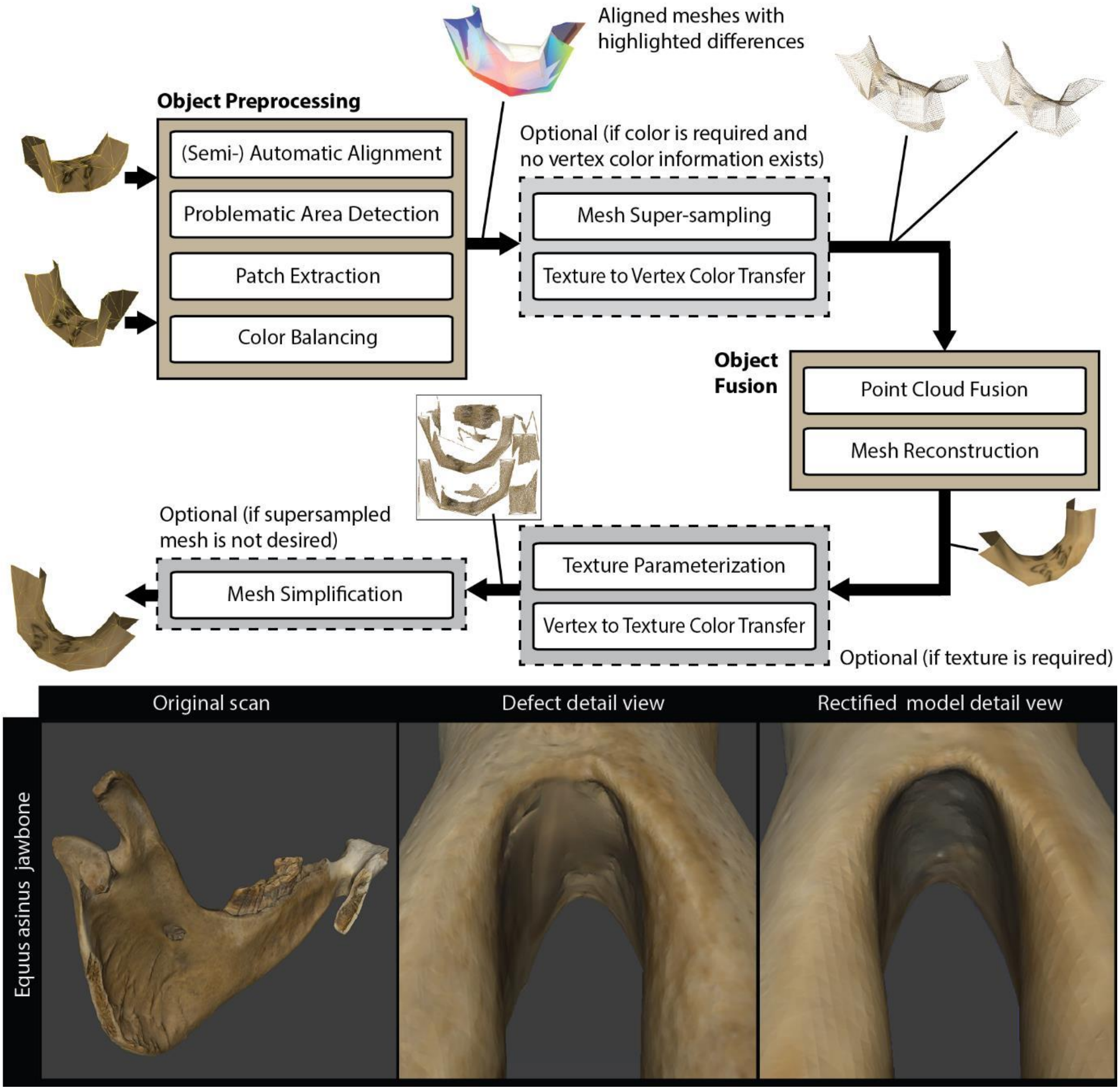
Object preprocessing. For each artefact or specimen, the most reliable digitization source is used as reference to align the other version(s) and act as the model to be rectified. Computational alignment is a very crucial part of the process and must be carefully supervised, at least when using a standard local average error minimization approach, as available in Meshlab (Ranzuglia et al., 2013).

Problematic patches are removed and replaced with the corresponding parts from the secondary source(s): After, alignment, major surface deviations can be detected and visualized and the user determines which parts should be retained from each digital version. Optionally, if texture is present on the input geometry in the form of bitmaps, surfaces are super-sampled and texture is transferred to the digitized point cloud. Super-sampling is necessary to ensure that point cloud density conforms to the spatial granularity of the texture applied to the surface.

Object Fusion. The high-detail point clouds containing the geometric and color information of the retained parts is fused to create a new 3D mesh, using the Screened Poisson reconstruction method (Kazhan and Hoppe, 2013). The reconstruction method requires oriented point samples, but these are available by construction, since the input comes from surface data.

Outline of the corrective hybrid 3D digitization pipeline and an example of a case study.
If the output model requires texture maps, a new surface parameterization is generated and color for the texture atlas is sampled from the dense point cloud. The resulting mesh can be optionally simplified to match the original density of the input models.
We implemented the entire pipeline in Meshlab (Ranzuglia et al., 2013) with the exception of the texture parameterization step, for which other modelling software have been proven more effective.

Evaluation and results
We specifically focused our case study on three diverse, problematic and hard to digitize zoological specimens, which are used in zooarchaeology for comparative study. These have been first carefully digitized with a high-precision structured light scanner with color capture. A second digitization stage, using structure from motion (SfM) photogrammetry, was performed on objects on which defects on the 3D models were identified. The structured light scanned models were used as the primary meshes (to be corrected) and reference models for quantitative measurements. In the case of SfM digitization, we specifically concentrated more shots on the problematic areas of the specimens. The output of the SfM reconstruction was used to patch the results of the structured light data.
We successfully performed corrective hybrid digitization using structured light scanning and photogrammetry on the zoological specimens and evaluated the results against measurements from the original objects and the primary scanned data.
Qualitative analysis. The three subjects were evaluated against the original specimens and the structured light 3D model in terms of improvement of the captured geometry and surface coverage, geometric consistency, presence of artifacts, texture and detail preservation.
The original scans exhibited mismatched surfaces and under-sampling in blade-like thin structures, bridging artifacts in high-occlusion areas (see example in the figure), skewed elongated structures and holes at very thin parts.
Most artifacts were successfully corrected using complementary, healthy parts from the SfM reconstruction. The only exception was the patching of holes on a seashell sample, which, although successful, lead to the generation of new holes at a different location. Still, these artifacts were less pronounced than those on the original mesh. Textural information and general mesh integrity were preserved consistently.
Quantitative analysis. All corrected specimen meshes exhibit a near-zero distance from the original scans on the parts that were not replaced, indicating no error from the surface reconstruction stage. Results were found to improve mesh quality, while sufficiently preserving texture information.
It is important to note here that the proposed process for repairing problematic scans is not dependent on a particular digitization method. We have conducted experiments on scanned objects with structured light technology and structure form motion photogrammetry, but the approach is just as well applicable to any method that can generate a surface model with or without texture, such as isosurface extraction from Micro CT or Neural Radiance Fields.



Outline of the corrective hybrid 3D digitization pipeline and an example of a case study.

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469. Using 3D techniques in facial reconstruction and determining facial features for the calcholitic population of Banat region, Romania

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Introduction
The Chalcolithic period, spanning the transition between the Neolithic and Bronze Ages, is a pivotal era for understanding the cultural and biological evolution of prehistoric populations. The Banat region of Romania, with its rich archaeological record, offers an invaluable window into the lives of its inhabitants during this period. However, reconstructing the physical appearance of these ancient populations has long been constrained by the limitations of traditional methods.
This study leverages advancements in 3D imaging and modeling techniques to reconstruct facial features from skeletal remains, providing new insights into the biological and cultural attributes of the Chalcolithic population of Banat. The research aims to address key questions: What anatomical characteristics define this population? Can 3D reconstructions enhance our understanding of their social identities and interactions? By integrating archaeology, anthropology, and cutting-edge technology, this paper seeks to shed light on the interplay between physical appearance and cultural identity, contributing to a more nuanced understanding of Chalcolithic communities in Southeastern Europe.

Methods and Materials
The first case studies have been two skulls, from a male and a female, both from the same grave, dated through radiocarbon dating to the chronological interval of 4320-4050 calBC. Afterwards, four more skulls have been scanned and will be further processed in the next two months. The methodological framework involves high-resolution 3D scanning of cranial remains to capture precise geometric data, which is then processed using specialized software for facial reconstruction. This approach integrates soft tissue thickness data, derived from comparative anthropological studies, to approximate facial features with high accuracy. Additionally, digital tools are employed to simulate muscle structure and skin texture based on craniofacial landmarks. To achieve a detailed and accurate reconstruction, this study employs a multi-faceted 3D imaging workflow, incorporating advanced scanning technologies and specialized reconstruction software. High-resolution 3D surface scanning and computed tomography (CT) scans are utilized to capture the geometric and anatomical details of cranial remains. Surface scanners provide precise external morphology, while CT scans offer insights into internal cranial structures, allowing for the accurate modeling of skeletal features.
The CT scan data, collected at a resolution of 0.5–1 mm slices, are processed using segmentation software such as Mimics or Amira, which allows for the differentiation of bone from surrounding material. This step ensures the preservation of intricate cranial details, essential for accurate reconstruction. Subsequently, the 3D models are exported to software like Geomagic or Blender for cleaning and surface optimization, removing artifacts or distortions from the scanning process. Facial reconstruction is performed using software such as FaceGen or proprietary plugins within 3D modeling platforms like ZBrush. These tools incorporate databases of soft tissue thickness, correlated with demographic factors such as age, sex, and ancestry, to approximate the placement of facial muscles and skin. This approach combines anatomical precision with biomechanical realism, ensuring that the reconstructed faces not only reflect accurate morphology but are also life-like in appearance. Throughout the process, statistical

methods, including Procrustes analysis, are employed to compare the reconstructed features with reference datasets from modern and ancient populations. This integration of cutting-edge 3D imaging and robust analytical tools ensures a methodologically sound and scientifically rigorous exploration of the Chalcolithic population of Banat.

Results

To date, we have made significant progress in our research on the Chalcolithic population of the Banat region. We have successfully scanned a number of Chalcolithic skulls using high-resolution 3D surface scanning, capturing detailed external cranial morphology. Additionally, CT scans have been performed on select specimens, providing comprehensive internal structural data essential for accurate reconstruction. Complementing these efforts, we have gathered comparative data on facial markers from the modern Romanian population to establish a reference framework for soft tissue reconstruction. Our methods and preliminary findings have already been disseminated to the academic community, notably through a presentation at the 2024 CAA (Computer Applications and Quantitative Methods in Archaeology) conference. This exposure has allowed us to refine our techniques through peer feedback and engage with interdisciplinary experts, strengthening the foundation for the next stages of our research.

From all the skulls that have been 3D scanned, up until now we have managed to apply facial reconstruction techniques on two of them, a male and a female skull, both from the same grave. Our results show that the male has a long, narrow skull with high cheekbones, a pronounced brow ridge, a strong jawline, and medium-to-light skin tone. Until further DNA analysis, we can only assume, based on available data, that the hair is dark. On the other hand, its female counterpart has a slightly rounder but still narrow skull with softer features. High cheekbones, a narrower nose, and a medium tone skin, resembling the male.

Discussion

The potential results of this research extend beyond the immediate objective of reconstructing the facial features of the Chalcolithic population in the Banat region. By creating scientifically accurate 3D facial reconstructions, this study contributes to a deeper understanding of the biological and cultural identity of prehistoric communities. These findings can enhance our knowledge of population dynamics, such as migration patterns, interregional interactions, and genetic continuity or diversity within Southeastern Europe during the Chalcolithic period. On a broader scale, the research underscores the value of integrating advanced 3D technologies with traditional archaeological and anthropological methods, setting a precedent for future studies. The application of CT scanning and sophisticated reconstruction software can serve as a model for interdisciplinary approaches in bioarchaeology, paving the way for similar investigations in other regions and time periods.

Furthermore, the reconstructed faces can engage both academic and public audiences by providing a tangible connection to the past. They can be used in educational settings, museums, and digital media to humanize and bring to life ancient populations, fostering a deeper appreciation of cultural heritage. Ultimately, this research bridges the gap between science and public engagement, contributing to the preservation and dissemination of historical knowledge while promoting the use of innovative technologies in the humanities and sciences.

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398. Not just for show: using 3D models as "simple" tools to enhance archaeological understanding of an Etruscan Site

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The colony of Musarna, located in the eastern part of the territory of the great city of Tarquinia, was founded at the end of the 4th century BC, in response to the Roman expansion that began a few decades earlier. First Etruscan, then Roman, it was occupied until the 7th century AD. Rediscovered at the end of the 19th century, Musarna was mainly investigated between 1983 and 2003 under the direction of Henri Broise and Vincent Jolivet (École française de Rome; Broise and Jolivet 1997; Jolivet 2013). Numerous surveys, drawings, test pits, excavations and artefact studies have shed light on and provided a better understanding of the layout of the city and its road network, a number of important buildings (domus, Hellenistic baths, public buildings, etc.) as well as, the Hellenistic and Imperial necropolises, and the environment (agricultural landscape). This research has resulted in a wealth of written and graphic documentation (exclusively in 2D , such as survey and photos), a variety of publications, a lot of artefacts and numerous remains that are still accessible, but which are not always easy to study due to erosion of the land and vegetation cover. Since 2023, the site has once again been the subject of research as part of a doctoral project (focused on the defensive system) and a postdoctoral project (examining the Hellenistic necropolis and sarcophagi). This renewed investigation is distinguished by the integration of a substantial academic legacy, the exploration of new research questions and methodologies, and, above all, the application of advanced tools to deepen our understanding of the site.
The city and necropolis of Musarna are complex entities, whose identity is deeply rooted in a unique and remarkable three-dimensionality. This characteristic is not only a defining feature of the site's current organisation , but also a key element of the plateau's natural conformation, even before the foundation of the city. The site's morphology, with its pronounced gradients and contrasts between the steeply sloping western slope (a 40-metre depressed valley) and the more gently undulating eastern slope, provided a structural basis for settlement choices, offering natural protection and functional differentiation. This three-dimensional landscape, shaped by a combination of natural forces and human intervention, gave rise to a city where surface and underground spaces, as well as aerial and semi-rupestrian constructions, are in constant dialogue. In a way the above-ground city corresponds to an underground city; the same applies to the Hellenistic necropolis, where funerary monuments built in tuf blocks materialise the burial chambers beneath on the surface.
The current graphic documentation of the Musarna site, limited to 2D representations (mainly excavation plans, with few sections and elevations), does not allow the complexity of the terrain survey to be fully seized. As a result, it is not possible to fully understand its strengths and limitations, nor the extent of tuf extraction and, consequently, the topographical transformation that the site underwent. Furthermore, one cannot fully appreciate how the structures are arranged, both above and below ground level, often on multiple levels.
Today, modern tools and methodologies, such as topography, digital photography, photogrammetry, lasergrammetry and 3D modelling, offer a new and more comprehensive opportunity to analyse the site, through the use of old data and the acquisition of new, natively digital and 3D data. These integrated approaches make it possible to examine Musarna on multiple scales and over the long term, enabling the study of both its overall spatial organisation and the visibility of individual structures. Furthermore, current technologies make it possible to

combine old data with newly acquired data, providing a more precise understanding of the city, its construction methods and its development over time.
The study of the Musarna site presents significant challenges due to its pronounced and uneven topography, the variable state of preservation of the remains, and the multiplicity of partial and incomplete data, which can only be properly understood through an overarching perspective. To achieve this, creating one or more digital duplicates of the site, incorporating the current state of the site and the previous excavations, which have largely been filled in, is essential if we are to have this overall view.
Depending on the data that already exists, and the accessibility and visibility of the remains, several low-cost 3D digitisation methods that are quick and easy to implement can be envisaged:

- Topography using differential GPS and a tacheometer;

- Photogrammetric surveys of the area by drone (LIDAR is currently excluded for budgetary reasons but remains under consideration) and on ground level (topography, buildings, excavations);

- Lasergrammetric surveys, particularly in underground areas;

- Creation of photogrammetric models from photos (black and white, colour) of previous excavations;

- Using archive documentation (plans, sections, elevations, stratigraphy) to feed a 3D database.

All this data is used as a basis for producing phased reconstructions of the site, using Blender software in particular.
The 3D data is used at various levels:

For a simple visualisation, at different scales and with viewpoints impossible to reach in reality (aerial views, views of underground spaces in their entirety, etc.);

To extract high-resolution ortho-images (plans, profiles, elevations) as a basis for traditional 2D archaeological surveys;

3D is becoming a major asset, enabling the rapid and accurate production of a large number of plans and sections that would be impossible or at least difficult to produce using traditional techniques;

For 3D analysis, whether to produce a DEM or calculate volumes, for example.

Ultimately, they are intended to be integrated into the MUSARNA project's GIS.
For us, any 3D production serves primarily as a tool for archaeological inquiry and reflection, rather than as an end in itself. At this stage of the research, the quality of geometry and geo-referencing is prioritised over textures and the production of 'clean' models, which are difficult to obtain due to vegetation and difficulties in the underground. Leading to the creation of three-dimensional models that are low-quality from an aesthetic point of view, but of extreme importance for the data that can be obtained for archaeological reflection.
The first two years of the Musarna project focused on identifying existing sources and dataset that could be exploited with the digital and 3D tools now available to us, and to assessing the feasibility of this new 3D approach.

The archives from the excavations conducted by the École française de Rome (1983-2003) constitute a rich collection, the inventory and study of which is a major undertaking. The photographs (black and white and colour) relating to the defensive system and the Hellenistic and Imperial necropolises have been scanned. Numerous general views of the excavation areas and monuments, with good resolution and from a variety of viewpoints, were used to produce photogrammetric models which, once scaled and geo-referenced (a lengthy process based on existing topographical data and new surveys), feed into the project's GIS.
On the ground, the initial surveys carried out have enabled us to reinterpret certain remains or landforms and to identify new structures that were absent from the ancient plans, thereby updating the map of the city and its surroundings. A number of photogrammetric surveys have already been carried out by drone (of the entire area for one DEM in particular) and on the ground (of surface and underground monuments), all of which have greatly improved our perception of the site, not only in terms of its topography, of course, but also in terms of roads and traffic flow and the constraints involved in installing masonry structures, for example. The cartography of the city, its necropolises and its territory is also gradually being enriched with new, precise, standardised data, accompanied with metadata.
The 3D reconstruction work is still in its early stages. Starting with the DEM generated by aerial photogrammetry, we are gradually adding the main civil, defensive and funerary buildings in Musarna. These are still only simple volumes designed to provide a better understanding of the general organisation of the site and the relationships between the land and the buildings and between the buildings themselves.

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245. Removing Vegetation from Point Clouds: A Case Study from Bluefish Caves, Yukon Territory, Canada

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Bluefish Caves is an archaeological Site located in northern Yukon about 54 kilometers southwest of the community of Old Crow. It is one of North America's most significant archaeological discoveries for the study of the earliest peopling of the continent via the Bering Land Bridge. Despite its significance, 3D scanning technology for archaeological analysis had never been used for this important site. As a result, we collaborated in an international joint project in the summer of 2024 to use 3D scanning technology to capture the four individual caves and overall landscape of Bluefish Caves. This paper documents the data processing method focusing on 3D model generation through point cloud data obtained using the GeoSLAM ZEB Vision 4K panoramic camera 3D laser scanner on site. Such scanners use light detection and ranging (LiDAR) technology which emit laser pulses and penetrate through vegetation to the surface below. This is a huge benefit to archaeologists as vegetation often obscures important ground-level details. In the case of Bluefish Caves, the diverse types of vegetation obstructed how the caves were perceived and their bare form. Hence, this paper aims to reveal the caves' bare landform formation by: 1) overcoming the challenges of removing vegetation in the cave/rock shelter environment, 2) visualizing the bare landform of the caves by converting the point clouds to 3D models, and 3) examining what these 3D models can be used for in the future.

Inspired by multiple scholars who stressed the importance of removing vegetation that obscured the landform and provided workflow for extracting cave features, we see the significant benefit of removing the vegetation of the Bluefish Caves.[1,2] CloudCompare and Blender were both free open-source software that was used for vegetation filtering, 3D model creation, and final visualization. The workflow of removing vegetation began with extracting the ground floor, followed by initial filtering through the Cloth Simulation Filter (CSF) and further filtering using the combination of rasterization and distance computation tool. Next, a rasterized, single-layer topographic representation of the bare ground was then merged with the subsampled remaining point cloud. Normals were then computed on the merged dataset using triangulation as the surface approximation. Subsequent, using the Poisson Surface Reconstruction plugin in CloudCompare, a mesh was generated and imported into Blender. Extra elements that did not contribute to the model's structure were removed in Blender by using the various functions in the edit mode including Separate by Loose Parts, Deleting Loose Vertices, Fill, and Smooth Vertices. The overall 3D models of bluefish caves that were generated through the experimental workflow of removing vegetation and unneeded elements, provided a highly detailed and accurate representation of the cave's bare landform. The model preserves the rugged textures of the rocky limestone landscape with intricacy walls surface of the cave revealing its structural complexity. In addition to the main "positive" view, users of the 3D model have the unique opportunity to observe the "negative" or back side of the cave model offering a perspective that highlights the outer shape and full structure of the cave formation. For example, the "negative" model of Cave 3 exposed a previously unnoticed connecting tunnel. This tunnel ran from a small hole in the exterior wall to the main interior space of the cave and appears to be clearly identifiable by examining the model from its "negative" perspective. By isolating the cave's primary features and removing any irrelevant geometry, this model presents a focused and comprehensive view of both the interior and exterior complex structural characteristics.

The detailed 3D models of Bluefish Caves created from point clouds might potentially benefit future education, public engagement, and research. These models can be presented to viewers in two ways: 1) through virtual exploration with the use of digital platforms, 2) and/or physical interaction with these models using 3D printing technology. This experience might increase the public's interest in exploring Yukon's paleogeography and the geology of how these caves were formed. Furthermore, it is crucial to acknowledge the archaeological significance of Bluefish Caves. These 3D models may open a gateway for associated Indigenous communities and the public to engage with and explore the past lifeways of the Indigenous peoples and gain greater interest and appreciation for precontact Indigenous cultures. This could be done specifically with the model of Caves 3 and 4, as it showed the archaeological excavation for viewers to examine the models from various angles to grasp complex concepts such as stratigraphy and the archaeological interaction with natural formations. Moreover, these 3D models might have significant implications for research. They may contribute to the analyses of cave systems and assist the studying their structural integrity. For instance, the negative views of Cave 4's excavation pits allow archaeologists to visualize spatial dynamics that could be helpful to excavation planning and highlight important geological features. Also, archaeologists can examine these caves in a new way. With the example of Cave 3's hidden tunnel, the visualization of this hidden connection would have been difficult without the 3D model.

The success of converting complex point clouds into detailed 3D models represents a new way in which we explore, understand, and share the presence of Bluefish Caves. Each model is a direct result of the repetition of the workflow suggested in this paper. This process captures the details of the cave environment, allowing researchers to preserve the caves' features digitally and make them accessible to a wide audience physically and virtually. Finally, these 3D models created a multidimensional learning experience that allows the development of a deeper appreciation for this area's paleographical formations and Indigenous culture, connecting people to Yukon's natural and cultural heritage in a way that is engaging, informative, and accessible.

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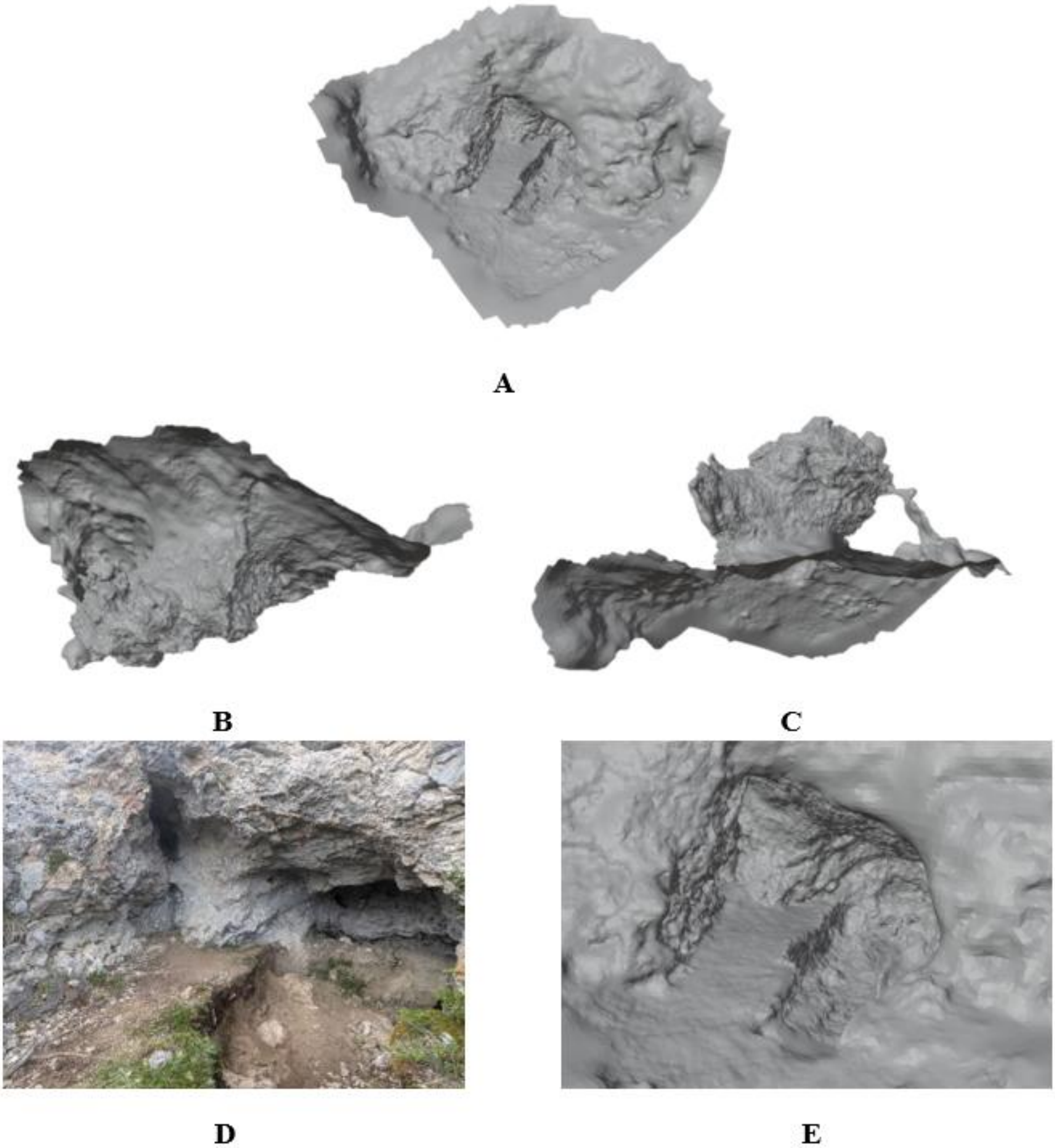

Figure 1. The overview of the Cave 3's 3D model. A) Angled front view of Cave 3; B) Side view of the negative of Cave 3; C) Top view of the negative of Cave 3 showcasing the hidden tunnel; D&E) photograph captured the vegetation at Cave 3 on-site in comparison to its 3D model after the vegetation was removed.

471. Visual Evaluation and Argumentation for 3D Scanned Terracotta Figurines

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Nowadays, precise data acquisition through 3D scanning can be considered a valuable addition to the studies of ancient terracotta (the coroplastic studies), as proven in various research projects (e.g. Rieke-Zapp and Trinkl 2017; Caputo and Mandelli 2023). These publications however focus mostly on one specific application of the 3D medium. At our Lab, we pursue a holistic approach to the 3D medium, comprising the areas of documentation, analysis as well as knowledge communication. This paper presents the methodology developed for a study of a specific type of mould-made nikai figurines, as described below. Accurate 3D scans of various objects form the basis for a visualisation-based investigation, particularly the mesh comparison to identify shared moulds. In addition, reconstruction modelling and simulation were deployed to shed light on their production and use in the burial context, which are not yet properly understood.

The case study consists of Hellenistic terracotta figurines depicting winged female figures (so-called nikai). They have so far only been documented from the necropolis of the city of Myrina in Asia Minor. As is often the case, only very few of these pieces come from secure excavations (French excavations, kept in the Louvre in Paris). Most have been acquired by numerous museums in the art trade since the late 19th century. The figurines were used in sets in the tombs and are characterised by iconographic variability and rich colouring / gilding. There are only a few types of nikai depending on their general habitus and clothing (e.g. the phainomeris type), but although the examples within one type are very similar to each other, there are differences in the used moulds.

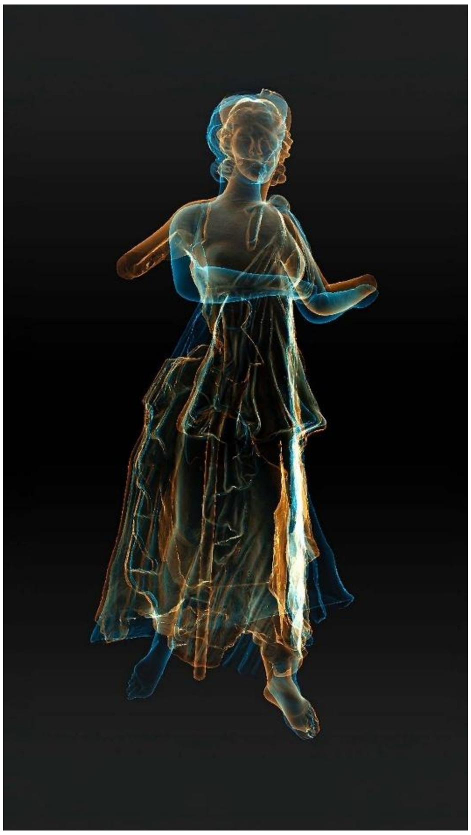
Thanks to the manipulability of the 3D models, the torsos of the figurines can be directly compared virtually, which allows to define series according to moulds used in common. By comparing isolated parts of the arms, feet and heads of different figurines, it shows that they as well are at least partially mould-made. This leads to the conclusion, that the coroplasts repeatedly recombined different individual parts coming from different moulds so that the nikai carried different objects such as masks, drinking pots etc. in completely different arm positions. Besides the working process and wokshop relations in this city, we hope to reconstruct for the sets in usage the specific grouping in a grave – an information which is lost due to the problematic situation of the art trade from the late 19th century onwards, where findings coming from the same grave likely got separated to be sold better.

The comparison of the different 3D scans was achieved through multiple approaches: Through movement during a manual alignment process; by different view modes, e.g. with transparency or so-called “X-Ray” mode; or on a mathematical level through colour maps generated by mesh deviation analysis. Based on the many options, the main question is not on how to do mesh comparison, but rather, how to document and visualise the findings in a way that is well understandable and comprehensible for an audience not familiar with 3D technology, and that is equally suitable for conventional forms of publication, meaning 2D images.

As our solution to this issue, we designed comparative illustrations with a visual language similar to conventional archaeological illustrations. Well combined with screenshots and 3D renderings, they allow the beholder to gain a full image on the interpretation of the artefacts and to some extent a comparison even if original 3D data might get lost.

As these figurines carried wings and had to be hung up (holes are preserved), the question arises as to how they were used in the tombs. Various possibilities of their original use and appearance with wings, attributes, colours and gildings in the funerary ritual must be simulated, in order to better understand the meaning of this set of images at the tombs in Hellenistic Myrina. Thanks to the reconstruction modelling and 3D printing it is possible to test different solutions as much in a virtual environment as well as in the physical world – an opportunity not to be underestimated!
The 3D scans of the nikai figurines formed the basis for detailed virtual 3D reconstructions. The reconstruction model were created based on the knowledge gained through the previously mentioned construction analyses and the study of the object group generally. The reconstruction modelling process itself we understand as an epistemic tool. It makes us aware of gaps in knowledge and supports the development of varying solutions, which can be evaluated and refined on the model in an iterative process. Of course, the modelling process gets thoroughly documented and specific visualisations get created to communicate the interpretation in a clear and transparent way.

To conclude this abstract, 3D scanning helped this project not only to analyse and compare the find objects spread far apart, but to bring research even a step further through the epistemic qualities of virtual reconstruction modelling and the medium of 3D printing. In all this, it is important to continually think on how to document the findings visually and finally, how to create visualisations that communicate them in a comprehensible way. Thankfully, also here 3D visualisations offer a range of solutions, and proves once again the importance of the 3D medium in contemporary research practice.



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12. Filling a hole in the wall: the contribution of 3D reconstructive models to the study of Roman windows (2nd century BCE - 1st century CE)

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Construction archaeology has evolved profusely during the end of the 20th and the beginning of the 21st century, especially regarding the Roman world. Starting with planimetric approaches, studies have then evolved to include construction techniques and preserved elements from the elevations. However, some construction materials, such as perishable materials (wood) or easily recyclable materials (glass, metal) are not preserved very often and have only left traces. It is especially the case for architectural features as windows: their complete preservation is almost impossible as the elevation and the perishable elements all would have to be present and preserved, which is not the case in a vast majority of archaeological contexts. In the Roman world, only Roman Campania contexts preserved the different constructive elements, sealed by the eruption of Mount Vesuvius in 79 CE.
Because of these difficulties, Roman windows have been very scarcely studied in the realm of Roman construction archaeology. The first comprehensive study on the matter was conducted by Lucia Michielin during her PhD in 2019 and published in 2021 (Michielin 2021). In this work, she conducted several studies in luminometry, reconstructing domestic spaces and openings to evaluate the quantity of light. But little has been made on the closure systems and the closure system materials. The various components of the closure, such as wood or glass panels, have sometimes been studied separately but rarely been put together. The aim of this communication is to present different reconstruction of windows and window closures and thinking about the economy being them. How where they made? With what materials? At what cost?
Starting with examples of cities in Roman Campania (2nd century BCE- 1st century CE), the goal of this communication is to propose reconstructive 3D models of various examples of existing windows. Then, using the system of the Extended Harris Matrix (Demetrescu 2015), the aim is to suggest reconstructive hypothesis of closure systems, thanks to archaeological comparison but also to some literary evidences. The idea is then to compare the various closure system hypothesis, evaluating the weight and the resources necessary to build these closure systems. This reflection participate in a broader archaeological reflection about computer based treatment for construction archaeology , how it can be useful to study these kind of objects, but also in what way it can be useful to process issues about construction sites and constructions techniques as a whole (Dessales 2017).

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392. Purpose classification and digital virtual reassembly of unidentified stone structure components based on three-dimensional shape analysis

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Many stone structure components remain in historic areas; however, their origins are often unclear. To determine the historical and cultural significance of these unidentified components, precise examination is necessary. However, physical constrains such as size and weight often hinder such efforts. To address these challenges, three-dimensional (3D) shape analysis and multifaceted interpretation based on digital records are required (Roberto and Maarten., 2020; Yu et al., 2023). In this study, digital shape analysis was performed through 3D scanning, and the functions of each stone structure component were categorized. Additionally, components with geometric similarities and connections were reassembled in a virtual environment to infer the original structure.

Handheld medium-precision scanning was used to capture the overall shape of the components, while handheld high-precision scanning acquired detailed pattern data. The scanned data for each component were aligned, merged, and optimized to create high-quality polygon mesh models. Drawings were then created to classify the architectural purposes of the components based on their shapes.

As a result of the classification, 24 bridge components and 31 architectural components were identified. The bridge components were further categorized into 2 arch bridge parts and 22 flat bridge parts, displaying features consistent with wooden building construction methods. The architectural components were classified into 10 architectural foundations, 16 bases of buildings, and 5 stair elements. Additionally, three other stone components had unclear purposes.

Traditional physical reassembly methods pose a risk of secondary damage to cultural heritage. Therefore, digital technology was employed to virtually join and reassemble the components without causing harm. The joining faces were visually inspected, and trends in alignment were identified by virtually positioning the 3D models. Depth information of the matching faces was visualized to facilitate a face comparison analysis. A 3D bridge model was subsequently created based on these analyses and corroborated with historical evidence. This virtual reassembly resulted in the identification of 22 flat bridge components, including 10 bridge pier bases, 2 bridge piers, 1 sleeper stone, 2 floor frame stones, and 7 floorboard stones. Models with two and three lines of bridge pier bases were created, adhering to historical evidence. Since physical data such as weight and material density were unavailable, interference issues were addressed in virtual space, and physical contacts were tested using 1/10-scale 3D-printed models.

Through digital recording and shape analysis, the specific uses of 94.8% of the 58 unidentified stone structure components were determined. The classification results enabled the analysis of structurally complex components in a virtual environment, overcoming physical constraints to reconstruct the shape and scale of the bridge. This study demonstrates the broad applicability of digital technology in recording and analyzing the geometry of stone structures. The methodology is anticipated to be effective in evaluating the historical value of heritage assets that are challenging to handle due to material, size, or structural limitations.

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387. Virtual positioning and restoration of Chimi (ridge-end tiles) excavated in Mireuksaji Temple Site using three-dimensional scanning and printing

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Chimi are decorative tiles located at the ends of a roof's ridge and serve as significant historical artifacts for determining the dimensions and architectural characteristics of ancient buildings. Hundreds of Chimi fragments have been unearthed from the Mireuksaji Temple site in Iksan; however, they remain unrestored and stored in their fragmented state. To reconstruct the original forms of these fragments, virtual modeling and noncontact digital recording techniques are essential (Jo et al., 2020; Adamczak et al., 2024). Additionally, restoration efforts should prioritize artifacts with a higher number of preserved pieces. This study employed three-dimensional (3D) recording techniques to document the excavated Chimi fragments and recreated their original positions in a virtual environment. Customized restoration principles were established based on the unique features of each Chimi, enabling the virtual restoration of missing components.

The first key process of Chimi restoration involves selecting fragments suitable for physical reconstruction. To achieve this, fragments were assessed for compatibility through shape analysis using 3D scan data, visual inspection, and descriptive investigations. The fragments were categorized into three grades: Grade A, fragments that can be directly connected and whose original locations can be identified; Grade B, fragments whose locations can be estimated but cannot be directly connected; and Grade C, fragments whose original locations and connections cannot be determined. Analysis revealed that the upper section of the Chimi included 8 Grade B fragments, while the lower section comprised 17 Grade A fragments and 1 Grade B fragment.

The curvature and fracture surfaces of these fragments were meticulously analyzed and virtually positioned. Joint compatibility and morphological consistency were examined, followed by physical verification using 3D-printed outputs of the fragments. Reference modeling of the remaining Chimi fragments guided the restoration process. For missing asymmetrical parts, similar Chimi cases served as historical reference material are utilized for the restoration.

As a result of the virtual restoration process, approximately 75% of the total volume of the upper section and 48% of the lower section were reconstructed. A total of 54 out of 124 Chimi fragments were virtually positioned using 3D scanning and printing technologies. The missing sections were restored to near-complete form through historical evidence-based modeling. The data and outcomes generated through this process are semipermanently stored and can be updated or refined when additional joinable fragments are identified.

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195. Environmental Ethics for Digital Archaeology: Applying the GREENER Principles to Archaeological Computing

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Sustainable archaeological research today relies on the ability of communities and institutions to work together to integrate a variety of analog and digital methodologies for conservation, education, and documentation. Science, and archaeology by extension, is generally a public good, but requires macroethical guidance in order to fulfil that ideal and not become a social detriment [1]. Archaeologists have recently begun adapting ethical frameworks such as the FAIR, CARE, and TRUST principles to digital methodologies such as remote sensing and open-access data management. However, these standards do not directly address the potential negative impacts of archaeological research on the natural environment, which is rapidly becoming the greatest macro threat to communities and their built heritage.

Digital documentation affords a range of techniques that support broad geographic coverage and dissemination of results, but as data-rich methods of recording archaeology such as LiDAR, photogrammetry, and Very-High-Resolution satellite imagery interpretation expand in use, alongside the growing number of documented resources globally, both vertical and horizontal scalability become essential concerns. Growing computational and storage requirements increase both embodied carbon emissions and raw material extraction, impacting the environment and contributing to anthropogenic climate change. Similarly, duplication of digital documentation efforts can produce redundant datasets, frivolous resource consumption, and, ultimately, unnecessary strain on the natural environment. In turn, increasingly extreme climatic activity presents further long-term risk to archaeological remains and immovable cultural heritage.

Considerable energy consumption and material extraction are required to support the rapid growth of archaeological data creation and storage. Given the ethical and practical imperatives to address anthropogenic climate change, we argue in this paper that the field of digital archaeology should now expand its purview in order to consider the environmental implications of deploying advanced technologies. The newly published GREENER principles (Governance, Responsibility, Estimation, Energy and embodied impacts, New collaborations, and Research) offer guidelines for scientists to minimize their carbon footprint and mitigate their overall environmental impacts [2]. In order to pursue a more ethical digital archaeology, this paper explores how we might embrace such a framework and avoid becoming a net social detriment.

Our methods include problematizing the application of each GREENER principle to digital archaeology by approaching it in terms of logistics and ethical value. We consider case studies where applicable, such as using the Green Algorithms tool [3] to estimate the embodied carbon emissions of common computational archaeology processes. These estimations provide data indicating in which countries heavy computing might produce greater or lesser carbon dioxide emissions, supporting environmentally ethical decision making in digital archaeology. We furthermore consider the potential for synergy between GREENER and other frameworks such as FAIR and CARE.

Ultimately, this paper proposes that digital archaeology is both a key culprit of environmental impacts and one of the archaeological specializations best positioned to mitigate those by applying a set of guiding principles. It explores the energy consumption of digital storage and computational analysis in order to better understand how to develop digital systems for collecting, storing, and analyzing archaeological and cultural heritage data in concert with the GREENER principles. Going further, it considers the possibility of building a meta framework for digital archaeology that integrates and synergizes various ethical standards. In doing so, it explores modes of archaeological digitalization that engender technical, social, and environmental sustainability.

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68. Digital Diplomacy Leveraging social media for archaeological and Buddhist tourism in Pakistan

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Pakistan, home to numerous Buddhist heritage sites, including Taxila and Takht-i-Bahi, faces challenges in attracting international tourists. Digital diplomacy through social media offers a viable solution. However, it raises ethical concerns regarding cultural appropriation, misrepresentation, and exploitation. This study explores the potential of social media platforms in promoting Pakistan's Buddhist heritage and tourism while navigating these ethical complexities.

Objectives:

1. Investigate effective social media strategies for heritage tourism promotion that prioritize cultural sensitivity and accuracy.
2. Analyze target audience engagement and preferences to ensure respectful representation of Buddhist heritage.
3. Examine collaborations with influencers and travel bloggers that adhere to ethical guidelines.

Methodology:

1. Social media analytics tools will be employed to track engagement and sentiment analysis.
2. Surveys and focus groups with tourism stakeholders, local communities, and Buddhist scholars will inform the development of culturally sensitive content.
3. Case studies of successful digital diplomacy campaigns will be analyzed through the lens of ethical frameworks.

Theoretical Framework:

This study is grounded in the discourse on digital ethics, cultural heritage, and tourism studies. Key concepts include:

- Cultural appropriation and representation (Harrison, 2013; Watkins, 2005)
- Digital diplomacy and soft power (Nye, 2004; Cowan & Arsenault, 2008)
- Heritage tourism and community engagement (Timothy & Boyd, 2003; Jamal & Getz, 1995)

Expected Outcomes:

1. A framework for promoting Pakistan's Buddhist heritage through social media that prioritizes cultural sensitivity and accuracy.
2. Insights into effective collaborations with influencers and travel bloggers that adhere to ethical guidelines.
3. Recommendations for policymakers, tourism boards, and stakeholders on harnessing social media's potential while navigating ethical complexities.

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121. Heritage Sovereignty: Holistic Approaches to Digitization of Esoteric Indigenous Cultural Heritage

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Introduction

In my recently completed master's thesis, I explored holistic approaches to the digitization of esoteric Indigenous cultural heritage, specifically focusing on the North Sámi communities in Norway. As museums and cultural repositories are increasingly utilizing novel technologies (see Magnani 2014) for documenting cultural heritage, the thesis examined the implications for Indigenous sacred heritage in the digital era. Through a case study method, the study emphasized the importance of culturally sustainable practices in three-dimensional (3D) heritage management.

I investigated how the integration of 3D technologies in cultural heritage management is transforming museums and cultural repositories, particularly within Indigenous heritage contexts. My research focused on the use of 3D technologies in Indigenous RUOKTOT exhibition production in Northern Norway, among the North Sámi communities. A key aspect of this exhibition was digital representation of ancestral Sámi drums, confiscated from various Sámi communities during the 1600s and 1700s. Through digitizing these drums, the exhibition explored complex cultural and ethical considerations involved in creating 3D digital representations of ancestral Sámi heritage.

The thesis highlighted the foundational aspects related to digitizing Sámi cultural heritage, addressing matters, such as community access to and control over cultural data, open-access to 3D models of esoteric Indigenous heritage, ethical responsibilities in the digitization process and the broader implications of 3D technologies in heritage management. The study also emphasized the importance of cultural protocols regarding digital representations of Indigenous heritage—a critical aspect that is often overlooked in conventional guidelines.

Methods and Materials

This research employed a qualitative case study approach to examine the RUOKTOT exhibition, focusing on the integration of 3D technologies in the context of Indigenous heritage. Guided by Indigenous methodologies, this approach honored

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Sámi cultural perspectives, emphasizing community engagement and ethical practices in digitization. Central to this research were the interviews and focus group discussions with a total of seven research partners, including Sámi community members, 3D technology and heritage experts. They provided key insights on digitization, ethical considerations, and cultural protocols. The RUOKTOT exhibition was chosen as a case study due to its status as one of the first Sámi museums to display 3D digital representations of Sámi drums, achieved through the use of 3D laser scanners. The thesis is grounded on theories from Indigenous research, by employing ontological approach to Indigenous Sámi cultural heritage (Virtanen et al., 2021).

Results

Photographs have long held an established role as 2D documentation method in the documentation of museum collections. These photographs are often published across various platforms, making them accessible to global audience. In Norway, 2D images of ancestral Sámi drums are available on multiple digital platforms, such as DigitaltMuseum and the websites of various Sámi museums. While these esoteric photographs are typically protected by copyright laws and IPR and governed by guidelines established by Sámi museum institutions, users are advised to handle them with caution and refrain from commercial use or unauthorized distribution. Despite these protections, the cultural commodification of Indigenous Sámi heritage continues to rise. Esoteric elements of Sámi cultural heritage, such as the Sámi drums, are increasingly appropriated by manufacturers and local businesses at rapid speed.

While documentation technology has evolved rapidly, it has also raised concerns among local Sámi communities and museums. The possibilities offered by 3D technologies present challenges to Indigenous Sámi communities, museums, and heritage repositories in protecting esoteric cultural heritage in an era of open access and increasing cultural commodification. It is crucial to examine the ways and mediums through which unrestricted open access shapes these markets—placing esoteric ancestral Sámi drums in vulnerable position in the evolving digital era.

While various white papers and guidelines on ethical responsibilities and 3D methods in cultural heritage are being established, there is no mandatory policy on how to approach, handle, digitize, and manage the captured data of Indigenous esoteric cultural heritage. Customary law should be integrated into all aspects of digitization practice, rather than treated as a voluntary element.

The findings indicate that digitization serves as a valuable method for preserving and visualizing Sámi heritage, but raises ethical considerations regarding its

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management and use. The discussions with research partners highlighted the need for collaborative frameworks between Indigenous communities and museum institutions to ensure culturally sustainable practices in 3D heritage management.

Future research endeavors could explore Sámi communities' interpretations of community management of captured data and examine how customary law could help mitigate cultural commodification.

The thesis explores the potential of Indigenous data sovereignty to deepen understandings of esoteric Indigenous cultural heritage. The research findings uncover the material networks of ancestral Sámi drums from the 1600s and 1700s, which hold significant spiritual value for Sámi communities in Norway. At the same time, these drums have become highly contested symbols of cultural appropriation in contemporary Norway. Safeguarding and protecting these drums from misuse in the era of 3D technologies and open access presents challenges, which local Sámi communities and Sámi museums are addressing together.

This safeguarding process begins at the earliest stages and encompasses the entire workflow—from preparing esoteric cultural heritage for digitization projects, to managing cultural data and deciding whether or not to publish the material to global audience. Such efforts require close collaboration and guidance from local Indigenous communities.

Unrestricted access to 3D models of esoteric Indigenous heritage exposes a complex landscape of appropriation, placing esoteric heritage in a vulnerable position. Granting Indigenous communities and Indigenous-led museum institutions the authority to decide on open or restricted access to these 3D models represents an impactful way to formalize Indigenous agency as a mode of governance.

The thesis further demonstrates that understanding the complexities involved in creating 3D digital representations of Indigenous esoteric cultural heritage can support Indigenous efforts to self-determine representations and safeguard esoteric materials.

Discussion

The study highlights the importance of thoughtful engagement with stakeholder communities and cultural heritage, prioritizing the perspectives of the communities from which these heritage materials originate. This approach not only enriches the dialogue on Indigenous data sovereignty and cultural rights regarding esoteric heritage but also addresses the role of technology in preserving and revitalizing Indigenous cultures. By recognizing cultural rights, meaningful partnerships can be fostered between museum institutions and communities, ensuring that Indigenous heritage remains relevant and culturally sustainable in the contemporary digital era.

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541. Shape Machine: a vector-based shape search software in the documentation and reconstruction in archaeological research

Myrsini Mamoli (Georgia Institute of Technology)*; Athanassios Economou (Georgia Institute of Technology)

Vector drawings and models provide a primary means of representation for the documentation of archaeological findings and their reconstructions. 2D CAD models including plans, sections and elevations, tracing the analog lines of some original sketches, or constructed from scratch, and 3D CAD models produced by the lidar scanning of artifacts and their capture in point clouds continue to provide a primary visual documentation for both the found fragments or the hypothesized initial or the inbetween/transformative stage of a given artifact at various scales– ornament, building or city. And yet, these 2D or 3D CAD models are impenetrable to any visual inquiry or shape search – except the very primitive shapes that are used to construct them. The problem is not trivial: A shape, a profile, a detail cannot be found unless it is already recorded in the database of the digital model. And yet, by definition, the spatial elements recorded in the 2D/3D database of an in situ model are fragmented. Is there a possibility that the fragments of aligned line segments constitute a frieze, a pedestal or a pilaster? Is there a possibility that the fragment of a curve or a series of arcs make a circle or a conic? More severely —even for reconstructed 2D/3D models featuring pristine CAD geometry— is it possible to search for embedded shapes in an ornament or architectural detail if they have not been recorded as such in the database? And if we cannot search for them, surely we cannot replace them with other motifs to try out possible variations and critically expand our interpretation of the given evidence. The current work provides a brief overview of Shape Machine, a new vector-based shape rewrite technology developed at the Shape Computation Lab at the Georgia Institute of Technology, and currently integrated within Rhinoceros, a NURBS 2D/3D CAD software, that offers visual search and replace capabilities in the CAD documentation and reconstruction of archaeological artifacts. Significantly, this shape-rewrite computational system combines its native shape-based operations with a logical processing framework including states, loops, jumps, and conditionals to allow literally write programming code by drawing shapes offering thusly an unprecedented and sophisticated technology for creative queries and modeling in CAD representations in archaeology research. Several examples drawn from various scales in archaeological research including CAD models of existing or reconstructed artifacts at various scales– ornaments, buildings or city plans are given to suggest the possibilities this technology enables.

301. Development of a 3D Scholarly Edition: Reconstruction of the Düwelsteene using the Pure3D Infrastructure

Louise Tharandt (Humboldt-Universität zu Berlin)*

The Düwelsteene megalithic tomb represents one of the southwesternmost surviving passage graves of the Funnel Beaker culture. Excavated and restored in 1932 by the local history association of Borken under the supervision of August Stieren, archaeologist and director of the department for prehistory at the State Museum Münster, the physical reconstruction of the tomb reflected contemporary interpretations and methodologies. However, these approaches often altered the authenticity of such a site and left unanswered questions about its original appearance and function. In 2017, as part of the Antiquities Commission for Westphalia Megalithic Project (Altertumskommission, Landschaftsverband für Westfalen-Lippe), the Düwelsteene tomb was digitally recorded using image-based modeling, resulting in a detailed 3D model that serves as a baseline for ongoing research and public dissemination.

A citizen science initiative took place in 2020 and the results played a pivotal role in reconstructing the historical appearance of the Düwelsteene. During the initiative, residents of the surrounding areas were invited to contribute photographs and other archival materials from before 1932, which provided crucial data for reconstructing the tomb as it might have appeared before its restoration. These efforts enabled the creation of additional 3D reconstructions depicting the Düwelsteene in two key historical states: its condition prior to the 1932 excavation and its likely configuration around 3000 BCE, during its active use as a burial site.

As part of a master's thesis, these three 3D models—representing the tomb in 2017, 1932, and 3000 BCE—were developed, analyzed, and integrated with detailed metadata and contextual information. Initially, these digital resources were presented through a dedicated project website, designed to provide access to the models for researchers and the public. While functional, this approach revealed limitations in scalability, interoperability, and the ability to link 3D data with other forms of scholarly outputs.

The models were later integrated into the Pure3D infrastructure at Maastricht University, a platform developed to support the curation, contextualization, and dissemination of 3D objects. Pure3D aims to establish a robust digital ecosystem for 3D-supported research, enabling the integration of 3D data with accompanying textual, visual, and interpretive materials. Smithsonian Voyager was selected as the 3D viewer, offering a dynamic, interactive experience that has been continuously refined based on feedback from this project. Using this platform, the Düwelsteene project introduced curated tours and annotations that guide users through the history of the Düwelsteene, its archaeological significance, and digital reconstruction process. This approach bridges the gap between complex scientific outputs and accessible public engagement, demonstrating the potential for broader applications across disciplines.

This project illustrates not only the technical and methodological advances in 3D modeling but also the challenges of effectively presenting and reviewing such data within academic and public domains. By comparing the workflows of standalone websites and structured infrastructures like Pure3D, this study highlights the need for standardized frameworks that promote collaboration, peer review, and long-term accessibility. The integration of the Düwelsteene models into the Pure3D infrastructure underscores the potential for 3D-supported research and publication to enhance interdisciplinary collaboration, scientific transparency, and community engagement.

This paper will provide a detailed overview of the workflows and challenges encountered during the creation and publication of the Düwelsteene 3D models. It will also explore the broader implications for future research in archaeology, digital humanities, and public history, offering insights into the evolving role of 3D infrastructures in these fields.

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380. Building a system for disseminating 3D cultural heritage models. Some challenges and solutions.

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This presentation describes an ongoing project focused on building a system for disseminating information of cultural heritage (CH) 3D models. The benefits of this system are conspicuous in the context of galleries, libraries, archives, and museums (GLAM), where it is necessary to find and retrieve 3D models from large collections. Specifically, the presentation shows the implementation of the first module (MeshAnalizer) of a system called ArcheoShape, based on three types of shape descriptors and four dissimilarity measures that facilitate the matching and retrieval operations. The module functions as a search engine that instead of using keywords recognizes objects automatically by comparing their numerical shape descriptions. Though the system works with good level of success, there are still two basic limitations that we planned to address as the project advances, namely the lack of mechanisms to segment and annotate the models. These challenges are present in the development of any 3D data management system and we are convinced that reviewing state-of-the art solutions can benefit the CAA community.
Segmentation and annotation can be performed either through manual procedures - a time-consuming effort - or with semi-automatic tools. Some successful projects are reported in the field of architecture. For example, manual segmentation and annotation through interactive software has been developed for managing thousands of condition reports, architectural descriptions, chemical and physical analysis generated during the restoration of Notre Dame Cathedral (Roussel & De Luca, 2023).
Though no ideal solution exists yet, some semi or automatic segmentation techniques based on deep-learning methods are promising (García-García et al., 2017). Deep-learning algorithms, however, focused on segmenting objects according to their geometric properties, regardless if these have a semantic meaning for the final user (Attene et al., 2009). Cultural heritage objects are particularly challenging for this kind of approaches, because contrary to architecture in which parts of a building (columns, porticos, doors, windows etc.) have certain standard structures, artefacts y objects in general present an enormous diversity of features, which complicates the recognition task. Also, the techniques have to account for the fuzziness in the boundaries of those features. As Attene et al. (2009) point out: "... in a human body model the neck may be considered part of both the head and the torso". To complicate matters further, the training of deep-learning models relies on the availability of massive amounts of data, a condition rarely met in cultural heritage applications, though this limitation can be reduced with transfer-learning, an approach in which the recognition capabilities of a model trained with massive generic data are extrapolated to analyse a smaller sample of data.
The presentation discusses these issues and compares solutions developed in the field of deep-learning that can be applied for the effective dissemination of 3D cultural heritage models.

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127. From the Map to the 3D Model: Franz Kreuter's Topographical Collection as a VR Application

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Project Background

The “Topographical Collection” by Franz Kreuter is kept in the Historical Archive with the Rhenish Image Archive of the City of Cologne. It is also known as “Kreuter's maps” for short. The maps show individual streets and squares in Cologne with the facades of the adjacent houses in outline. Numerous annotations provide further information on each building. The maps have long been recognized as an important source for Cologne's city history, but they are still not in depth researched and hardly known to the public. Researchers must treat the delicate, sometimes large-format documents with great care. Some rows of houses are merely pasted on with a narrow strip of paper. However, this also allows them to be carefully folded up. This quasi 3D feature gave rise to the idea of digitally erecting the facades of all the buildings and creating a 3D model from Kreuter's maps. This model was to be presented in an exhibition in the Historical Archive of Cologne from October 2023 to March 2024, which had Cologne's urban development as its theme and in which the Topographical Collection was shown as a central object (Wendenburg 2023). In order to make the project available as a practical part of a scientific qualification thesis, the archive approached the Chair of Computational Archaeology at the University of Cologne. There I was lucky enough to be entrusted with this project and in my Master's thesis I looked at how the maps can best be digitally represented and published under the conditions of limited time and resources (Lammers 2024).

The Source Material and Used Software

Kreuter's topographical collection comprises 112 physical documents, 89 of which show the particularly relevant house facades. They also contain information on parish districts, house numbers, house names, changes of ownership and businesses. No study of the historical context of the maps was available at the start of the project. While the maps were digitized in high resolution, the initial focus was therefore on background research on Franz Kreuter and the aim of his work.

The 3D modeling program Cinema 4D was then used to cut out the rows of houses, virtually erect them and place them next to each other. As the 89 maps do not depict the entire topography of Cologne, placeholders were inserted in the undocumented, open spaces. In accordance with the London Charter and its specification for archaeology, the Seville Principles, these additions were designed in such a way that they can be clearly distinguished from Kreuter's drawings.

Virtual reality was chosen as the medium for presenting the model in the exhibition. Four Meta Quest 2 headsets were provided by the Historical Archive for this purpose. The VR application was developed in Unity. In parallel, I developed a desktop version of the application, initially only for evaluation purposes, as well as a short information video.

Results of the Project

The results of the historical research suggested that the maps were produced between around 1850 and the end of 1857. Franz Kreuter criticized other researchers of his time for neglecting certain aspects and focusing on the history of nobility and clergy. He evidently tried to fill these gaps with the Topographical Collection by himself and to document as much of the town's secular medieval buildings as possible. As a consequence, the written annotations are just as important as the graphic representations and absolutely must be integrated into the 3D model and the VR

application. The VR application was ultimately very well received in the exhibition and the information video also found a place there, although it wasn't originally planned to be in it.
The latter is still available on YouTube after the exhibition (https://www.youtube.com/watch?v=IhEugtEpMKc). Both applications are published in Zenodo, with the number of downloads of the desktop application quickly surpassing that of the VR app. This indicates that publication via various media is more sustainable in the long term.
The 3D model itself was published via the specialist information service BauDigital. An upload in GLTF format was possible there. Its JSON structure made it possible to write Kreuter's annotations directly into the 3D data of the model using a Python script.
All project data was also long-term archived at the University of Cologne's Regional Computing Center.

Dissemination of the 3D-Data
There are numerous examples and published studies on the use of VR in museums (Kimmel et al. 2020). However, no published projects could be found in the context of archives. Archives have a special status in Germany. They are required by law to protect sources and at the same time make them accessible to the public. Museums and other cultural institutions do not have this explicit legal mandate. Archives are therefore faced with a difficult conflict of objectives, which probably can be remedied by digital media.
Nevertheless, the Historical Archive of the City of Cologne has no means of securing the various digital formats created in this project and making them available to other researchers under the FAIR principles. Other repositories therefore had to be found that were easily accessible and could be used free of charge, not just because of the limited duration of the project. The most difficult part was choosing a suitable repository for the 3D model. Sketchfab could have been used as an alternative to BauDigital. From Sketchfab, models can be added to Europeana, enriched with metadata using an additional tool. However, this important metadata is missing in the actual data repository. For this reason, Sketchfab was not used. In the end this project serves as a significant step in making the valuable yet delicate historical materials of the Topographical Collection accessible to the public in a sustainable digital form, while carefully balancing the preservation and accessibility requirements inherent to archival work.

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446. Connectivity and Mobility in the Early Bronze IV of the Southern Levant: Social and Spatial Inquiries into Mortuary Landscapes

Tucker Deady (University of Toronto)*

Discussions of urbanization during the Early Bronze Age (EBA) tend to revolve around an urban-rural dichotomy, in which the EB III to IV periods witnessed a stark transition from urban to rural settlement systems. Recent EBA scholarship has advocated for a more nuanced understanding of temporal, spatial, and social networks, one less defined by division and instead by concepts of integration, communities of practice, and kinship (Chesson and Philip 2003). However, there remains a lack of collaborative, multivariate approaches in which both quantitative and qualitative methods are considered.

This paper aims to contribute to conversations of integration by giving insight into alternative trajectories of connectivity and mobility through the lens of EB IV mortuary practices. It likewise discusses exploratory measures one might take to widen their methodological approaches to best address the questions at hand while accounting for issues of missing data, bias in the archaeological record, and uncertainty in methodological approaches to analysis. I demonstrate a range of methods, the benefits of them, and interpretations of their results. At the heart of the conversation is the importance of mixed methodology and the need to compare the variation in results to ensure that we are using the right methods for the right research questions and types of data.

In applying statistical, social, and spatial analyses to EB IV tomb data, this paper tackles these disparities at intra- and inter-site scales utilizing tomb material, architecture, and geographical attributes. The high level of EB IV mortuary data representation in published material, the often-complete nature of burial assemblages, and the broad spatial distribution of excavated and surveyed mortuary landscapes provide a particularly fruitful foundation for conducting case studies. Data reduction techniques reveal patterns at different spatial scales providing a better understanding of communities of mortuary practice throughout the Southern Levant. Mortuary procedures function as examples of place-making routines, processes which contribute to the memories inscribed on a landscape that become evident in the archaeological record (Porter 2016).

My dataset incorporates information from over 1400 tombs from 85 sites including the cemeteries from Khirbat Iskandar, Bab adh-Dhra', Tell es-Sultan, Tiwal esh-Sharqi, Dhahr Mirzbaneh, Tell el-Mutesellim, and Tell ed-Duweir. A wide range of elements from ceramics to plants, beads, metals, chipped stone and architectural and environmental factors are incorporated in my studies which use this multivariate data to employ statistical analyses. The data is first analyzed at the intra-site scale through correspondence analysis and hierarchical clustering. Results of these evaluations indicate possible "tomb types" based on similarity measures. These results guide further data reduction techniques and reveal patterns at different spatial scales. The intra-site perspectives serve as the foundation for larger-scale examinations of EB IV mortuary landscapes, which, in turn, give significant insight into communities of practice and offer indices for comparisons in subsequent research.

Finally, I examine the material at the inter-site scale by applying a range of results of cluster analyses to network models. These are first assessed using similarity models based on material culture and tomb architecture and are further examined by adding geological and landscape variables. Next, a spatial component is analyzed to question the dependence of these networks on physical proximity, accessibility, and movement (Mills et al 2013). Likewise this evaluates the assumption that sites with obvious physical connections are more likely to express similarity in material culture.

Traditional academic accounts would suggest that the Early Bronze IV is marked by a breakdown in communication, trade, and complex interactions, trends replaced by isolated groups that lost touch with the nucleated centers of previous years, and lacking the elements of Childean definitions of what an 'urbanized' society looks like, most often relying on architectural markers to distill the entire Southern Levant into a single, cohesive narrative. Instead, we need to consider concepts of integration, ancestral memory, and movement and ask how these may have played a role in the ways people interacted and how this connectivity may be expressed in the archaeological record. The methods reviewed in this paper help shed light on the reality of both differentiation and similarities, the results of which display that the EB IV is highly dynamic and cannot be explained by drawing boundaries or ticking boxes. Furthermore, this mixed methodology has the potential to not only test hypotheses, but also question the validity of certain methods by comparing their results. This is not intended to eliminate methods from the repertoire, but instead help further refine the models used to best suit the data at hand.

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189. Collectivity in Death: Practice, Variation, and the Emergence of an Urban Collective in EB I Tombs at Bab adh-Dhra', Jordan

Megan Nishida (University of Notre Dame)*

The Early Bronze Age (EBA), c. 3700-2000 BCE, is characterized as the emergence of urbanization in the Southern Levant. People aggregated into larger, denser walled towns and cities with civic architecture and urban planning, intensified agricultural technology and output, and complex, communal mortuary rituals (Philip 2001). Agglomeration into these new urban spaces impacted every level of social interaction. Recurrent practices are central to how people build, maintain, and pass down social relationships and organization. Analyzing variation in mortuary practices over time is a critical window to understand the shifting ways people organized themselves during the first experiments in urbanism in the Southern Levant.

At the site of Bab adh-Dhra', Jordan, the people of the Southern Ghor established a shared mortuary center during the EB I period, c. 3700-3050 BCE. Over the course of using the cemetery together, people settled permanently at the site, eventually constructing a walled town in the EB II-III period, c. 3050-2500 BCE. The EB I tombs at Bab adh-Dhra' are a material record of how the people in the region related to one another within the context of their shared landscape before permanent settlement. I investigated grave goods, tomb construction, and treatment of the dead from the EB IA and IB tombs to explore similarities and differences in mortuary practices, with an eye to identifying communities of mortuary practitioners. I hypothesized that increasing similarities in funerary practices may be evidence for other social and economic ties between groups in the Southern Ghor, setting the stage for smaller groups to aggregate together to form a permanent town on site.

I used correspondence analysis to visualize the relationships between individual tombs and variations in mortuary practices and material culture. I compared the results to ceramic typologies from contemporaneous stratigraphic contexts to determine whether variation is a result of purposeful differences in practices between groups or if it is a result of stylistic change in material culture across time (Kintigh, Glowacki, and Huntley 2004; Bill 2009). The results of the correspondence analysis were then compared with spatial relationships between tombs.

The results indicate a complex relationship between group differentiation in mortuary practice and chronology. While some of the variation present in the CA was likely related to the natural progression of ceramic typology over the hundreds of years of cemetery use, there were specific choices in tomb architecture and types of grave goods that may speak to similarities or differences between mortuary practitioners. The use of CA in ceramic seriation is known but this research provides another avenue to explore how evidence of variation in human practices, and therefore social organization, may be recognized through the material past.

This paper uses statistical and spatial analysis to explore the complex interaction between groups of people during the critical emergence of urbanism in the EBA. Periods of transition – nomadic camp sites to sedentary villages, small villages and towns into aggregated cities, cities to abandonment – are lynchpins in archaeological research, representative of larger transformations of life-ways, technology, social organization, and subsistence practices. This paper contributes to this discourse by investigating the underlying human practices and relationships that the foundations of those larger social transformations.
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521. Understanding City Planning in Syro-Anatolian Cities

Zeynep Kuşdil Sak (University of Toronto)*

The built environment of the Iron I and II periods (1200–700 BCE), often misrepresented as a "Dark Age," has recently come under scrutiny to illuminate the complex political and social realities of Syro-Anatolian city-states. The ruling factions of these city-states used building programs in their main cities to justify their existence and authority. After the dissolution of the Hittite Empire and the decline of centralized Anatolian power, the empire's peripheral administrative structures (e.g., viceroyalties) fragmented into smaller polities (Weeden 2023). This region roughly corresponds to southeastern Turkey and northwest Syria.

These city-states have historically been understudied as surrounding regions and empires have attracted more scholarly attention. However, new excavation projects, improved research methodologies, and better data are addressing this gap. This period and region are particularly compelling not only because they are understudied but also because these city-states, despite being surrounded by larger powers (e.g., Neo-Assyrian, Urartian, Phrygian), persisted and developed their own complex cultures. The use of sculptural art, particularly relief orthostats, likely served to link these city-states to the legacy of the Hittite Empire, thereby legitimizing their political entities (Hawkins 1982; Harmanşah 2011).

Previous research on Syro-Anatolian city-states has focused primarily on sculptural art. However, understanding the structuring of the city, especially in the ceremonial center where most of the rituals took place through the integration of architectural practices with visual representation and inscriptions in city planning, remains underexplored. The inhabitants of Syro-Anatolian cities created complex settlements where monumental architecture (e.g., palaces, temples, gates), burial sites, sculptures, relief orthostats, and inscriptions contributed to a cityscape rich in visual narratives. Scholars have interpreted these narratives as reflecting themes of power, lineage, kinship, and ancestor veneration.

My research examines how these narratives were embedded within urban planning through the use of mortuary installations. I call them mortuary installations because no bones or mortuary inclusions have been found in these burials. They look like burials but seem to be commemorative and ancestral mortuary installations. Using methods such as Space Syntax and Viewshed analyses, I investigate how spatial configurations, combined with mortuary, architectural, textual, and artifactual evidence, shaped the intended experiences of these cities. Space syntax analysis is a series of graphical representations and quantitative analyses that look at buildings or settlements and analyze how people move through their smallest units –rooms in buildings or spaces/streets in settlements (Hillier and Hanson 1984: 66, 81; Hillier and Vaughan 2007: 206). The analysis provides a look into how people used the space, which in turn provides insight into what this space may have been (public vs. private). At the same time, viewshed analysis is applied to understand what was visible from a particular point in an environment in our context the built environment within the settlement. This multivariate approach is essential, as the material remains, especially in conjunction with this central mortuary installation, provide social cues that shift the perception of the city's narrative depending on the viewer's perspective. By analyzing these narratives, I aim to provide new insights into Syro-Anatolian political organization, specifically how ruling elites used the built environment, specifically a central "grave" within the settlement, to construct historical narratives centered on their authority and ancestral heritage. I discuss that this burial found in the ritual center of the settlement and rituals, imagery, and related construction created the archaeological context we find today. These burials created the nexus of power for the ruling family to create narratives around the ancestral figure, both physically within the city and visually through imagery on orthostats, to convey deep connections.

I propose that these narratives they were trying to convey were multivocal, varying according to the viewer's physical position (e.g., approach to the ceremonial center) and social status (e.g., elite, inhabitant, visitor). The few excavated Syro-Anatolian sites suitable for such analyses, including Karkemish and Tell Halaf, reveal distinct levels of communication between visitors and the city. Preliminary findings suggest that these interactions often centered around this central grave in the ritual core of settlements. By integrating the methods mentioned above with rigorous archaeological approaches, I argue that we can better understand the ideological motivations that shaped the urban layouts of these settlements of Syro-Anatolia.

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50. QuantWealth, a multivariate approach to modelling grave wealth display and inequality

Mikkel Nørtoft (University of Copenhagen)*

Introduction:
While methods such as correspondance analysis can help to illuminate horizontal aspects of social organisation from burials through associations between grave goods and age or gender groups (Kolář 2020), the vertical aspects of social organisation (such as wealth, inequality, hierarchy) from burial data are still often based on one or few variables of wealth from grave goods, or grave architecture. In this talk, I will show how I apply the recent multivariate framework, QuantWealth (Nørtoft 2022), to burials to assess wealth display (in various forms) and use this to estimate inequality over time and space.

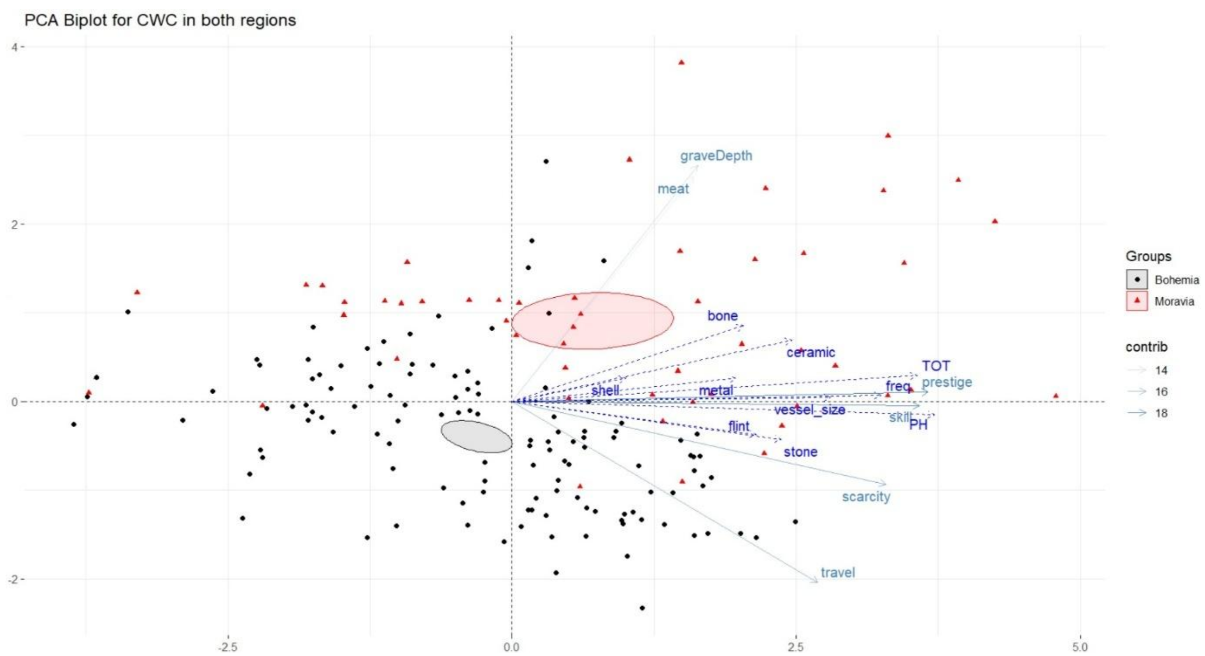
Materials and Methods:
The current case study is based on more than 300 Czech Eneolithic Corded Ware culture (c. 2900-2200 BCE) graves from both large and small cemeteries, barrows and barrow groups. The QuantWealth framework itself focuses mostly on assessing various parameters of "value" and wealth from grave goods (using individual object measurements), grave architecture, animal bones, and demographics from commonly available legacy data from grave catalogues. However, because burial wealth display may mask or exaggerate lived wealth/status and inequalities, I apply this to more recent bioarchaeological data for the same graves to correlate grave wealth display with factors such as skeletal or genetic pathologies, haplogroups, ancestry, and kinship (also diet and mobility isotopes which was not available for this data), along with spatial attributes such as provenance and estimated travel routes of grave good materials from their suggested sources. I use PCA to visualise and explore the correlations between the different wealth measures and materials associated with these as well as the positions of graves in this multivariate "wealth space". I also employ a combination of network analysis and Least Cost Path to estimate resource networks and travel routes, GIS for spatial analyses of wealth on cemetery and regional levels, various inferential statistics methods to test the validity of observed patterns from the explorative PCA, and I use Gini coefficients contrasting adult and non-adult inequality over time.

Results:
Among other things, QuantWealth has revealed wealth display through animal bones (as proxy for funerary feasts) to be specific to certain age groups, fluctuating long-distance resource connections between sites over time, surprisingly not at sites along main rivers, inequality fluctuating over time. Also, inequality seems to contrast among adults vs. non-adults, questioning whether rich child burials reflect inherited wealth or changing mediums of family wealth display from adults to non-adults. Furthermore, a potential shifting social order is observed (with migration and a shift in paternal lineages) during the Corded Ware period in Bohemia, which may have affected age representation in the burials.

Discussion:
QuantWealth is a reproducible, semi-automated, and flexible open-source framework, and can thus be adapted to specific needs, and the digitized data is added in full to public repositories such as GitHub and Zenodo for anyone to use. This means that even with different available data between case studies, QuantWealth can be used as a tool to still assess developments in social organisation on similar, but flexible, principles, and with more high-quality bioarchaeological

data on health, kinship, and mobility, we can easily rerun these analyses and better understand questions of lived vs. performed wealth and inequality on larger scales than previously.

One limitation of QuantWealth is that its experimental archaeology reference data used for some of the wealth measures (manufacturing time and skill) are currently tuned mostly to European Neolithic-Early Bronze Age artefacts, and that the resource travel route estimates require (at least approximately) provenanced materials. Therefore, I created an online app which agnostically calculates and visualises one of the wealth measures in QuantWealth, exclusivity (or "prestige") values, for grave goods and/or grave architectural elements from any spreadsheet with grave good or architecture element counts. These "exclusivity values" can be added back to the spreadsheet to download and analyse elsewhere, or, within the app, various inequality measures can be calculated from these values and added to an online atlas and database which accumulates and maps wealth and inequality results and/or data in an interactive spatiotemporal wealth and inequality scape. The goal is that, apart from visualising the global wealth and inequality scape over time, researchers donating their results or data to the atlas should also be able to access the resources and data donated by other researchers, thus making wealth and inequality data available much more widely for future studies on increasing scales, and new synergy effects.



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348. Between the Rhine and the Rhone, across the Alps and the Jura mountains: A similarity network approach to Early Iron Age burial mounds in western Switzerland

Timo Geitlinger (University of Zurich)*

During the Early Iron Age, western Switzerland is a key area in between the Alps and the Jura mountains, connecting the upper Rhine valley and the Rhone basin. Due to the scarcity of settlement evidence our current understanding of this crucial transitional period, however, is mainly based on abundantly attested burial mounds. Looking at the longue durée, Early Iron Age burial mounds are preceded by Middle Bronze Age mounds and Late Bronze Age flat burials and succeeded by Late Iron Age flat graves. A similar, yet regionally more divergent pattern can also be reconstructed for the fluctuation between cremation and inhumation burials. For the greater part, Early Iron Age burial mounds were excavated by early antiquarians in the 19th century and have since been subject of some meritorious yet slightly outdated compilations. Nonetheless, their landscape context has so far not been systematically studied.

Arguably, the burial mounds of western Switzerland are particularly suitable for a landscape archaeological approach. As materialisations of social practices, burial architecture, goods, and rituals associated with the mounds can themselves been seen as agents and manifestations of the past landscape (Ingold 1993). As monumental features burial mounds are important landscape markers which still today visually contribute to the appearance of the landscape. Nowadays, western Switzerland is an intensively settled and managed area, whose appearance has been majorly changed in the last two centuries through melioration works (Geitlinger et al. 2022). Even though these interventions obstruct the understanding of the environmental setting of the burial mounds, a landscape archaeological approach can draw on first-hand results of the interdisciplinary ArchSeeLand project, which aims to decipher the palimpsest of today's landscape and reconstruct the Late Bronze Age and Early Iron Age landscape setting.

This paper presents preliminary results of a dissertation project and focuses on the Early Iron Age evidence of western Switzerland. Building on a database having been compiled for the sake of the project and containing detailed information of roughly 200 sites and 1500 grave objects, the aim of the paper is to develop a similarity network approach to the Early Iron Age burialscape (Bourgeois and Kroon 2017). The similarity between the sites is established considering object-related information, the environmental placement of the tumuli, and differences in the burial ritual and architecture. Looking at changing similarity connections through time and space, differences in how the mounds reference themselves as well as other sites and their immediate surrounding manifest themselves. Furthermore, these changing edges hold the potential to shed light on the altering relationship of western Switzerland with adjacent areas in eastern France, south-western Germany, and the Alpine region. As such, the similarity networks are providing us with unique insights in a past Early Iron Age landscape.

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522. Of bones and people: using intra and extra-site spatial analyses of mortuary contexts and landscapes to explore disperse, multi-source archaeological data and learn about the living

Mónica Corga (Uniarq | Morph)*; Mónica Corga (Uniarq)

In Iberia, as in other European megalithic cultural landscapes, the study of the prehistoric burial monuments, ritual behaviours, and funerary objects represents one of the most active early research traditions, most certainly due to the imposing presence of its prominent architecture in the landscape. If this long research history provides us with invaluable theoretical constructions and sensational collections of archaeological objects, it also introduces specific data-related challenges and the consequent epistemological need to adequately address the question of these legacy datasets methodological heterogeneity and frequent fragmentary character and ambiguous contextual provenance.

Suffering from this abundancy of diverse data, the Copper Age (In Iberia generally corresponding to the 3rd millennium BC) is a crucial period to understand the acceleration of socio-economic complexity and early development of economic intensification and urbanization in Europe, as this period corresponds to; (1) the intensification of natural resource exploitation, (2) landscape anthropization and monumentalization, (3) increasing social stratification, (4) expansion of distant cultural, political, and commercial networks, and (5) the emergence of dominant centralities.

Ranging from the southeastern mediterranean shore to the Atlantic façade of today's southern and central Portugal, the archaeological record shows common social, cultural, and economic traits across a vast territory of southern Iberia punctuated by such mega-sites as Los Millares, Marroquies Bajos, Valencina de la Concepción, Cabezo Jure, Santa Justa, Alcalar, Perdigões, Leceia, or Zambujal.

Although only very scarcely excavated, the ditched enclosure of Porto Torrão (Ferreira do Alentejo, Portugal), has long been certified as one of these Southern Iberia Copper Age central places, as demonstrated by its unusual dimensions, ditch structures, and archaeological remains indicative of social stratification and long-distance relationships.

At the Porto Torrão mega-site, however, the available archaeological information exclusively derives either from early and very limited archaeological tests or from disperse, equally limited, preventive Archaeology operations. Although both those early research works and the recent preventive Archaeology operations all benefited from adequate methodological protocols, the observed field recovery criteria and resulting contextual information and inventory necessarily consist of disparate, heterogeneous datasets, as the site still lacks a structured research program able to guide the scientific exploitation of such information and coordinate any upcoming research efforts.

This informality, methodological diversity, and absence of scientific strategy and structured research program is even more damaging as extensive areas of the site are currently submitted to persistent pressure of urban development and intensive agriculture projects that constantly threaten the remaining archaeological information.

As is the case in other of these Copper Age mega-sites, Porto Torrão also preserves an astounding array of mortuary practices and contexts, ranging from the end of the 4th to the end of the 3rd millennium BC. Human remains are found either within or outside the enclosed area; in ditches, pits, or collective tombs; in clusters or isolated; as primary depositions or displaying intense manipulation.

Amongst this funerary diversity, the tholos type tombs of Horta do João da Moura 1, located outside Porto Torrão, demonstrate the existence of large scale economic and social interaction

networks, which seem to have been purposefully made visible during funerary performances through the significant introduction of foreign goods in greater quantities and variety than observed in earlier prehistoric funerary monuments of the region. The allochthonous objects, including lithic tools, gold artifacts, cinnabar, limestone vessels, and marine shells, offer objective documentation interactions with different peninsular areas, in some cases very accurately pinpointed in the Iberian geography through macroscopic or elemental analysis for petrographic, mineralogical, or faunal determination and correlative comparation with known sedimentary, ore, or ecological areas.
Our approach to the study of this extremely detailed information in the context of other preventive Archaeology and legacy archaeological datasets relies on a regressive reconstruction of the cultural/economic past landscape based on a detailed as-is 3d aerophotogrammetric model of the area, integrating remote sensing geometric data with non-invasive Geophysics results, further densified by contemporary and legacy contextual data through GIS technology, also used to concentrate and analyse all intra-site excavation information.
The resulting intra-site spatial analysis of the two Horta do João da Moura 1 tholoi, on the other hand, revealed the complexity of the funerary procedures, thanks to a state-of-the-art field archaeothanological recovery method and subsequent micro-stratigraphic approach showing the opposition (if not complementarity) of the two tombs:
- One consisting of a collective secondary burial of disarticulated and previously skeletonized bones; and
- Another delivering primary burials of successive individuals.
The detailed intra-site spatial analysis and micro-stratigraphic analysis of these human remains and the associated ceramic and lithic artefacts allows the reconstitution of significant funerary practices, including an initial founding deposition, preferential deposition areas, rearrangements of buried bodies and the funerary package of offerings, including the use of cinnabar. The emerging picture at Horta do João da Moura 1 is one extreme detail of very complex funerary practices that only DNA based kinship analysis will further enlighten (since funerary behaviour is inherently linked to individual and group identity), as strontium dentine analysis of dental enamel are expected to do for the diet and geographic circulation of the individuals, thus adding to the inter-site spatial analysis of allochthonous materials.
Moreover, as the referred diversity of funerary contexts within the Porto Torrão area offers an invaluable window to study the 3rd Millenium mortuary behaviours and the ultimate interpretation of these behaviours within the social and psychological frameworks of the site's coeval community, these detailed results from the Horta do João da Moura 1 tholoi must be put into perspective with all other (if disparate) information from the multiple known funerary contexts in the Porto Torrão area, including both other structured, complex collective burials (such as the rock-cut tombs of Monte do Carrascal 2) and more or less disperse contexts within the enclosed area.
While observing strict interpretative prudence (because burial rituals and offerings are highly selective not directly representative of the community's everyday life or socio-economic strategies), this comparative study of intentionally closed funerary contexts aims to recreate social and political relations inferable from the funerary practices, in order to discuss their ontological place in ritual performances, the persistence, disappearance and change of their intentional and tangible outcomes that may shed light on the evolution of the attitudes of the living towards death and the dead and the underlying economic, social and cosmological order.

19. Open, reusable and interoperable data work in plural, or making (open) science practices in archaeology open to whom?

Isto Huvila (Uppsala University)*

Archaeology has a long history of emphasising the importance of documenting not only research results but also their underpinning scientific and scholarly practices, decisions and intellectual premises in notebooks, grey literature reports and publications (Huvila, Sköld, och Andersson, 2023). While producing documentation is only one of the possible approaches to opening science and scholarly work, it has advantages to, for example, direct participation in enabling asynchronous conveying of understanding of archaeological practice over time and space. Documenting such information – increasingly often termed paradata in the literature – has, however, varied to what extent and how this has been done in practice – similarly to for whom the practices and their premises have become (more) open and understandable (Huvila, 2022). From this outset, a crucial question to ask when aiming at advancing openness of science and scholarly work, reuse, reusability and interoperability of data and data work through documentation, and especially when discussing mandates, is to consider the implications of specific efforts to different degrees and forms of desired and problematic senses of openness to various audiences. Openness is much more than sharing data or documentation. It is about processes, collaboration and inclusion (Leonelli, 2023) – the practices of making science paradata elucidate.

Based on comprehensive interview, survey and document based research on archaeological paradata and paradata practices in the ERC-funded CAPTURE project (www.uu.se/en/research/capture) between 2019 and 2024, this presentation sheds light on how specific types of practices of generating paradata are linked to particular forms of openness, how individual types of paradata are informative for different audiences, and how all meaningful paradata generation is contextual to research practice. An assumption of the possibility of generic acontextual openness, reusability and interoperability through documentation is deeply problematic. Instead, the findings emphasise the importance of accounting for research practice and context as a key premise of understanding what is needed to attain particular forms of openness, and to be mindful and explicit of what forms of openness are worked towards and how the chosen means are aligned with the chosen aims. In the closing, the presentation outlines starting points for possible strategies to address the multiplicity of opennesses in practice on the basis of the findings.

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170. Transforming access to Mediterranean cultural heritage science collections

Eleni Gkadolou (British School At Athens)*; Mark Jackson (Newcastle University); Nathan Meyer (British School At Athens); Rebecca Sweetman (British School At Athens)

Over the past century, leading UK researchers working under the auspices of the British School at Athens (BSA), British Institute at Ankara (BIAA) and British School at Rome (BSR) – members of the British International Research Institutes (BIRI) – have generated heritage science collections of international significance for addressing big-picture questions concerning the human past in the Mediterranean. These collections have substantial research value in terms of ancient technologies and economies, impacting on innovation and societal change, with unparalleled value for investigating mobility of objects, raw materials and humans.
Specifically, 50-years of scientific study of Mediterranean ceramics at the BSA's Fitch Laboratory has created a unique collection of unrealized potential: discipline-leading Greek geological and ceramic samples documented by rich archival material on traditional pottery production. This combination of assets is uniquely positioned to provide scholars and the public with world class capabilities for the study of Greek pottery production (ancient and traditional) and thus the Fitch laboratory has been recognized as a vibrant international center of excellence in ceramic studies. However, the above-mentioned fundamental collections remain inaccessible to most researchers for various reasons (many of these are not digitized, lack of resources for digitization, complex heritage science data concepts not handled by typical collection management systems, lack of mechanisms to build upon these collections to name a few).
Recently (September 2024) Newcastle University - which works closely with the BIRI and has an international reputation for research in archaeological heritage science and archives, as well as substantial expertise in collections management - collaborated with the BSA to apply for and win a 2-year grant to build a versatile and powerful heritage science collections management infrastructure to host the BSA's Fitch Laboratory and the other BIRI heritage science collections. This project entitled "Transforming access to Mediterranean cultural heritage science collections" is funded by the Arts and Humanities Research Council in the framework of the RICHES program which aims to maximize the research, development and innovation potential of UK heritage science by increasing sector effectiveness, efficiency, and excellence.
The goal of the new infrastructure is twofold:

1.
To make primary data freely accessible: Providing access - based on multi criteria, descriptive and spatial searching capabilities - to this infrastructure will enable researchers to explore inherent, meaningful spatio-temporal networks of information in diverse collections, so that they can explore and analyze relationships between objects, people and places.

2.
To enable the combination of collections and the creation of thematic stories through custom web themes, with resulting websites made available for public and educational programs from school children to post-doctoral researchers.

The infrastructure that is being developed is aligned with the FAIR and CARE principles and digital humanities best practices (Figure 1) and includes tools for the collections management, websites development (with minimum IT skills) and research collaboration. The database schema is created as a CIDOC-CRM application ontology to ensure that a) the database is created as a domain knowledge database, solid, autonomous, re-usable in the Semantic Web, and separated from the operational data required for the development of the system, b) the semantic and technological interoperability of the system with other complementary systems is feasible, c) semantic queries in the database and across databases as well as Knowledge Graphs capabilities can be enabled, and d) linked open data can be supported. On top of these critical components of the system, the spatially enabled functionality will allow the visualization of complex data relationships, the identification of spatial (that otherwise would remain hidden) patterns and the creation of thematic and story maps as a way to invite the wider, non – specialized, audience into new paths to discover the cultural heritage and history of the Mediterranean.

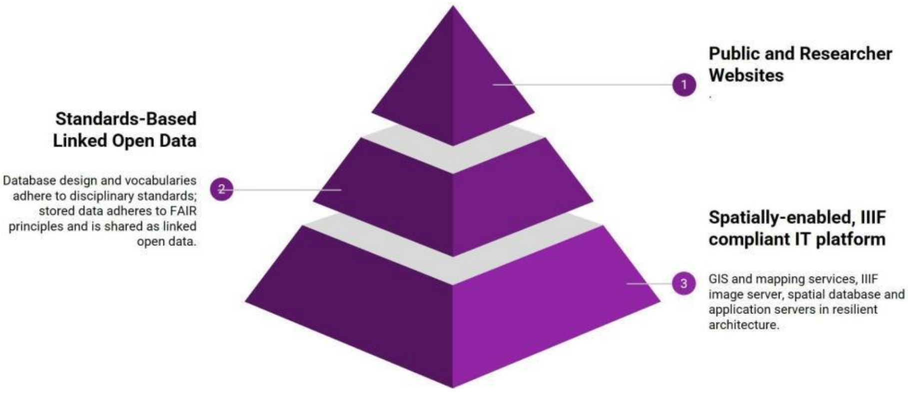

Figure 1. Main components of the infrastructure

The technology to be used has been selected to ensure a meaningful research resource and a proof of concept for compatible expansion and is being built around open-source tools: Omeka-S as the core platform and Cantaloupe as the IIIF image server. Omeka-S was chosen as the core platform because of its overall ease of use, facility in managing the CIDOC application ontology, relevant connectors to 3rd party data stores, and facility in creating many websites on a data repository. The sample datasets that will be initially included into the system are: a) the BSA's Fitch Laboratory geological and ceramic sample collections supported by archival material on traditional Greek pottery production, and (to showcase the ability of the system to host diverse collections) b) the BIAA lithics, ceramic sherds, botanical samples collections and the BSR Marble Reference Collection.

Although the challenges to be addressed in terms of this project are many and diverse (technological complexities, archaeological and heritage data stewardship, sustainability issues etc.) we already foresee this as an excellent opportunity to establish a fruitful dialogue towards science openness and public engagement to new digital cultural heritage products.

69. The ARIADNE Research Infrastructure: Working towards sustainable open data for the archaeology community

Holly Wright (University of York)*; Julian Richards (GB); Franco Niccolucci (PIN – University of Florence)

The ARIADNE Research Infrastructure (RI) is the result of over ten years of research effort, largely based within Europe, but with a range of international participation showing the more universal potential of this initiative. The recent creation of the ARIADNE RI (https://www.ariadne-research-infrastructure.eu/) as an independent legal entity now allows the consortium to both participate as a project partner within other projects and initiatives, while also charting an independent and sustainable course, and continuing to serve the archaeological domain.

This paper will discuss the history of the ARIADNE initiative, including the first and second formal development phases, the capacity-building work of the COST Action (SEADDA) Saving European Archaeology from the Digital Dark Age (https://www.seadda.eu) and the creation of a business plan to ensure the sustainability of the ARIADNE RI through the Sharing Archaeological Data Effectively (SHADE) COST Innovation Grant (https://www.ariadne-research-infrastructure.eu/shade-cost-innovation-grant/). It will also discuss the participation of the ARIADNE RI in new projects and future planning to ensure this resource continues to evolve, grow and better serve our community in a way that is both sustainable and responsive.

85. Data Management in Archaeological Research Networks- Strategies and Solutions of the FAIR.rdm Project in SPP 2143 "Entangled Africa"

Eymard Fäder (Universität zu Köln)*; Lukas Lammers (Universität zu Köln); Eleftheria Paliou (University of Cologne); Brigitte Mathiak (Universität zu Köln)

Since 2018, the German Research Foundation (DFG) has been funding the Special Priority Programme "Entangled Africa (SPP2143), Intra-African relations between rainforest and Mediterranean, ca. 6000 - 500 BP". Alongside 12 research projects, FAIR.rdm at the University of Cologne stands out in pursuing to represent "entanglement" with the help of research data management (RDM). To this end, we have set ourselves the goal of publishing the research data of the SPP 2143 in accordance with FAIR standards and CARE principles. This should also enable the (re-)usability of the data, especially for the African partners.

All projects in SPP2143 are based at German institutions and pursue their own research objectives with various methods in different regions and periods of African Archaeology. Although the SPP 2143 has an archaeological focus, it is interdisciplinary in nature and thus includes projects that use exclusively natural scientific methods.

In addition to the technical challenges of establishing joint data integration in an interdisciplinary research network, there are also two special organizational peculiarities. FAIR.rdm does not operate its own infrastructure, nor does the funding institution, DFG mandate an integrated RDM. We therefore depend on the voluntary cooperation of numerous partners.

As the project nears its end in 2026, we would like to share the strategies and solutions that have been developed and tested in order to best achieve the goal stated above.

Approaching Cross-Repository Data Integration

In the first funding phase of "Entangled Africa", the FDM project primarily used mainly the repositories and standardized data platforms of the German Archaeological Institute (DAI), which are integrated in the so-called "iDAI.world". The level of data literacy among the Researchers in "Entangled Africa" was very heterogeneous. With the help of open consultation and workshops, we pursued to sensitize researchers to the relevance of RDM according to the FAIR principles.

This approach was continued in the second phase with slight modifications. It also became apparent that systems outside of iDAI.world would increasingly be used. Options for cross-repository data integration were considered, with the ARIADNE Research Infrastructure (RI) emerging as the favorite. The biggest technical challenge here is the standardization of metadata. On the one hand, the ARIADNE RI provides its own ontology based on CIDOC CRM; on the other hand, the metadata in the numerous repositories used by the SPP researchers is very heterogeneous. For starters, systems used were conceived with different concepts and on different architecture due to the respective year of their creation. On the other hand, data models in archaeology do not necessarily conform with other disciplines, i.e. paleobotany, mineralogy or language sciences.Thirdly, not all systems offer connectivity or provide semantic ontologies. To bridge this gap, FAIR.rdm developed a metadata converter and implemented an OAI-PMH interface for automatic data exchange with ARIADNE RI (Niccolucci & Richards 2019).

The publication of the metadata from "Entangled Africa" in the ARIADNE RI will facilitate searching by provenance, subject, location, chronology and also in multiple languages, alongside other data on archaeological research in Africa. From the RI, persistent identifiers then link to the repositories of origin for the respective data sets.

We hope that the metadata converter developed by FAIR.rdm will be useful for other projects, too and it will be published in GitHub for sustainability. In addition, publication data compilations that illustrate results will be made available.
The close inter-programme collaboration faced some organizational challenges, to which the project had to adapt along the road (Lammers et al 2022, Fäder et al 2019) by organizing workshops that dealt with concrete and current topics. It was shown that consultations are better received and have a more lasting effect when they are conducted with individual researchers on specific data.

Implications and Open Questions
We hope that our six years of practical experience of research data management in archaeology will be beneficial for other researchers, particularly in terms of the possibilities for implementing cross-repository data integration. Efficient data management clearly requires both theoretical and technical expertise. Therefore, we strongly advocate for the inclusion of specialized data stewards in archaeological projects, or even better, permanent funding to support dedicated institutions.
Two key aspects still warrant further discussion: the integration of paradata and the interaction between the FAIR and CARE principles.
First, the significance and relevance of paradata in digital form is, from our perspective, not yet widely recognized within the archaeological community. This presents challenges when attempting to integrate paradata into existing data repositories. The best practices for such integration remain an open question for us.
Secondly, while the CARE principles emphasize the authority and control of communities over heritage data, the FAIR standards focus on making data findable, accessible, and reusable. A critical question is how the open science paradigm can align with the CARE principles, particularly in the open sharing of African research data that constitutes heritage data.

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192. Linking the fragments: Outcomes from Greece's SHADE national workshop on digital archaeological data integration

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Archaeological data in Greece face persistent challenges in preservation, accessibility, and reuse due to the sector's fragmented structure, lack of uniform standards, inconsistent digital practices, varying policies on data sharing and persistent mentalities of data ownership (Tsiafaki & Katsianis 2021). Despite commendable efforts, archaeological data creation and stewardship remain largely sporadic, with significant barriers to fully adopting Open Science practices across the sector (Katsianis & Tsiafaki 2024).

This paper reports and critically assesses the main discussions from the workshop entitled "Bridging the landscape of digital archaeological data in Greece" (Athens, 29/5/2024), which was organized under the SHADE (Sharing Archaeological Data Effectively) project following similar national workshops held during the activities of the SEADDA (Saving Digital Archaeology from the Digital Dark Age) network (Richards et al. 2021). The event brought together a diverse group of stakeholders — including the Archaeological Service, academic and research institutions, foreign archaeological schools, as well as citizen science initiatives— to evaluate the current landscape of digital archaeological data in Greece, identify common and ongoing challenges, and explore opportunities for common strategies in data management and dissemination across the sector. Drawing on presentations and discussions from the workshop, this paper summarizes the practical and structural challenges affecting how archaeological data is preserved, accessed, and reused in Greece. We highlight opportunities and potential solutions proposed by various stakeholders and advocate for a unified, coordinated strategy in Greek digital archaeology centered on collaboration, infrastructure development, and Open Science principles.

During the event representatives from existing digital infrastructures shared their experiences in data curation and dissemination. They emphasized the lack of standardized or interoperable data infrastructures, outdated technologies, and significant obstacles to adopting Open Science practices. Workshop participants explored ways in which sector-wide collaboration and alignment with international frameworks, such as FAIR and CARE, could enhance data management in Greek archaeology. Engagement with international infrastructures like ARIADNE and OpenAIRE was also considered for their potential to offer practical guidance to advance data stewardship within Greece. A third critical area of discussion concerned the necessary steps to build capacity and support sustainable data management across Greek archaeological institutions, including ongoing education, the development of shared terminologies, and the creation of interoperable data systems.

Based on these observations, this paper argues for a cohesive, collaborative approach to digital archaeology in Greece, addressing the fragmented, project-specific practices and inconsistent data management standards that currently hinder progress. To advance digital archaeology, we propose the development of robust infrastructures and shared resources that equip researchers, archaeologists, and cultural heritage professionals with tools for effective, standardized data management. Moving beyond isolated projects, we advocate for a national framework that prioritizes accessibility, interoperability, and data reusability, promoting the wider adoption of repository infrastructures aligned with Open Science principles to facilitate data sharing within Greece and internationally. Key to this approach is sustained capacity-building, which would include knowledge exchanges as part of specialized training in digital curation and Open Science practices, fostering a culture of collaboration and shared responsibility. By empowering professionals across the sector, such a framework would ensure the consistent quality and

ethical management of archaeological data, paving the way for greater accessibility and innovation in research.
In the long term, this collaborative approach could transform digital archaeology in Greece, making data widely accessible for interdisciplinary research and public engagement while preserving it for future generations. By prioritizing common digital infrastructures, continuous professional development, and adherence to shared open practices, the Greek archaeological community can make significant strides in embracing sustainable digital practices.

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194. From Interoperability to Interoperation: Integrating Archaeological Data across Heterogeneous Systems

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Digital archaeology projects striving for compliance with the FAIR guiding principles [1] can draw on a variety of techniques and tools to make their datasets theoretically interoperable, such as incorporating semantic domain upper ontologies and standard vocabularies or utilising a Resource Description Framework for Linked Open Data. However, functional interoperation across individual databases presents additional obstacles, even when projects share general methodologies and data management platforms. In order to begin addressing the challenges of integrating different regional datasets, Arches Cultural Heritage Partners (ACHP; https://github.com/achp-project) is a meta project formed out of eight individual digital archeology projects working in different geographical regions across the globe. All projects use the same open source software (OSS) geoweb-based stack (Arches) to store and disseminate their data, but each implements their own setup, data models, and reference vocabularies. The aim of this paper is to present a proof-of-concept for collating and integrating all of the datasets together on a single server, moving from the horizon of interoperability to the reality of interoperation.

Each project deploys a custom instance of the Arches semantic graph database platform, one of the most widely used OSS platforms for managing archaeological and cultural heritage data [2], in order to digitally document the archaeological landscapes of their target regions. Based on mature technologies such as Python, JSON derivatives, PostgreSQL, Elasticsearch, URI/URL, and API, among others, it enables multilinguality, graph data structures, CRMbase and CRM ontologies, advanced geospatial querying, a GeoJSON API, interpretive plurality, Linked Data, controlled vocabularies, and tiered permissions. However, the region-specific needs of each heritage project demand customised solutions that get expressed in their data models, thesauri, and access structures, making functional interoperation far more challenging than interoperability alone.

The ACHP is a collaboration among a range of archaeological and cultural heritage preservation projects with foci spanning the globe, including Central Asian Archaeological Landscapes (CAAL), Endangered Archaeology in the Middle East & North Africa (EAMENA), Mapping Archaeological Heritage in South Asia (MAHSA), Mapping Pre-Columbian Heritage in South America (MAPHSA), Maritime Endangered Archaeology (MAREA), Mapping Africa's Endangered Sites & Monuments (MAEASaM), and the Mongolian Archaeology Project: Surveying the Steppes (MAPSS).

Integrating the data from multiple ACHP projects is a fundamental realization of the FAIR principles. Each project individually began steps toward this in their early phases by drawing their reference data from standard vocabularies such as the Getty Art & Architecture Thesaurus and building their data models on top of the domain-standard semantic upper ontology, CIDOC-CRM. In order to move toward functional interoperation, we more recently implemented a containerised version of the Arches software on an AWS server and copied the resource models (Arches data models) there, along with reference vocabularies. We imported sample data from each project onto the server and were able to successfully display the information from each, instantiating them on the singular instance. This has been the first step of integrating infrastructures across projects, with testing the reference data and then data models to follow.

Overall, this paper proposes a methodology for generating interoperable but heterogeneous archaeological datasets and then integrating their data within a single system. It conceives of a solution by outlining a series of steps, beginning at project conception, that is rooted in FAIR and CARE compliance but necessarily goes beyond both sets of principles. It then finally considers the drawbacks of such an approach and postulates the overall value of this means of data interoperation for archaeological research and immovable cultural heritage documentation.

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397. Workflows for 3D Scholarship: Conceptualising, Authoring, and Publishing 3D Scholarly Editions within a National Infrastructure

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For the past 20 years, 3D media have been struggling to gain a foothold in open science initiatives for cultural heritage.They are either offered as accompanying downloads for offline exploration or they are presented in a 3D viewer that offers limited visual inspection and often even less in terms of annotation or semantic enrichment. Many concerted efforts have sought to address 3D data curation and publication at various levels – from standards for 3D digitisation methods, to consistent metadata and paradata, from web streaming to peer review protocols (Alliez et al., 2017; Hardesty et al. 2020; Cyprus University of Technology, 2022; Moore et al. 2022; Papadopoulos 2024). While all these aspects of making 3D digital heritage part of the scholarly research ecosystem are crucial for data quality control and long-term preservation, there is a lack of (sustainable) infrastructures that combine a viewing and repository function, as well as tools that would allow the enrichment of 3D models that turning them into useful scholarly resources. Such infrastructures require not only robust software and hardware but also humanware, i.e., expertise in infrastructure development and operation, as well as a diverse user community with varying disciplinary backgrounds and digital skill levels. These elements are essential for sustaining such systems.

PURE3D (funded by the Dutch PDI-SSH (Platform Digitale Infrastructuur–Social Sciences and Humanities) is addressing the infrastructure concerns raised by prior digital humanities scholars and 3D heritage working groups while also centering the perspectives and experiences of stakeholders. This is being done through the development of a prototype infrastructure dedicated to fostering the creation of 3D Digital Scholarly Editions by individuals from across the humanities, sciences, and social sciences – from students to curators, from public sector officials and museum staff who inherit commissioned 3D assets to researchers with experience in creating 3D models themselves. 3D Digital Scholarly Editions are an intermedial constellation of knowledge within which 3D models embed within them scholarly arguments (in the form of metadata, paradata, annotation, and argument), as opposed to the ways in which 3D models are currently engaged with: as ‘twirly things’ available on a platform such as SketchFab (with limited annotation available) or in surrogates such as videos and 2D images in published articles. While a 3D edition can in theory be constructed in any feature-rich 3D web viewer, the PURE3D infrastructure currently deploys the Smithsonian Voyager 3D viewer for editing and publishing the 3D projects. Besides being an open-source software with a long-term outlook for committed development and maintenance, the framework offers a user-friendly editing interface called Voyager Story that can empower non-technical edition creators (with training) to curate their knowledge and expertise around a 3D digitised object or through a 3D reconstructed scene.

At the same time, PURE3D, funded by NWO Open Science, researches - in the context of research assessment reform, how 3D is valued and rewarded as scholarship in its own right, and how an evaluation system designed for this particular output enhances the quality and reach of open science in our field.

While previous efforts by journals to publish peer-reviewed research incorporating 3D components have been fragmented or unsustainable, PURE3D engages stakeholders to understand their challenges in having their work evaluated. This dialogue informs the development of an evaluation framework - both conceptual and technical - that redefines how 3D scholarship is valued.

Over the past four years, PURE3D has uniquely bridged infrastructure development with community building among 3D scholarly edition creators. This dual focus has enabled reflection on workflow – from data handling and preservation concerns dand a critical evaluation of outputs by both experts and end users. This presentation will outline the development of the PURE3D infrastructure, the establishment of workflows - from conceptualising to publishing 3D scholarly editions, and will reflect on lessons learned. It will also propose future directions for infrastructure development in light of current EU initiatives and the impending closure of SketchFab's ad-hoc role as a repository for digital heritage.

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307. The erasure of humans from the archaeological archive: Grappling with the contradictions of open science

Sara Perry (UCL)*; Anna Simandiraki-Grimshaw (UCL); Holly Wright (University of York)

While open science may claim commitments to transparency, collaboration and accessibility, and existing digital infrastructures in archaeology may strive to realise these commitments through different frameworks or principles of practice (FAIR, CARE, OCAP, etc.), the everyday experiences and needs of audiences still often sit in tension with the data made available through digital repositories. There is no shortage of research and investment into infrastructure-level efforts to address biases, fill gaps and cater to wider communities through archives, ostensibly in pursuit of more and different forms of 'openness.' In the UK alone, we see such work manifest recently in, for example, futuring reports (e.g., Ross et al. 2024), museums innovation (e.g., the Museum Data Service: https://museumdata.uk/; the Sensational Museum: https://sensationalmuseum.org/), cross-institutional cultural collections integration (e.g., Towards a National Collection: https://www.nationalcollection.org.uk/), and analyses of collections-holding organisations' perspectives on such integration (e.g., Humbel et al. 2024). Yet even as these initiatives proliferate, wider systems – for instance, the General Data Protection Regulation (GDPR) – often operate in fashions that thwart, confuse or constrain their possibilities. Without conscientious, interlinked efforts to manage the conflicts between these endeavours, investments in open science seem likely never to reach their full potential.

Here, we reflect on findings from a series of experiments in data reuse conducted with upwards of 175 people (archaeological specialists, creative practitioners, illustration and museum studies postgraduate students, school children, and adults living close to archaeological sites) as part of TETRARCHS: Transforming Data Reuse in Archaeology. TETRARCHs is a three-year, cross-European project to make data more amenable to storytelling at different stages in the archaeological process. We investigate not only how people create stories from archaeology, but how we can gather and organise data in ways that enable more multifaceted reuse for more diverse audiences. Our empirical studies into storytelling habits demonstrate the importance of the presence of humans in archaeological data, including human emotions, human sensations, and literal representations of humans in documentary records. For example, photographs picturing humans tend to see greater reuse than those without them. Problematically, in the UK, GDPR now results in the discard of much human data from the 'official' archive because of lack of consent. Such discard ultimately makes the data less available and useable (less open). Especially worrisomely, many seem to be unaware of the consequences of GDPR on their data, and hence are oblivious to the need to take GDPR seriously at the earliest project design stages.

Working alongside the Archaeology Data Service (ADS) and Museum of London Archaeology in the UK, we are developing resources to support archaeological units and others who deposit data into the ADS to do so in ways that enable inclusion of humans in the archive whilst also respecting inter/national regulations and different forms of consent. In this talk, we discuss these efforts to grapple with the consequences of the de-humanisation of archaeological archives. We reflect on wider structures - beyond GDPR alone - that undermine open science efforts. And we put forward various provocations, based on experiments with broad audiences outside archaeology (creatives, students, communities living local to sites), about how the curation and management of digital data repositories might evolve to ensure the ideals of open science are realised.

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447. Addressing Archaeological Data Governance Challenges through Data Management Plans (DMPs)

Angeliki Tzouganatou (OpenAIRE)*; Elli Papadopoulou (Athena Research Center)

The digitization and documentation of archaeological data present challenges that extend beyond the foundational FAIR (Findable, Accessible, Interoperable, Reusable) principles established by Wilkinson et al. (2016). While these principles have advanced the management, sharing, and reuse of scientific data, they do not address the ethical, cultural, and social dimensions essential for equitable and inclusive stewardship. This is particularly evident in archaeology, where data intersects with sensitive cultural heritage and the rights of indigenous and local communities.
This paper situates these challenges within the broader framework of participatory governance, which integrates technical rigor with ethical accountability. Within this context, Data Management Plans (DMPs) emerge as critical tools orchestrating the responsible management of digital artifacts to bridge technical standards with ethical imperatives. Complemented by digital infrastructures, DMPs provide a foundation for advancing inclusive, transparent, and sustainable management of archaeological data.

Digital Infrastructures as Ethical Enablers
Digital infrastructures, such as OpenAIRE, play a pivotal role in operationalizing FAIR and CARE (Collective Benefit, Authority to Control, Responsibility and Ethics) principles. They are evolving from static infrastructures into active enablers of ethical and inclusive practices. Digital infrastructures must also address ethical and cultural dimensions by incorporating mechanisms that respect community rights, manage sensitive information responsibly, and include marginalized voices in data governance towards social inclusion. Current systems often fail to adequately address these issues, leading to ethical oversights and perpetuating historical inequities in the management of cultural heritage data By embedding participatory decision-making models, these infrastructures can align technical functionalities with broader social and ethical responsibilities, reinforcing the integrity of archaeological data governance.

Data Management Plans in Archaeological Research
DMPs provide a structured framework for addressing technical, operational, legal and ethical challenges in archaeological data governance. As living documents, they guide researchers throughout the data lifecycle, from collection and documentation to sharing and long-term preservation. Recent advancements in DMP platforms demonstrate their potential to address the complexities of archaeological data governance by integrating FAIR principles.
One such tool, ARGOS, developed by OpenAIRE, exemplifies the operationalization of FAIR principles. It achieves this at different levels by: a. enabling seamless data exchange and integration within Open Science ecosystems, and b. providing domain data protocols (DDPs) addressing the specific needs of different domains in DMPs (Papadopoulou et al 2023). For archaeological data management, ARGOS maintains a DDP adapted from the ARIADNEplus DMP for Horizon 2020 research activities. It emphasizes key aspects such as intellectual property rights, Open Access, metadata, and paradata, providing a comprehensive guide to ethical and sustainable data management. Features such as versioning and DOI assignment enhance transparency, accessibility, and reusability, making ARGOS a versatile tool for researchers managing archaeological data.

Upon collaboration of OpenAIRE and the archaeological community, the ARIADNEPlus incorporated both descriptive metadata and procedural paradata ensuring that data practices remain culturally sensitive and contextualized, further supporting sustainable stewardship of archaeological resources. The FAIR principles have transformed data practices in archaeology by enhancing discoverability, accessibility, interoperability, and reusability. These principles facilitate collaboration across disciplines, especially for complex and dispersed datasets. FAIR principles often neglect contextual and procedural dimensions. Metadata, while essential for describing the "what" of data, frequently omits paradata, which documents the "how" and "why" of methodologies, decisions, and interpretative processes (Huvila et al 2024). This omission is significant in archaeology, where ethical and cultural sensitivities demand transparency and contextualization. Moreover, the CARE principles complement FAIR by emphasizing collective benefit, community authority, responsibility, and ethics. For example, ensuring that indigenous communities retain control over data related to their heritage or that benefits from data use are equitably shared requires a framework that incorporates these priorities. By aligning FAIR and CARE principles, DMPs can provide a comprehensive and inclusive approach to archaeological data governance.

Participatory Governance

Achieving inclusive and sustainable data governance requires a shift toward participatory models that center the voices and rights of Indigenous and local communities. Involving these communities in the development and implementation of DMPs ensures that cultural sensitivities are respected and that the benefits of data reuse are equitably distributed. Participatory governance fosters trust, transparency, and accountability, creating a more inclusive framework for archaeological data management.

Integrating CARE Principles into DMPs

While current DMP tools focus primarily on implementing FAIR principles, the planned integration of CARE (Collective Benefit, Authority to Control, Responsibility, and Ethics) principles represents a transformative step in archaeological data stewardship. Future updates to tools like ARGOS will prioritize community rights, promote equitable benefit-sharing, and embed cultural sensitivities into data governance. By aligning technical capabilities with ethical imperatives, these updates will expand the role of DMPs into comprehensive platforms for inclusive and sustainable data management.

Enhancing Archaeological Research through Reproducibility

Reproducibility is a cornerstone of responsible research and fosters transparency and accountability across disciplines. In archaeological research, it involves ensuring that research processes and findings can be verified or extended by other researchers using the same data and methods. This often includes sharing datasets, metadata, and analysis code, which allows others to replicate or reinterpret the results. Such practices enhance transparency and reliability in archaeological studies, addressing challenges like the complexity of computational analyses and the reuse of heritage data. For example, reproducible archaeological research might document workflows for geospatial analyses or statistical modeling, ensuring that both data and methods are accessible and interpretable. Building on the findings of the TIER2 project, the integration of reproducibility elements into DMPs represents a significant advancement in ensuring that methodologies, decisions, and results can be verified and built upon.

Conclusion

DMPs are indispensable for advancing equitable and sustainable archaeological data governance. By aligning with FAIR principles, leveraging digital infrastructures, and fostering participatory governance, DMPs provide a robust framework for managing archaeological data responsibly. Tools such as ARGOS and the ARIADNEplus DMP template exemplify how tailored solutions can address the unique challenges of archaeological research while balancing technical requirements with ethical accountability. The planned integration of CARE principles and reproducibility in DMPs represents a significant advancement, fostering inclusivity, equity, and accountability in the stewardship of cultural heritage

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29. Unlocking archaeological data: a study of researcher's practices and perspectives in Catalonia

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Archaeology has been engaging with open data for some decades now (Hansen, 1992), and more and more institutions and funding agencies are advocating for this model. It seems the logical option for a discipline that studies cultural heritage, that receives mostly public funding for research, and that generally uses a destructive methodology such as excavation. However, the implementation of open data practices has not progressed as smoothly as anticipated. Despite significant efforts to build infrastructure to support data publication, the adoption of open data remains limited (Karoune, 2022). Research usually revolves around technical issues, such as infrastructure or data description, and the focus is often set on an institutional level (Jakobsson et al., 2021). Therefore, a group of key actors of archaeological research has traditionally been neglected by the literature when studying and promoting the open data model in Archaeology: the researchers. This research aims to explore the current practices and perspectives of archeology researchers in Catalonia regarding data management and sharing, identifying the factors that influence their willingness to adopt open data practices.

To capture the voices of researchers we conducted a series of in-depth semi-structured interviews with principal investigators of archaeological research projects in Catalonia. These interviews provided insights into their data management practices, sharing behaviors, and the reasons behind their choices. The data collected were analyzed with Qualitative Content Analysis to identify common themes.

The results of the study comprise not only researchers' practices in data management and sharing, but also their perspectives. This has allowed us to approach the current panorama and identify the factors that drive or prevent researchers from making their data open. Key findings include the importance of excavation reports, the identification of social and personal barriers to open data adoption, and a general lack of awareness on data management and open data best practices.

The implications of these findings extend beyond Catalonia, offering valuable insights for the broader archaeological community. The research shows how the singularities of archaeological research and archaeological data affect the adoption of open data. By understanding the specific challenges faced by researchers, we can develop targeted strategies to promote open data practices. This results in a set of tailored recommendations to encourage the implementation of the open data model in Catalan archaeological research.

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45. Supporting researchers in Archaeology with Diamond Open Access. The experience of Transformations, A DARIAH Journal

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In order to support their work, Archaeologists manage and use a large range of digital methods and tools (3D techniques, notebooks, data visualisation) - often much more so than scholars from other Humanities disciplines. Still, they face issues or legal constraints when it comes to publishing their final research in Open Access, because commercial publishers still dominate the scholarly publication sector. Researchers then have to be compliant with restrictive publishers' access policies. Additionally, part of their research outputs might also end be limited in their accessibility due to their provenance (cultural heritage).

The DARIAH Research Infrastructure (https://www.dariah.eu/) can help the archaeological community to better embrace Open Access practices in a variety of ways. In this contribution, we would like to emphasize, in particular, how the newly launched DARIAH journal Transformations [1] can contribute to this dynamic. The goal of this new publication form is not to add yet another Digital Humanities journal to the publication landscape, but to provide a genuinely trusted, non-commercial platform for documenting various methodological and research activities in the arts and humanities. Processes of data gathering and processing, annotation and modeling, analysis and interpretation play a key role in the journal.

Transformations relies on a Diamond Open Access publishing platform, Episciences (https://www.episciences.org/fr/accueil/), a scholarly publication model in which journals and platforms do not charge fees to either authors or readers [2], a model that is currently gaining traction with an increasing number of researchers worldwide [3]. This paper explores how Transformations can be instrumental in supporting archaeological researchers through this novel form of publication.

Principles of Diamond Publishing and Overlay Journal:

Diamond publishing offers several advantages. First, it allows authors to retain copyright, enabling a wider dissemination and reuse of their work. Second, it can improve metadata quality, data linking and data citation by leveraging open repositories. These repositories provide a structured framework for data storage and retrieval, ensuring that research outputs are discoverable and interoperable (via OAI-PMH protocol).

Challenges and Issues of Data Sharing and Reusability:

Despite the benefits, data sharing and reusability in archaeology face several challenges. One significant hurdle is the diversity of data formats and standards used in this research field. Heterogeneity can make it difficult to integrate and analyze data from different sources. Additionally, concerns about data privacy and intellectual property rights can hinder sharing.
Another challenge is the lack of incentives for researchers to share their data. Publication pressure mechanisms often lead to prioritizing the dissemination of final research outputs, such as journal articles and monographs, while neglecting the importance of underlying data and methods. This limits the potential for replication, verification, and further research.

Transformations is providing a publication space where archaeological communities can share their digital tools, methods, and resources in a reproducible manner. It welcomes scientific contributions on collections of data, workflows and software analysis that could be initially deposited and linked to the SSH Open Marketplace (https://sshopencloud.eu/ssh-open-marketplace).

Better recognise and value a diversity of research outputs:

Transformations is currently working in the process of building assessment grids to create a solid and open evaluation process for different research outputs used by arts and humanities communities in Europe. The ATRIUM project [4], that aims to provide concrete solutions for both data management and workflow reusability challenges in Archaeology, is instrumental in this process.
The long-term goal of providing such a peer review framework is to incentivise Arts and Humanities users to follow the principles of Open Science and share not only final research outputs (journal articles and monographs) but also other important research outputs such as datasets, workflows, tools models etc that are still under the scope of the research assessment landscape [5]. It also aims to support reviewers in the evaluation phase, providing more transparent tools and methods and thus contributing to a better recognition for reviewers and more equity for authors (CRediT, https://credit.niso.org/).

Researchers in archaeology have strongly benefited from the advances in digital technologies improving as a consequence the quality of output data. But in the last years, we have also observed a large quantity of tools rarely compatible and frequently commercialised, obliging researchers to seek tailored solutions adapted to their specific needs. This is why Open Science practices are challenging both at a technical level and in terms of visibility within the research community. Moreover research infrastructures are key to provide virtual space for hosting, archiving, cataloguing information. DARIAH develops, maintains and operates an infrastructure in support of ICT-based research practices and sustains researchers in using them to build, analyse and interpret digital resources.

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TRANSFORMATIONS
A DARIAH Journal

333. Optimizing Archaeological Deposits: A Robotic Solution for Enhanced Storage and Manipulation of Archaeological Objects

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The final storage of archaeological objects is a complex issue that encompasses several critical aspects, especially given the continuous and exponential increase in archaeological material. Not only must conservation criteria be met within storage facilities, but accessibility and storage space are also significant constraints. In recent decades, digitalization of archaeological material for archiving purposes has increased thanks to new technologies; however, physical storage practices have remained largely unchanged. As a result, archaeological storage facilities are often overfilled and congested, reducing accessibility to materials and ultimately endangering the collections.

The international storage survey conducted by ICCROM and UNESCO in 2011 [1] revealed that 66% of museums recognized a general lack of storage capacity, and 25% also stated experiencing difficulties with circulation within their storage spaces. According to the ICCROM international survey of 2024 [2], the situation has not improved. In this survey, 75% of museums identified storage space as a major issue, and nearly 60% highlighted the lack of shelving, cabinets, or other appropriate storage equipment. Hence, the current solutions seem not to lead to feasible results so far. To address these challenges, this paper presents a robotic automated system designed to provide a breakthrough solution to storage and accessibility problems in archaeological warehouses.

Two technologies were involved: first one the robotic and automated handling systems are increasingly being applied in commercial warehouses due to their proven ability to provide flexibility in managing varying demands; second one, the combination of automated equipment, data collection technologies, and management solutions offers a flexible framework that can adapt to evolving needs while improving efficiency [3].

With this flexibility in mind, and aiming to optimize accessibility and storage space in archaeological facilities while maintaining specialized standards, the proposed automated solution consists of the following components:

Component (1): racks with transparent trays specifically designed to accommodate the weight and average size of objects, thereby optimizing storage space. The number of trays in each rack is determined by the characteristics of the stored material. These racks are organized within the storage room, taking into account the space requirements of the mobile robot (Component 2).

Component (2): an Autonomous Mobile Robot (AMR) equipped with a shelf transport system that attaches to the required shelf, lifts it, and transports it to the loading and unloading station (Component 3). The AMR uses a laser navigation system to map the storage environment, enabling it to detect and adapt to any changes in the storage area while avoiding collisions. The system is scalable and can employ multiple AMRs based on the specific requirements of each facility.

Component (3): a loading and unloading station consisting of a robotic arm (UR5) equipped with a gripper to hold and manipulate individual trays. Once the AMR safely releases the rack, the robotic arm picks the designated tray and makes it available for further tasks, such as automated scanning of the objects or other conservation and research activities.

The system is managed by software that, along with data collection technologies such as barcodes or QR codes, identifies the tray requested by the researcher and manages AMR traffic within the storage facility, optimizing navigation and avoiding collisions.

This proposal offers a highly flexible system capable of adapting to several materials, including particularly fragile objects such as organic materials. In such cases, tray materials can be customized to meet conservation requirements. For larger or heavier materials, AMRs and robotic arms with higher payload capacities can be employed. Additionally, the system can be retrofitted to existing museum storage facilities, maximizing space utilization. Implementing the system would also require updating museum documentation, which, while initially labour-intensive, would significantly enhance the digital information available about archaeological collections. This advancement alone would represent a major contribution to archaeological research, as many museums currently have only partially digitalized catalogues.

The application of an automated system within archaeological storage facilities introduces new challenges to traditional storage practices but also opens countless possibilities. It necessitates the development of a new logic for cataloguing objects within the domain of Human-Machine Collaboration, where flexibility optimizes both storage space and data collection, thereby improving long-term access and conservation of materials. In this context, the relationship between robotics and archaeology extends beyond digitalization practices for analysing archaeological objects, encompassing direct collaboration between robots and researchers. This integration requires designing systems that leverage the complementary strengths of human and machine agents.

The proposed robotic system underscores a significant opportunity for interdisciplinary collaboration between engineering and archaeology. Such partnerships can drive innovative solutions to longstanding challenges in museums storage, conservation, and research. In this sense, the automated archaeological storage facility represents a milestone in the application of robotics to the discipline, providing a foundation for further innovation, enhanced preservation, and the sharing of knowledge in archaeology and beyond.

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117. Digitising cultural heritage: the role of robotics in archaeological artefact documentation

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Archaeology involves numerous repetitive, time-consuming, and physically demanding tasks. Among these, documentation is particularly burdensome, requiring both specially trained staff and a significant amount of time to be completed properly. This complexity is especially evident in research centres and cultural institutions, where the number of correctly documented and studied artefacts is significantly lower than the volume of objects added annually to existing collections. This issue has led to the phenomenon known as the “curation crisis” defined as a severe imbalance between the continued generation of archaeological collections through excavation, and a corresponding lack of resources and facilities dedicated to their acquisition, analysis, conservation, and care (Advisory Committee on Curation 2003). The direct consequence of this imbalance is the creation of “orphaned” collections, which have either lost curatorial support or were never curated in the first place (Voss 2012). This causes the risk of losing uncatalogued artefacts along with the historical and cultural data they represent.
In order to address the curation crisis, the Center for Cultural Heritage Technologies (CCHT) at the Italian Institute of Technology has developed a new platform for the automated scanning of archaeological objects. This solution is part of the House of Emerging Technologies – Genova project (in Italian, Casa delle Tecnologie Emergenti – CTE) and includes automated robotic handling of artefact trays and their transport to a workstation for digitisation. The system utilizes two robotic arms: one arm, equipped with a gripper, holds and rotates the tray, while the second arm, fitted with a structured light scanner, moves around the objects to perform a 360° scan. The data is then uploaded and processed in the cloud, delivering high-quality 3D scans of the artefacts.
Tests conducted in our laboratory on Roman-era ceramic materials demonstrated the platform’s effectiveness in fully automating the digitalisation process. The digital copies produced showed a high degree of fidelity to the originals in terms of shape, size, and colour. Furthermore, the scanning was carried out at a fair speed, in the range of a few minutes, with only minor variations in time depending on the size and complexity of the objects.
These results highlight the potential of robotic applications digitising archaeological artefacts. The speed of the scanning process increases the number of digital copies that can be obtained within the same timeframe and with the same personnel compared to traditional methods. This will contribute to recovering “orphaned” collections, allowing for the acquisition, recording, and preservation of a significant amount of data about cultural heritage objects, which would otherwise be at risk of being lost. Additionally, this data will provide important information on the nature and origin of the artefacts, as well as their conservation status and restoration needs. Finally, the automated scanning process and the resulting digital copies will enhance accessibility to heritage artefacts for both specialists and the general audience.

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139. Plantoids in Pompeii: Conservation of detached frescoes of the Calidarium of Pompeii using self-growing robot intervention

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The development of bio-inspired robots holds promise for applications in challenging environments, particularly where human intervention is constrained. This study specifically focuses on self-growing robots, which autonomously expand their structure to adapt and maneuver within their surroundings. Specifically, the research examines the feasibility of these robots in archaeological conservation, with practical trials set in the Archaeological Park of Pompeii. By simulating the adaptive growth of plant roots, the robot, referred to as the "Plantoid," autonomously adjusts to confined spaces, making it well-suited for delicate preservation tasks within archaeological sites. This paper details the robot's design, functional principles, and testing protocols aimed at heritage conservation applications, proposing future pathways to extend bio-inspired robotics to additional fields of interest.

Introduction

Biological systems have evolved over millions of years to adapt and survive within the Earth's dynamic conditions, developing sophisticated behaviors and survival strategies. Harnessing these adaptive characteristics for technology, termed “bio-inspiration,” has gained traction across various scientific fields, including robotics. In recent years, bio-inspired robotics has introduced groundbreaking designs that mirror natural mechanisms. Notable examples include robots replicating animal movements, such as a robotic arms mimicking the muscular hydrostatics of octopus tentacles (Laschi, et al. 2012). These innovations enhance adaptability and precision, two attributes crucial for robotic interventions in complex environments.

Self-growing robots represent a significant departure from conventional robotic movement, which generally relies on locomotion-based mechanics. Instead, self-growing robots employ an extension mechanism for movement, enabling them to build and extend their bodies to navigate and interact with their surroundings, using methods such as additive manufacturing or pressurization of folded materials. This unique method of operation has potential applications in hard-to-reach locations, where environmental interactions must be both adaptive and non-invasive.

Methods and Materials

This research centers around the Plantoid, a self-growing robotic unit designed to mimic the growth process of plant roots, which grow from their tip. The robot's design enables it to extend from a head-mounted 3D printer, adding material incrementally to its structure as it advances (Sadeghi, et al. 2014). The structures fabricated can be reshaped and reconfigured by controlling physical parameters. Such an approach is distinct from traditional additive manufacturing robots that rely on pre-layered thermoplastic adhesives (Iida, Wang and Brodbeck 2014). By replicating the root-like growth pattern, the Plantoid can be directed to expand its structure in a controlled manner, allowing it to interact closely with its surroundings.

The primary objective is to assess the Plantoid's functionality within archaeological sites, specifically within the Archaeological Park of Pompeii. The robot's adaptability is essential in conservation tasks, particularly where heritage structures must remain undisturbed but require ongoing monitoring or intervention. For example, in the Calidarium of the Terme Femminili, some frescoes are detaching from the walls. The Plantoid's capacity to maneuver within narrow spaces and deliver adhesive material as needed can aid in preservation efforts without altering the frescoes' current positioning, which holds archaeological value.

Results

The Plantoid prototype is tailored to navigate the architectural constraints observed in Pompeii's Calidarium. It currently has a diameter of 30 mm to fit the variable cavity dimensions (3-7 cm) observed in the site. It features a single motor that performs dual functions: filament feeding for 3D printing and head rotation to deposit material, enabled by a system of gearwheels converting rotational to linear motion. This single-motor setup optimizes internal space and reduces weight, key considerations for air-based applications as opposed to the originally intended terrestrial use. This design also incorporates air passages to counteract heat accumulation from internal components.

The Plantoid's structural components are fabricated from PA 12 (Nylon 12) using selective laser sintering (SLS), which provides durability while keeping the structure lightweight. The motor is a 1000:1 micro metal gearmotor from Pololu, and the gear system is made from stainless steel for added resilience. The robotic head is configured to accommodate various sensors, including a camera for real-time teleoperation and proximity sensors for obstacle detection. These sensors enhance the robot's autonomy, allowing it to avoid environmental obstacles without external guidance. Additionally, a customized adhesive spraying mechanism is in development, tailored to deposit compounds with appropriate viscosities for conservation applications.

A significant aspect of this research involves testing the Plantoid in a controlled environment before deployment at the archaeological site. A mock-up model simulating the wall-fresco structure has to be created based on 3D reconstructions of the Calidarium obtained via laser scans. This model will be constructed using mortars similar to those found in Pompeii to approximate the actual site conditions closely. Given that portions of the wall cavities are obstructed by cone-shaped elements originally used to support the frescoes, an industrial endoscope will be used to map these structures through photogrammetric methods, providing comprehensive data for accurate mock-up fabrication. Although the endoscope's reach is limited to 2 meters, the recurring cone pattern along the wall enables extrapolation across the entire structure.

The mock-up serves as a critical testing environment, allowing researchers to evaluate the Plantoid's ability to navigate confined spaces and perform conservation tasks without risk to the actual heritage site.

Discussion

The Plantoid project demonstrates a pioneering integration of bio-inspired robotics in archaeological conservation, exemplifying how cross-disciplinary approaches can yield innovative solutions tailored to complex heritage environments. The implementation of self-growing robotics in the Archaeological Park of Pompeii highlights the value of merging principles from biology, engineering, and archaeology to address preservation challenges. The adaptability of the Plantoid's design, which enables it to navigate tight spaces and deliver materials precisely, is especially beneficial in settings where delicate interventions are required without disturbing the historical context.

Beyond the specific conservation tasks addressed in Pompeii, the Plantoid's self-growing mechanism holds potential for broader applications in fields that demand remote intervention and structural adaptability. Potential future applications include disaster recovery, environmental monitoring, and confined-space exploration, where autonomous growth and sensor integration provide critical advantages. The Plantoid's modular architecture, which accommodates additional tools like sensors and adhesive systems, further enhances its functionality, positioning it as a versatile robotic tool adaptable to a variety of complex scenarios.

In summary, this research not only underscores the potential of bio-inspired robotics in conservation but also contributes to a framework for interdisciplinary applications that can bridge modern engineering with traditional preservation techniques. Future studies will focus on refining the Plantoid's structural efficiency, material resilience, and autonomy, thereby advancing its capability for broader use across diverse heritage sites and other fields where bio-inspired robotics could offer incisive solutions.

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327. Advancing Archaeological Site Conservation with Robotics and Computer Vision – Insights from Pompeii

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Archaeological sites are increasingly vulnerable to environmental and anthropic threats, especially with accelerating climate change. Traditional inspection methods, reliant on human expertise, are often labor-intensive, time consuming, inconsistent, and costly. Addressing these challenges requires innovative solutions that prioritize preventive maintenance over reactive interventions. Nowadays, technological solutions to monitor archaeological sites are diverse, and the use of LiDar, Terrestrial Laser Scanner, or Radar Interferometry artificial satellites can provide insights into the deforming of structures [1] or evident material loss in earthen architecture [2]. However, some problems remain unsolved; how can we inspect different types of architectural structures, with non-uniform construction materials, each one with a particular type of defect? How can we detect and monitor them over time in large scale sites such as Pompeii (Naples, Italy)? Can we propose a mobile solution that does not depend on or is limited by the position of the sensors?

Taking in consideration these questions, an automated solution that incorporates advanced robotics and computer vision to identify and monitor defects is presented in this paper. This robotic system strives to ensure efficient and precise monitoring while reducing inspection time and the dependence on human expertise and above all subjective assessments. Moreover, the robotic platform is especially designed for challenging open environments such as those encountered in archaeological sites.

The system, named RINGHIO (Robot for Inspection and Navigation to Generate Heritage and Infrastructures Observations), is being tested in the Archaeological Park of Pompeii [3], a paradigmatical case in world-wide archaeology. RINGHIO combines a wheeled terrestrial platform with an advanced vision system mounted on a vibration-dampening device, aiming to achieve autonomous navigation through rugged terrains, high-resolution images for defect detection, and the reduction of inspection time while maintaining high accuracy and consistency.

The Robotic Platform consists of a Robotnik Summit-XL self-propelled robot, chosen due to its all-terrain mobility design with elastic suspensions and specialised tires. On this platform, a Defect Detection Box (DDB) has been placed. The DDB encloses two telecameras and is completed with two vibration mitigation layers: passive dampers for high-frequency vibrations, and active stabilizers for low-frequency oscillations. The DDB has been completely developed by our team, with a design that seeks to ensure robust defect identification and generate a record of anomalies over time. This approach mirrors the successful implementation observed in the case of the San Giorgio bridge (Genova, Italy), where a similar methodology was meticulously designed, executed, and extensively validated [4].

The vision system includes two Go-Pro Hero 12 Black cameras. These cameras are placed inside the DDB, perpendicularly to the direction of travel to capture 15,87MP (5312x2988) image data of the infrastructure being inspected. One camera will be oriented to capture a direct view of the infrastructure, while the second camera will be slightly tilted upwards to provide a wider field of view and capture details of higher surfaces. Vision data is captured at a rate of 30FPS with Linear field of view to eliminate the barrel distortion. Finally, the GoPro's in-camera stabilization HyperSmooth is activated to stabilize the video with minimal cropping.

To process the vision data captured by the cameras a defect detection algorithm was developed: A YOLO-NAS medium backbone model was employed for object detection. The model was tunned on, and target format transformation in a dataset of 100 images captured from various areas of Pompeii, focusing on defects like missing and exposed bricks and blocks. To enhance model robustness, data augmentation techniques such as mosaic, mixup, HSV adjustments, flipping, and rescaling were applied. By dividing the dataset into training, testing, and validation sets, ensuring that the model was evaluated on unseen data from distinct areas of Pompeii, the model's generalization capabilities were improved.

The workflow starts with the mapping of the archaeological site in order to propose the most reliable navigation route for the robot, allowing it to conduct an autonomous inspection that can be repeated. The autonomous navigation of the robot with the DDB allows for a complete scan of the walls, capturing high-quality images suited to be processed with the defect detection algorithm. Once defects are detected, preventive conservation can be accurately planned by specialists considering their evolution over time.

The tests carried out at the Archaeological Park of Pompeii allowed to assess both the navigation performance and the stability of the DDB. In the uneven and rugged streets of Pompeii, the robotic platform maintained its endurance and trajectory adherence, while the DDB maintained the camera balance, ensuring high-quality images with minimal blur.

The initial results of the YOLO-NAS model are promising, demonstrating its ability to accurately identify critical defects in the complex archaeological environment of Pompeii. Despite the challenging conditions, the model successfully detected four key defect types with reasonable confidence. While further refinement is necessary to enhance accuracy and robustness, these early findings showcase the significant potential of computer vision for automating archaeological site inspections. As the dataset expands to encompass a wider range of defects, the model's capabilities are expected to grow, providing invaluable insights to conservation teams.

The deployment of RINGHIO represents a significant step forward in heritage conservation, allowing proactive monitoring that enables the early detection of problems and preventing severe degradation. Also, it reduces the need for extensive human intervention, optimizing resource allocation. RINGHIO establishes a framework for broader application across other archaeological sites.

The current results obtained with RINGHIO have provided sufficient feedback to understand our current degree of development and to enhance its impact in cultural heritage inspection and monitoring. Further development is planned mainly to enhance AI Models with expanded datasets, since incorporating a larger diversity of environmental and structural scenarios will improve algorithm robustness resulting in finer defect categorisation. Finally, a finer localization integration of our robotic platform will facilitate the mapping of the detected damage, increasing RINGHIO speed to reduce monitoring time.

RINGHIO demonstrates the transformative potential of integrating robotics and computer vision into archaeological site management. Its success in Pompeii underscores its value as a scalable, efficient, and precise solution for preserving cultural heritage. By bridging technological innovation and historical preservation, this system contributes to safeguarding our shared past for future generations.

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180. Robotic experiments to unravel early human technological innovations: exploring technological shifts and raw material use during the Palaeolithic

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Identifying and understanding changes in past human technologies is key to reconstructing the behavioural dynamics that characterised the major evolutionary steps of human ancestry. The artefact variability visible in the archaeological record shows that, in the past, human populations have frequently changed, adjusted, and developed innovative technologies using different raw materials. Such adjustments represent human adaptive behaviours to dynamic ecological, social, and cultural processes. These processes resulted in the emergence of major behavioural traits, which are rooted in our early human evolutionary journey through the Palaeolithic and are commonly associated with innovative technological solutions (i.e. artefacts).

Archaeologists' ability to understand why these changes occur is restricted by the current limited understanding of how hominins used their technologies and why these were adjusted over time. The way hominins used their technologies is largely overlooked, and this obscures the behavioural demands and triggers for those adaptations, and consequently, major past human evolutionary steps remain invisible.

This talk aims to present and discuss the contribution of a series of laboratory/controlled experiments to resolving this gap by investigating the engineering principles of tool use and function: effectiveness, efficiency, and durability. While tool function can be assessed through use-wear analysis, experiments can measure tool efficiency, rates of the consumed resource to achieve a goal, and durability, i.e. the ability to retain function over time. By evaluating the relationship between raw material, tool design and performed task, these experiments aim to investigate how different technologies emerged in the archaeological record from the perspective of tool use and function. Examples from the Lower and Middle Palaeolithic records will be presented and discussed (Schunk et al. 2024; Paixão et al. 2021; Nora 2021).

Results from the different experiments show that there is a significant difference in the efficiency and durability of different raw materials and tool designs, which is likely to correlate with the mineral composition and the mechanical properties of each type of rock. However, the efficiency and durability of a raw material or tool type seem to be also dependent on the activity and worked material. This clearly shows that different raw materials and, ultimately, different tool types are more suitable for specific tasks than others, which might have influenced the way early hominins selected and manipulated different types of rocks.

Apart from reconstructing the demands for such technological shifts and inferring what they tell us about changes in human behaviour, topics such as the variability of raw materials are fundamental to identifying and comprehending early decision-making processes in hominins' ecological and cultural dynamics. The discussion is illustrated by several case studies from the Lower and Middle Palaeolithic tool design and use. Our data and results shed light on key decision-making processes of early hominins, and how processes of cumulative cultural evolution underlie cultural success in our human journey, making us who we are today.

366. From manual to highly mechanised experiments – assessing the impact of human variability on tool performance and use-wear formation

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The interpretation of past human lithic technologies relies heavily on understanding the function and use of tools. Experimental approaches are essential to assess these functions and build a reference collection. Additionally, use-wear analysis plays a key role in identifying potential use activities. By combining both approaches, a more comprehensive understanding of the function and use of lithic technologies can be achieved.

Traditionally, experiments have been conducted manually; often to test preliminary interpretations or identify broader correlations. In contrast, mechanised, highly controlled experiments can test variables independently to identify diagnostic, repeatable patterns. While results of manually conducted experiments may impact the interpretation of the archaeological record directly, mechanised experiments usually do not. Their goal is not to reproduce archaeological traces directly. To bridge the gap between these two approaches and allow for comparability, a comprehensive tri-parted experimental workflow was designed. The overarching aim was to assess in how far the previously identified causal, mechanical relationships remain relevant when human variability is factored in. This involved conducting different but complementary types of experiments: a highly controlled experiment (material tester), a controlled experiment with human-like variation (robotic arm) and a manual experiment. The controlled experiment was further subdivided into three setups to perform distinct tasks: a controlled, linear movement; a manually guided movement; and a controlled, linear movement with programmed jitter (= random inaccuracy in position) and exhaustion (= decreasing force throughout the experiment).

In all experiments, a predefined number of unidirectional cutting strokes of a given length were performed using standardised flint samples on artificial bone plates. Force, speed, and acceleration were either (sensor-) controlled or monitored in both mechanised experiments.

The width and depth of the grooves, along with material loss from the samples, were quantified and statistically evaluated. The applied experimental trajectory allows for a direct comparison of tool performance. Furthermore, the developed use-wear on the samples was analysed both qualitatively and quantitatively to identify differences according to the type of experiment performed. Lastly, the recorded movements of the mechanical devices (material tester and robotic arm) were studied to assess and measure the actual level of control (i.e. accuracy and repeatability).

The results of the performed tri-parted experiment emphasise the limitations and advantages of each individual setup. While material loss from the samples appeared consistent throughout the experiments, the analysis of the grooves led to differing results. The more variability added to the performed movement (i.e. jitter or human inaccuracy), the higher the depth and especially the width of the grooves. The force, which was applied in a non-controlled way during the manual experiment, seems to notably influence the outcome. At the same time, the data suggests that the use-wear – qualitatively as well as quantitatively – developed comparably throughout the different experiments. The way the surfaces abrade due to use appears homogenously despite the incorporation of the human(-like) variation.

The methodological approach highlights the importance of both mechanised as well as manual experiments to understand the cause-effect relationships between individual variables and the formation of use-wear, within a larger framework of archaeological questions. By integrating human variability through the robotic arm, this workflow effectively bridges the gap between the two experimental extremes. The here presented tri-parted experimental workflow offers a comprehensive approach to interpret lithic technology more thoroughly and reliably.

411. Robotic Solutions for Archaeological Challenges: First Steps

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Introduction

Recent advancements have made robotic systems for identifying and documenting archaeological artifacts a reality. When paired with AI, automation devices hold significant potential as future field assistants, transforming how archaeologists produce knowledge. However, the integration of robotics into archaeology presents various approaches and related problems. Considering these challenges, this presentation focuses on two types of machines: ground rovers and linear robots.

In recent years, the ability to analyze terrain using satellite and aerial sensors has significantly improved. While archaeologists can now identify and document features remotely, current detection capabilities have yet to reliably reach the artifact level. Researchers have demonstrated that drones can be used to detect small-scale artifacts (Orengo and Garcia-Molsosa 2019), but issues such as limited operation time and flight restrictions persist.

Ground rovers, however, represent an emerging paradigm. These devices are becoming increasingly more available, opening new possibilities for archaeological research and revisiting old survey challenges with fresh perspectives. Similarly, linear robotics offer promising archaeological applications. These machines are characterized by two or three principal axes that move in straight lines. One relevant application is artifact sorting. When equipped with a vision system, linear robots can assist archaeologists with precise pick-and-place operations.

Using these two types of automation devices this presentation addresses several questions: • How effective can ground rovers be in documenting artifact scatters? • How scalable off-the-shelf ground rovers for deployment as a swarm? • What technical and practical challenges arise in integrating linear robotic systems into archaeological workflows? These questions underscore the intersection of technology, archaeology, and experimental robotics, highlighting the transformative potential of these tools in advancing archaeological methods.

Methods and Materials

The exploratory study employs two main platforms: (1) two LeoTech rovers that are equipped with Intel depth cameras and low-cost GPS for potential tandem operations, and (2) an IGUS linear robot outfitted with a depth camera, prototyped for picking, and sorting small artifacts.

The wheeled rovers are capable of traversing landscapes in various capacities. Currently, our research is focusing on best practices for navigation and obstacle avoidance. While we are at the preliminary stages, early results are promising. The current research also includes integrating low-cost LiDAR sensor for better situation awareness. As for object detection and mapping, our first efforts include using deep learning models to map objects on video streams. To "simulate" the process we performed transect walking and recorded video data using a smartphone camera. The next step in the analysis is to integrate ground-video recording using rovers and perform on-board computations, or instantaneously communicate with a mainframe computer for processing data.

Even more preliminary results come from the linear robot. An RBTX-IGUS XYZ Gantry system with (500mmx500mmx100m) is being prototyped for assisting archaeologists in sorting small finds. Currently, the focus is on understanding how linear robot mechanics work so that the process does not damage artefacts. Other working topics include integration of vision systems that can detect various archaeological material in soil samples. Our first experiments include finding small metallic objects using a magnet attached to the robot.

Results

The ground rover system demonstrates high capacity to move in different ground conditions, but more experiments are needed to pinpoint the best locomotion setup (i.e., wheeled, tracked, or legged) (Bruzzone and Quaglia 2012). While object detection on video data reveals promising results, on-board computation remains a challenge. The ground rovers show the capacity to communicate, setting the stage for swarm robotics. The linear robot shows potential for taking over basic archaeological sorting tasks, but wider operability remains a concern. At this stage, more research and experimentation are needed for more conclusive statements.

Discussion

This research underscores the transformative potential of robotics in archaeology, particularly in automating artifact documentation and sorting. The successful application of tandem ground rovers, and eventually a swarm might be able to survey large archaeological sites with minimal human intervention. Similarly, the linear robot offers a novel solution for laboratory-based artifact processing, enabling archaeologists to focus on higher-order analysis rather than routine sorting tasks.

The implications of these findings extend beyond archaeology. The rover system could be adapted for applications, such as mapping endemic species. The linear robot can be reconfigured so that it is possible to use it, for instance, in experimental archaeology (Calandra et al. 2020). While it seems feasible to deploy these machines as field assistance, further development and integration of low-weight AI models and hardware systems will be essential for achieving greater accuracy and reliability in these applications.

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346. The Edge Effect. A network-driven quantification of distortions in raster-based transportation models.

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Since its origins, landscape archaeology has employed geographic information technologies to visualise, analyse, and model territories. However, some of these models exhibit distortions that prevent the full exploitation of the generated data.
One such issue is the so-called Edge Effect. This distortion is a recurrent problem in raster-based analyses that calculate values for each pixel in a given map. This effect is particularly evident in mobility analyses, where the modelling of transportation networks, such as those performed using methodologies like Focal Mobility Network (Fábrega-Álvarez 2006; Llobera et al. 2011), is especially limited at the edges of the raster. In many cases, data in these areas are underrepresented and fail to provide valid results for visualisation. Although it is often possible to mitigate this issue by expanding the study areas and relegating the effect outside the analysable zone, there are regions where this solution is not possible.
Moreover, a more detailed analysis reveals that the Edge Effect not only impacts the raster edges but also affects the entire set of pixels that compose a given raster map, thereby distorting the overall results. The distortion originates in the central pixels of the raster and gradually intensifies as it approaches the edges. For instance, this distortion hinders the effective use of flow accumulation values, as seen in models developed with Focal Mobility Network, where such accumulation could indicate different levels of transportation routes.
To identify this distortion, we propose analysing the raster pixels as if they were nodes in a network. Each node is connected to its immediate neighbours, creating a network that allows us to measure their relevance within the study area. Specifically, we use betweenness centrality (Freeman 1979), which measures how many of the shortest paths between two pixels pass through a given pixel. This approach enables us to identify the most important pixels in terms of connectivity and to quantify the distortion related to their position on the map.
The identification and quantification of this effect aim to develop a normalisation of values that minimises its impact. This approach will enable more accurate analyses and open new possibilities for data that were previously constrained by this issue.
To illustrate this, we present a case study where it was not feasible to expand the study area. This is the region of Marmarica, a case that poses challenges due to its predominantly desert environment but includes ports of significant importance to Mediterranean economic networks throughout various historical periods.

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32. Pathways to Power: Spatial and Network Analysis of Romanisation in Central Italy

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This paper explores the application of combined spatial analysis to model effects of the Romanisation process, shedding new light on one of the most intensely debated phenomena in classical archaeology. The case study focuses on the Valle Peligna (Abruzzo, Italy), a region of strategic importance during Roman expansionism. Valle Peligna has long attracted scholarly attention due to the extensive data gathered over a century of research, as well as its key diplomatic, commercial, and political role. In antiquity, this area lay at the heart of a complex web of relations connecting it closely with Rome. After a series of conflicts during the middle Republican period, the region—along with other local communities—was integrated into the Roman sphere of influence through treaties, becoming a “foederati” state. Nevertheless, tensions persisted, culminating in 90 BC when one of the municipia in Valle Peligna served as the capital of the Italic League during the Social War against Rome. Within this historical and geographical context, our study employs Least Cost Paths and Network Analysis to investigate the connectivity between various settlement types, including municipia, pagi, vici, and hillforts, across distinct phases of development—from the late archaic period and the Samnite era through to the Roman Republic and the post-Social War period. This method offers a fresh perspective on Romanisation, enabling us to visualize and assess the relational dynamics between archaeological sites as they evolved under increasing Roman influence. The specific focus of the study is the road network, which played a crucial role in the internal and external connectivity of the valley, shaped by the Apennine orography. Strategic passes, valleys, and gorges became critical nodes for movement and control. The “fossilisation” of these routes provides a framework of well-defined topographical points, which we analyse using GIS and least-cost path models to reconstruct the most efficient routes between settlements. This least-cost path modelling, based on topographical and environmental constraints, allows us to simulate the probable movement corridors used by ancient populations and how these routes facilitated interactions within and beyond the valley. The introduction of distinctly Roman infrastructural elements into the local context serves as the primary variable in our analysis. Through network analysis techniques, we analyze similarities and differences of the pre-roman and roman road infrastructures according to specific centrality measures (closeness, inbetweeness). The results will allow us to interpret the evolution of road networks in response to shifting patterns of resource exploitation, trade, and territorial control across different historical periods. This analysis is contextualised through comparisons with other studies from the region, adopting a holistic, multidisciplinary approach to the cultural and economic transformations that accompanied Romanisation. By reconstructing the political, social, and territorial shifts that occurred in Valle Peligna from pre-Roman to Roman times, we highlight the broader impact of Romanisation on the ancient landscape. Finally, we compare our findings with other case studies, seeking to identify overarching trends and insights that can deepen our understanding of Romanisation and its transformative effects on ancient societies and landscapes.

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33. Landscape Archaeology in Salento (Southern Apulia): Investigating Mobility through GIS-Based Analysis

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The dense road network that characterizes the ancient topography of Salento draws its origins from the Messapian period when, having achieved considerable urban development, the cities equipped themselves with the indispensable infrastructures that connected them to each other and to the sea. With the Roman domination, the territorial reorganization led to the definition of four main roads, which guaranteed the connection between the City and the most important Apulian ports: the last part of the Via Appia from Taranto to Brindisi; the Via Traiana along the Adriatic coast from Egnatia to Brindisi and its extension towards Otranto with the so-called Via Traiana-Calabra and finally the Via Sallentina which guaranteed the connection between Taranto and Otranto along the perimeter of the Peninsula.

This paper aims to investigate the characteristics that distinguish mobility through Apulia region and its connections with the City during the Roman domination. Thanks to the traditional sources of ancient topography, it is possible to know which were the main roads of the region, the respective capita viarum, and the distance in miles between them and the different road stations. However, these sources alone can hardly help archaeologists understand the reasons behind selecting specific routes to connect locations. Therefore, this research aimed not only to reconstruct Roman roads in Apulia but also to identify factors that influenced their development in the past. The case study proposed is the Via Traiana "Calabra", located in the Salento peninsula (southern Apulia), which guaranteed Rome the access to one of the most important ports to the East: the city of Otranto. As for the second half of the road, still uncertain, there are two hypotheses of the path. Through a post-dictive approach, we used GIS applications to explore the complexity of the natural and anthropic factors that may have affected mobility in this area. The GIS approach consists of modelling cost surfaces based on geomorphological, hydrographic and archaeological data and calculating the least cost path, or the most convenient route to reach a point from another by moving in a certain direction. This framework aims to assess potential least cost paths to compare to the two hypotheses of the route in order to understand which could be the most reliable in Roman times. However, given the prolonged use of this road even in later eras as evidenced by the numerous archaeological data from

medieval and modern times, we thought of adding additional GIS analysis to study the routes. By analyzing the landscape and the distribution of anthropogenic poles of attraction in different eras, we applied GIS methodologies to understand whether there are multiple routes leading to the same destinations. Such multiple routes would form travel corridors that may change or remain unchanged over time. The purpose of these analyses is to understand which of the two options is valid for the geographic area analyzed. The reconstruction of the road routes and corridors serves as a proxy for modeling connectivity, understanding human mobility, route networks, and land use within the context of ancient Apulia.

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123. Complexity at what scale?: A quantitive multi-scalar approach to topographic complexity at the Acheulean Site of Rodafnidia (Lesbos, NE Aegean)

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Rodafnidia is an open-air, Lower Palaeolithic site situated on the island of Lesbos (NE Aegean), and the site preserves evidence of multiple visits from hominins using an Acheulean lithic technology (Galanidou et al. 2013). During different periods of the Pleistocene, Lesbos would have been connected to extensive lowlands across the Mediterranean basin, and periodically connected and disconnected from the Greek and Anatolian mainlands. The area is key for determining the timing and nature of wider Pleistocene hominin dispersals in the region, making this a unique assemblage for the north-eastern Mediterranean record. The island has been shaped throughout its history by active tectonism that has resulted in a relatively rocky, variable, and topographically complex landscape. These tectonic forces are implicated in the formation and sustaining of a number of environmental attractors for Pleistocene hominins in the local landscape, including a number of cold and thermal water sources, and a source of hydrothermal chert. The ‘Complex Topography Hypothesis’ (or ‘Tectonic Trail’), originally formulated by King & Bailey (2006), proposes a connection between early hominin sites and areas of complex topography and active tectonics, which is comparable with the situation at Rodafnidia. King & Bailey (and subsequent authors) have suggested that tectonic forces and topographic complexity in these regions throughout the Pleistocene may be generating and sustaining a number of resources and landscape factors that would have been attractive to hominins. In the present study, we aimed to examine the relationship between Rodafnidia and the topographic complexity of its wider landscape through a series of spatial analyses that quantified landscape heterogeneity. The analyses compared Topographic Position Index (TPI) and Deviation from mean elevation (DEV), methods of landform classification that serve to quantify landforms from a Digital Elevation Model (DEM) (Wilson and Gallant 2000). TPI and DEV surfaces were calculated at a range of scales for the island of Lesbos and the local area around Rodafnidia specifically, and then interrogated through a variety of statistical analyses. The results facilitated the identification of scales where structured variability in the landscape were identified, enabling a further analysis combining scales across this range for the whole island. Further comparison with the results of a separate edaphic analysis allowed us to interrogate the local relationship between topographic complexity and ecological richness, which is sometimes assumed in Palaeolithic GIS models. The results ultimately demonstrated that TPI is effective for capturing topographic complexity at local and regional scales, and we also provide specific recommendations for the use of TPI in these analyses. This has allowed for the contextualisation of the site of Rodafnidia within its topographically complex landscape, and provides a nuanced case study for consideration in connection with the Complex Topography Hypothesis. Quantification of landform heterogeneity allows us not only to measure topographic complexity, but also to interrogate its definition and scaling behaviours, and also to consider its role in Pleistocene dispersal and occupation.

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284. Spatial Interactions and Socio-Political Organization in Late Helladic Messenia: A Computational Modeling Approach

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Spatial interaction models are computational tools that simulate the flow of people, goods, and ideas within networks of geographical locations. These models have been widely applied in modern geography and archaeology to understand settlement dynamics and the emergence of hierarchical systems (Paliou and Bevan 2016). This study applies these models to investigate how interactions among settlements in Late Helladic Messenia (ca. 1600–1050 BCE) may have shaped the region's socio-political dynamics during this pivotal phase in Mycenaean civilization.

In the LH II period (ca. 1450–1400 BCE), some Messenian settlements began to expand, gradually leading to the construction of the Palace of Nestor at Ano Englianos, which emerged as the dominant center in the region during the LH IIIB period (ca. 1330–1190 BCE). While the prevailing model suggesting that this state formation arose through unification of pre-existing regional centers, recent findings from Iklaina (Cosmopoulos 2019) challenge traditional views of centralized control, and suggest a potentially decentralized political landscape. Therefore, the central research questions in this study are how the spatial organization of settlements from the LH II to LH IIIB periods reflects the development of political hierarchy and what role other centers, such as Iklaina, could have played in this process.

Previous archaeological studies have emphasized Pylos' influence, focusing on its administrative and economic control, while recent GIS-based research (Malaperdas and Zacharias 2018) has examined settlement distribution and connectivity in the region. Building on these insights, this work identifies key settlements and examines how their interactions shaped the Messenia's political hierarchy. GIS mapping tools and gravity-based spatial interaction models, adapted from Paliou and Bevan and implemented in R, were used to analyze settlement interactions across the region. A dataset of known settlement locations was used, supplemented by a small number of predicted "missing" sites to address potential survey bias. By leveraging simple data such as site coordinates and inter-site distances, the study seeks to shed light on the evolution of settlement hierarchies and Messenia's broader socio-political landscape.

Conducted as part of a master's thesis, this research represents one of the few applications of spatial interaction models in Greek archaeology. It aims to highlight both the advantages and challenges of using computational tools to investigate ancient political networks. Ultimately, the findings will contribute to debates on Mycenaean state formation and help establish a framework for future archaeological studies exploring complex political structures.

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325. Spatial Interaction Models of Fort Networks: Insights from the Zhidao Highway (China)

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This study employs spatial interaction modeling to explore the logistical organization of the Qin-Han Dynasty's northern frontier, with a specific focus on the Zhidao highway, a key military route connecting administrative and frontier regions. By analyzing the spatial relationships among 165 forts and simulating traffic flows, the study evaluates how these models align with archaeological evidence and historical records. The findings demonstrate the strategic integration of forts, defensive walls, and transportation networks in facilitating frontier governance and military mobility. This research highlights the potential of computational modeling for addressing the complexity of ancient urban and frontier contexts, including fragmented datasets and multi-scalar interactions. Through the case study of the Zhidao highway, it showcases how spatial interaction models can provide fresh insights into urban-hinterland dynamics, movement, and the broader logistical strategies of ancient states.

147. Assessing results from spatial interaction model

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Spatial interaction models have been successfully applied to investigate settlement hierarchies and interaction strengths using limited archaeological data, such as the early work of Rhill and Wilson (1987). These models estimate various flows between settlements based on interaction costs that are generally derived from their geographical positions. The models also estimate settlement importances. The geographical characteristics of the study region are used to estimate the difficulty of exchanges between different settlements, considering factors such as travel distances, costs, or times. Some of these models incorporate a dynamic aspect that can be utilised to examine the variability of interaction strengths over time, be it days, months, or centuries.

A primary challenge in spatial interaction modelling is the calibration of numerical parameters. Researchers commonly rely on extensive comparisons of model outputs across a pre-determined grid of plausible parameter values. Due to the complexity of these outputs, comparisons are often conducted using simpler aggregated measures. Rhill and Wilson pioneered the use of terminals, settlements that dominate the flow matrix, and examined the number of terminals as an aggregated measure. More recently, Davies et al. (2014) investigated additional properties of the Nystuen-Dacey graph, formed by connecting terminals to the settlements they dominate. They also compared the distribution of settlement importance with the distribution of their actual size (in terms of occupied area). By utilising these aggregated measures, stable zones can be identified where parameter modifications have limited effects. Researchers then typically examine a selection of full results within these stable zones using expert judgement.

A major limitation of these approaches is the information loss incurred by assessing variability through aggregated measures. For instance, using the number of terminals presents two key issues. Firstly, it transforms continuous values (importances) into discrete values, resulting in artificially sharp transitions between similar importance distributions. Secondly, it conflates diverse scenarios that share the same number of terminals.

Ideally, we would directly identify regions in the parameter space that correspond to stable results in terms of inter-settlement flows and importances. Selecting a representative example from each region of the parameter space would provide a more systematic approach to extracting relevant and diverse outputs for further comparison with material evidence. This approach aligns with the typical goals pursued when clustering data. By clustering flows or importances into homogeneous groups, we identify comparable results. The cluster barycentre can be considered a representative example. Finally, each cluster is associated with the set of parameters that generated its elements, effectively partitioning the parameter space into zones of stability.

Clustering methods rely on computing dissimilarities between objects to be clustered, with the quality of results heavily influenced by the chosen dissimilarity metric. For example, two results can be compared by summing the squared differences in importance values across all settlements. A similar calculation can be applied to compare flows between settlements. Using this definition, the barycentre of a set of results is determined by averaging the quantity of interest (importances or flows) across the cluster. Results obtained with this dissimilarity metric are promising and offer a principled approach for systematically analysing model outputs.

However, this solution overlooks geographical positions (or interaction costs). Consider two configurations of settlement importances associated with different parameterizations, differing only in terms of settlements A and B: in the first, A is significant, while in the second, B is significant. Using the squared difference metric, the dissimilarity between these configurations is independent of the geographical positions of A and B. Nevertheless, if A and B are close (relative to other settlements), the difference between configurations represents a local reorganisation of settlement influences. Conversely, if A and B are distant, the difference signifies a more substantial, global reorganisation of exchange patterns. This should be reflected by having different dissimilarities between the two configurations. Therefore, it is necessary to incorporate both model output quantities and the underlying geographical structure into the dissimilarity metric.

We propose utilising transportation theory to integrate both aspects. Initially formalised by G. Monge and refined by L. Kantorovich, the optimal transport problem involves finding a plan to move a collection of goods from various locations to new destinations, minimising the total transportation cost. The cost of moving a unit of goods between two locations is determined by the distance between them. The minimal cost required to transport a collection of goods to their new destinations can be interpreted as a dissimilarity measure between the two configurations, known as the Earth Mover’s distance.

This approach can be directly applied to our context as a method for computing dissimilarity between two sets of settlement importances: importances represent the goods, while settlements represent the locations. Although settlement positions remain fixed, differences in importances between the two configurations necessitate reallocation among settlements. The cost of reallocating a unit of importance is set to the distance between the settlements (or to their interaction cost). This elegantly addresses the aforementioned problem, as the dissimilarity between the two abstract configurations is simply the distance between A and B. A similar approach can be derived for flows between settlements. Additionally, one can compute barycenters that are consistent with the Earth Mover's Distance, serving as representative examples of each cluster.

We illustrate the benefits of this approach using the settlement dataset of Rhill and Wilson (1987), comprising 109 population centres occupied in Late Geometric Greece. We automatically identify stability regions in the model outcomes by clustering them using the Earth Mover’s distance. We represent each region by a typical configuration computed as the barycenter of the corresponding cluster. Our results are similar to those of the original paper and the refined analysis by Evans and Rivers (2017). Our approach offers a systematic and efficient method for conducting such analyses, reducing the reliance on manual selection of relevant configurations. It is not limited to the Rhill and Wilson model but applies to interaction models in general as long as they produce flows between settlements or importances for them.

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6. Landscape archaeology of the Mazovian Centre of Ancient Metallurgy. Spatial analyses of the settlement pattern in the Łowicko-Błońska Plain, Poland

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The Mazovian Centre of Ancient Metallurgy (hereinafter MCSH) was one of the three main iron production centers in the area occupied by the Przeworsk culture during the late pre-Roman and Roman periods. It is located to the west of Warsaw, Poland, and its area primarily covers the eastern part of the Łowicko-Błońska Plain. Despite a long history of research and good recognition of the MCSH in surface surveys and excavations (Woyda 2005), only a few works focusing on more detailed aspects of its functioning have appeared to date.

One insufficiently discussed issue is the settlement pattern, understood as a model of spatial organization of the settlement system in a given region (Willey 1953). This issue is seen as crucial for understanding the processes at the centre of metallurgical production, where the choice of the right location may have been one of the main factors enabling iron smelting. It is also important to recognize the spatial relationships that existed between its various elements, such as settlement sites, production sites and cemeteries.

Another important issue is the area used economically by the Przeworsk culture community in the MCSH. For the existence of intensive iron metallurgy, the most important elements were the resources of bog iron ore, clay, charcoal (wood), and water (Orzechowski 2013). For metallurgy, all these elements had to be present in the vicinity. The question remains how the individual settlements were established in relation to the local deposits and how the spatial organization of the settlements changed over time through the gradual depletion of these resources. The studies presented will also attempt to answer the question of whether the location of the earliest iron production centre of the Przeworsk culture was dictated by favourable environmental conditions, or whether factors beyond environmental determinism should perhaps be considered as reasons behind the origins of the MCSH.

According to preliminary observations, ancient metallurgy in Mazovia covered a much more extensive area. In addition, it is possible to distinguish areas with traces of metallurgy that have not previously been included in MCSH studies. Notably, there are clusters of sites with traces of metallurgy in the vicinity of Nadarzyn, Piaseczno, Łomianki, along the Jeziorka River, and by the mouth of the Bzura River. Metallurgical sites are also documented in right-bank Mazovia. Through queries conducted at the Provincial Office of Monument Preservation, it has been possible to confirm the presence of production sites with clusters of slag pit furnaces within the aforementioned regions.

The collected GIS database contains information on more than 1,000 archaeological sites. This data will be combined in the GIS with materials concerning deposits, soils, geology, hydrography, and topography (DTM) of the area. The work involving GIS will utilize tools such as near analysis, density analysis, cluster analysis, spatial networks, least-cost path analysis, etc. The results will be supplemented with other spatial analyses and statistical analyses, such as Average Nearest Neighbour and Ripley K-function. The analyses will focus on recognizing the settlement pattern and the relationship of the known patterns to the natural resource deposits.

By employing spatial analysis methods within a GIS environment to recognize the factors mentioned above, we can gain insights into the assumptions that influenced the population of the Przeworsk culture in their decisions to establish specific settlements or clusters of settlements in the area. This approach will enable us to reconstruct the settlement patterns and examine the relationships between individual settlements and available resources. Consequently, we will better understand the extent of the explored territory and the mobility of the Przeworsk culture groups that inhabited the MCSH area.

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422. The inscrutable ways of God? Deciphering Egyptian religious landscape strategies in late antiquity through computational analysis.

Pau de Soto (Universitat Autònoma de Barcelona)*

The Coptic Project investigates the large-scale exchange systems that operated in Late Antique Egypt (4th-7th centuries AD) and their impact on the Coptic monastic landscape. Following the the Imperial Roman Period, Egypt emerged as a prominent religious region, witnessing the expansion of Christianity across a network of past Pharaonic cultic structures and territories. In this political, economic and social context, the Coptic monastic settlements emerged outside the urban cities. This landscape configuration was initially identified as eremitic communities despite the most recent research is challenging this hagiographic perspective (Papaconstantinou 2001).
A multi-proxy analysis, which combines archaeological data, road networks, economic papyri documentation, computational analyses and network science, allows to obtain a more complete picture of the Egyptian landscape in Late Antiquity. In order to conduct our research, we have created a comprehensive database of all Coptic monastic settlements devoted to the Coptic cult, including such as monasteries, eremites, lauras, churches, and other types of communities, which were either male or female. The database has been designed to allow a detailed characterisation, encompassing the following variables: type, chronology, gender, pre-use building, and religious significance, among others. Furthermore, our analyses include all documented Roman roads extracted from the Itiner-e project (Brughmans et al. 2025). In addition to the archaeological sources, we have also employed other historical data, namely monastic papyri, which provide a substantial corpus of economic information pertaining to individuals, locations, financial transactions and the relationships between monasteries and settlers. By combining these contrasting data sets with a variety of methodological approaches, we have developed a novel understanding of these communities during Late Antiquity. The integration of location, chronological, typological monastic data, road structure and functionality, and economic insights extracted from the papyri within computational models has enabled us to delineate the landscape configuration of Coptic Egypt (de Soto and Guimerà forthcoming).
The objective of this presentation is to introduce the research scope, methodology and preliminary results. Our multiscale methodological approach enables us to characterise the transformation and resilience of Egyptian sacred landscapes over centuries. Some of these preliminary results challenge past interpretations of Coptic attitudes and cultic strategies, such as eremitism and the search for isolation. Conversely, our studies provide historical and archaeological evidence to justify their selected locations based on road connectivity and accessibility.

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431. Modelling Settlement Dynamics and Interaction: Exploring the Landscape of the Bronze Age North-East Peloponnese

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Introduction

Spatial interaction models have proven valuable in archaeological studies for exploring questions of settlement evolution and socio-political dynamics (Paliou and Bevan 2017). These models are based on the premise that interactions between sites can influence the formation and development of spatial and socio-political structures. This study applies a spatial interaction model to the context of the North-East Peloponnese during the Bronze Age period to simulate inter-settlement networks and examine their socio-political implications. The importance of cultural networks and their contribution to the formation of the political geography of the region has been attested from qualitative studies and economic models (Galaty and Parkinson 2007).

In this study, a spatial interaction model is employed to explore patterns of asymmetry between settlements, assess the emergence of hierarchical relationships, capture the persistence of dominant locations and understand their evolution over time. By comparing the model outputs to empirical settlement data from prior surveys, this study tests hypotheses proposed in qualitative research while offering new insights into the socio-political organisation during the Early, Middle, and Late Bronze Age periods. The concept of landscape ‘affordances’, offers a fresh approach to the conceptualisation of complex relationships that led to the formation of the socio-political landscape of the region.

Methods and Materials

The approach presented here is based on a spatial interaction model developed by Davies et al. (2014), for analysing settlement dynamics in Bronze and Iron Age Syria. Adapted to the NE Peloponnese, the model integrates data on settlement size, inter-site distances, and considers trade impedance and environmental constraints to simulate interaction flows during different phases of the Bronze Age. Settlement data is compiled from existing surveys, while site sizes, which are used as proxies to assess the attractiveness of settlements and to validate the model, are categorised into small, medium, and large due to inconsistencies in recorded measurements. Cost matrices are generated using a 25-meter DEM in ArcGIS Pro, accounting for travel distances and environmental barriers. The utility of the interaction between pairs of sites is computed iteratively, with settlements growing in size proportionally to their total incoming interaction flow. The outputs, represented as nodes and arcs – sites and flows – are compared to the empirical size data to identify best-fit parameters.

Results

The simulated networks reveal diachronic variations in connectivity, site prominence, and regional organisation across the Bronze Age. Outputs match empirical records variably, with key sites often identified, though discrepancies emerge due to spatial distribution and parameter sensitivity. Despite deviations from empirical sizes, the model consistently captures locations favourable for larger settlements and consolidated regional networks, demonstrating its potential to identify persistent spatial patterns. Results also suggest that changes in parameters, particularly those governing site attractiveness and long-distance connections, strongly influence settlement hierarchies.

Discussion

The model highlights the persistence of regional networks over time, as documented in the literature, and it underscores the role of regional exchange systems in shaping socio-political identities prior to the emergence of the Late Bronze Age palatial organisation. The gradual consolidation of networks and inter-site connections contribute to the formation of these identities, whilst suggesting the coexistence of localised and regional networks, a concept supported by archaeological studies. Additionally, the findings emphasise the complexity of factors influencing site dominance and socio-political organisation.

This study contributes to debates on the political organisation of the Aegean Bronze Age by offering a quantitative framework for exploring settlement hierarchies and socio-political dynamics. The spatial interaction model demonstrates its potential as a tool for testing qualitative hypotheses, identifying persistent patterns, and providing a diachronic perspective on settlement evolution. When contextualised in the theoretical concept of affordances, it offers a nuanced approach in understanding complex historical processes and patterns of human behaviour. The findings challenge linear narratives of socio-political centralisation, emphasising the interplay between regional and localised dynamics. They also highlight the importance of integrating quantitative models with archaeological data to refine interpretations of complex spatio-temporal processes.

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531. Revealing 2000 years of the Beauce landscape through headland field boundaries

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This paper builds on a PhD thesis recently defended by the author and centered on the fabric of agrarian landscape in the region Centre-Val de Loire of France, with a diachronic approach. The remains of thousands of archaeological structures, forming a complex network of parcels and fields were discovered thanks to the availability of a new Digital Elevation Model (DEM) with enhanced quality. The goal of the study was to map these structures, understand their formation processes and their relation to the landscape and the archaeological sites they surrounded.

The main source for this study is a high-quality DEM named "RGE Alti" and provided by the French national Institute for Geographical Information (IGN). The focus was an area of 8000 km^2 situated in the northern half of the Centre-Val de Loire region, between the rivers of Loire in the south, the Loir and the Eure in the west, and the Loing in the east. In this area, linear structures in elevation were systematically vectorized amounting to hundreds of thousands of line segments being drawn. After the completion of this inventory, a series of morphological characteristics were chosen to be extracted or calculated on each structure. These characteristics were then used in a quantitative approach to calculate a Principal Component Analysis (PCA) and a Hierarchical Agglomerative Clustering (HAC) allowing the creation of classes and groups of structure based on the similarities in their morphologies.

The direction of the different structures was also calculated to use as a point of comparison between groups of linear structures. The direct comparison of directions between structures is often complicated by the circular nature of this characteristic. The use of alternative indices, mainly the circular variance and the circular average, allowed me to overcome these problems and compare the difference between the directions of groups of linear structures.

These quantitative methods offered new insight into the planning and the understanding of this network of field structures. The morphology of the structures is generally characterized by a small height, from a few centimeters to 50 or 60 centimeters and a width of a few meters to 60 or 70 meters. Their lengths are also variable, stretching from a dozen meters to several kilometers. While they appeared similar based on the study of the DEM, the morphology of the structures also revealed a clear distinction between the structures situated below contemporary forests and the ones outside in open grounds. Furthermore, the discovery of important axes, characterized by higher, larger, and bigger structures revealed a possible planning of the implantation of fields around "Beaugency", between the cities of Orleans and Blois. A dozen main axes seem to have been implanted perpendicular to the river of Loire, stretching for sometimes up to 10 kilometers in the land. These elongated coaxial fields were then subdivided into smaller parcels.

Another important result was related to the nature and chronology of these structures. Most of the linear structures discovered (70 to 80% in the municipalities tested) were situated on the boundaries of fields shown in the cadaster implemented in France in the first half of the 19th century, the Napoleonian cadaster. For the most part, these structures seem to have been created thanks to their position as headlands, the place on the small boundary of an elongated parcel where the plough turns before starting the next furrow. It is known, in agrarian history and archaeology, that these actions can lead to the accumulation of soil on the headland, creating a small but very long elevation, that can reveal hidden fields even after the boundaries changed. The structures discovered on the DEM were still active, for most of them, as field boundaries in the 19th century.

To understand if this link dated back further, I compared the directions of the networks to known archaeological sites in the nearby areas, from Protohistory, Gallo-roman and Medieval periods. Several networks with differing directions were identified, but at least three of them, spreading on thousands of square kilometers, show a link between the direction of the dozens of thousands of structures and those of the hundreds of archaeological sites close to it, from the Iron Age to the modern period. It seems likely that the pattern of fields was already implemented in this densely occupied region, with a lot of agricultural dwelling and fertile soil, since the Iron Age, even if the headlands could be formed later.
This study shows the resilience of landscape organization, despite major evolutions such as the implantation of open field that was a massive transformation in the medieval era for the Beauce country. It also revealed the weak impact on these fields' organization of the main road networks, as the creation of regional Roman and medieval roads between the main population centers did not profoundly modify the fields directions and organization.

As open high quality DEMs, based on LiDAR or photogrammetry are becoming more and more accessible, in France, Europe and beyond, studies on a smaller scale are also going to become more and more accessible. The mere scale of these works will require to integrate quantitative methods and to create, or rediscover tools that were previously ignored. These will allow the archaeological community to understand all kinds of landscapes, and the impacts of societies on their environment.

125. Divergent Developments: The Impact of the Roman Limes on the Structure of the Settlement Landscape in Borderland Communities

Mark Groenhuijzen (Utrecht University)*

The Lower Germanic limes, which formed a frontier of the Roman Empire from the 1st to 5th centuries AD, is thought to have profoundly impacted borderland communities on either side of it. Especially the Lower Rhine region is a clear example of regional variability of socio-economic responses to Roman imperialism on the basis of traditional archaeological studies. The Batavian civitas, despite heavy involvement in the Roman military, continued local tribal identities throughout the Roman Period, while the regions directly south saw pronounced Roman economic influence, evident in the formation of a villa landscape. North of the Rhine, however, Roman involvement is assumed to be lesser after the first half of the 1st century, with the socio-economic structure remaining largely unchanged from the preceding pre-Roman Iron Age.

One of the aims of the “Constructing the Limes” project is to study the functioning of the limes and how it influenced borderland communities living on either side of this frontier zone. The objective in this paper is to test the prevailing views on how the Roman limes influenced settlement patterns in these borderland communities. Is it justifiable and quantifiable to speak of divergent developments in the structure of the settlement landscape of the communities living north and south of the Rhine?

As part of the “Constructing the Limes” project, a large site dataset of over 10.000+ archaeological sites was compiled across the Netherlands, Flanders and the western border zone in Germany primarily on the basis of archaeological data from national repositories, including Archis (Netherlands), PAN (Netherlands) and CAI (Flanders), as well as other sources. This dataset builds upon earlier initiatives, notably the “Finding the Limits of the Limes” project (2012-2018). The construction of this large site dataset enables cross-boundary research on unprecedented scale for the first time.

Using this large dataset, we divide our research area into systematic subdivisions. We define a limited number of typologies of the settlement landscape, in order to track the structural development of the settlement landscape in each of these subdivisions across our region and throughout the Roman Period. This allows for the quantified comparison of developments in settlement patterns. One important issue that is addressed is the influence of uncertainty, which is defined in our site dataset in multiple ways: chronological uncertainty, location uncertainty and uncertainty in interpretation. Another variable is the retrieval rate of archaeological sites: some areas have seen higher research intensity and have yielded higher volumes of sites, while others may suffer from a lack of research and even site erosion. These factors are taken into account dynamically to ensure the robustness and reliability of the analysis, thereby supporting an informed assessment of divergence in the structure of the settlement landscape across the frontier.

83. Food Production in the Workmen's Village of Amarna: An Activity Area Analysis Using Digital Humanities Methods

Sarah Klasse (German Archaeological Institute / Freie Universität Berlin)*

This paper investigates activity areas related to food production within the Workmen's Village (WV) of Tell el-Amarna, a city founded by Pharaoh Akhenaten during the 18th Dynasty (1539 – 1292 BCE, New Kingdom) in Egypt. The primary goal is to answer the question "Where and how was food produced within this planned settlement?". This study focuses on archaeobotanical and archaeozoological remains, along with tools used primarily for food production, to reconstruct the dietary and agricultural practices of the inhabitants. It implements Digital Humanities methods to carry out an Activity Area Analysis (Pfälzner 2015), to map and visually represent collected data, and to compare these findings with other ancient Egyptian and Nubian settlements.

This work is significant as it reveals how ancient Egyptians sustained a planned settlement that was dependent on, but spatially detached from the main city, through resourceful logistics. The findings show bread-making as the primary activity. Animal husbandry, mainly of pigs, provided meat, while diverse small-scale gardening offered additional food sources. The use of digital tools like QGIS and R enabled precise mapping of food production areas, showcasing how Digital Humanities methods can enhance archaeological research and provide insights into the organization of ancient communities.

The WV (Stevens 2016) is a planned settlement designed to house the workers responsible for building the city's royal tombs. It was isolated from the main city, requiring importation of water from the nearby city of Amarna via an in-between area where large water jars were transferred to the village, highlighting the complexities of water management in this desert environment. The study examines the settlement's reliance on such infrastructure to support its food production system, emphasizing sophisticated logistics to sustain a community in an arid environment.

Several materials are used in this study: Botanical remains found in various parts of the village were examined to identify which crops were grown, stored, and consumed. Emmer wheat is notably the most prevalent plant remain. This aligns with other finds, like barley and lentils, which were used as staples in the diet. Fruits like figs and dates and vegetables such as onions and garlic further reveal the diversity of foods available, often cultivated in small-scale gardening around the village. These botanical remains provide insights into agricultural strategies of a community living in a desert environment.

The study also considers animal remains, primarily from pigs, goats, and cattle. Pigs were particularly significant, with many bones found in the settlement, indicating they were a primary source of meat. The fact that pigs, unlike cattle, required more frequent feeding and water points to the villagers sophisticated management of livestock, even in a desert climate. Goats and cattle bones were also analysed, with goats serving as a secondary meat source and cattle being imported from the nearby city.

In addition to remains, the distribution of tools for food production is studied, including querns, ovens, and grindstones. The presence of ovens and bread-making tools suggests that bread was the primary food produced in the settlement. Tools like mortars and grindstones were widespread and indicate methods of processing grains, confirming that grain preparation was a central activity. These tools, combined with archaeological excavation data, help map out food production areas, highlighting which areas were used for specific activities, like grain grinding or baking.

Overall data from excavations, like maps, excavation reports and databases related to the WV are studied, to give an overview on the settlements structure and its excavation history. Key data comes from early excavations by Peet and Woolley (1921-1922), as well as later work by Kemp and his team (1979-1986 and ongoing, Kemp 2012, 190–95).
Several methods are used to understand food production of the village. By using Space Syntax Analysis, the research assesses movement patterns within the settlement. This method helps define areas where food production likely took place. An Activity Area Analysis is performed to identify specific areas where food production occurred. The spatial analysis is supported by mapping out the distribution of tools and remains across the village, helping to establish a clear connection between tool-use and the movement of villagers in and out of their homes during food production activities. The study implements the Geographic Information Software QGIS and the programming language R to analyse and visualize spatial distribution of food-related activities.
The analysis reveals that food production in the settlement was focused on bread-making, as indicated by the prevalence of emmer wheat remains and related processing tools like grindstones and ovens. Animal husbandry, particularly the rearing of pigs and goats, was prominent, with pig remains being the most common, indicating their role in the daily diet. Archaeological evidence suggests a high level of self-sufficiency in food production. Various fruits and vegetables were identified, indicating a diverse diet supported by small-scale gardening around the settlement.
Comparisons between the WV at Tell el-Amarna and other state-planned settlements, such as the nearby Stone Village or the Nubian settlements Sai and Amara West, is drawn. The Nubian Settlements adapted their food production to local conditions, with agriculture and livestock tailored to the environment. These comparisons highlight varied food production strategies across Egyptian and Nubian settlements.
In addition, a logical data analysis is conducted to reveal patterns in the placement of tools in excavated houses. This approach involved categorizing the presence of tools with binary criteria. Key findings included common locations: mortars were frequently found in front rooms, ovens in the back, and grinding stones rarely in central rooms. These patterns suggest typical layouts related to breadmaking, potentially informing expectations for unexcavated houses and aiding future comparisons with other partially-self-sustaining settlements.
The application of Digital Humanities methods has not only provided organized insights into food production in the WV but also highlighted the potential for these methods to be applied in future archaeological research. These tools allow for a better understanding of how ancient communities organized their food production. The study concludes with recommendations for further research, particularly the integration of new digital tools in Egyptological studies and examination of other settlements that might yield additional comparative data.

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251. Middle Neolithic Monuments in Austria: Insights from Site Analysis and Predictive Modelling

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Introduction

Kreisgrabenanlagen (KGAs), a specific type of circular enclosures dating from the Middle Neolithic Period (4850/4750–4650/4550 BC) are recognised as the earliest monumental buildings in Central Europe. Although each site is unique, they share a common conceptual scheme, characterised by a circular layout, V-shaped ditches, palisades and placement in a settlement environment, as defined by Trnka (2005) and Petrasch (2012). Their purpose is still debated with a tendency towards multi-functional sites within the socio-cultural or socio-ritual sphere.

At least 200 KGAs are currently known, following the European Loess Belt in Germany, the Czech Republic, Austria, Poland, Hungary and Slovakia. Most of them have been discovered from aerial photographs, visible as soil or crop marks. The distribution of sites is concentrated in intensively used agricultural areas. Following initial observations made in the 1980s, common site parameters such as aspect, slope, soil type and proximity to water have been discussed by Neubauer (2010), indicating the potential for predictive modelling.

This study aims to identify site parameters that influence the distribution of Middle Neolithic KGAs in Austria (n = 57) and to use them for predictive modelling of potential sites. A statistical evaluation of the distribution of the sites is followed by an analysis of topographic, hydrographic and cultural parameters affecting site placement. The final model is validated to assess its predictive power.

Materials and Methods

The datasets used in this study are either open access or were kindly provided to the authors. ESRI's ArcGIS pro 3.2.2 and 3.3.1 were mostly used, along with QGIS 3.27.11 and Microsoft Excel. All datasets were converted to EPSG 32633 (WGS 1984 UTM 33N).

The study area is based on the distribution of the Middle Neolithic sites, which were buffered (r = 40 km) and clipped to the national border. In order to approximate the Middle Neolithic topography and to avoid distortions caused by modern transport routes, these were removed from the DTM.

All published KGAs in Europe were mapped to identify core regions based on their proximity of location. Within these core regions, Voronoi polygons were created and used to quantify site density (KGA/km2). Since predictive modelling relies on a non-random distribution of features, Average Nearest Neighbour analysis and Ripley's K-function test were performed.

The topographic parameters were derived directly from the DTM, by either using tools or calculated from their equations (Table 1) and classified using the Natural Breaks method.

Toolbox/Equation	Parameter(s)
Surface Parameters	slope, aspect
Relief Visualisation	Sky-View-Factor
Geomorphometry & Gradient Metrics	Heat Load Index, Slope Position Index
Visibility Analysis	Visibility Index
$DEV = \frac{z_0 - \bar{z}}{SD_{Elevation}}$	Deviation from Mean Elevation
$TWI = \ln\left(\frac{A}{\tan(\beta)}\right)$	Topographic Wetness Index

Table 1: Toolboxes and Equations used for the calculation of the site parameters

Proximities to contemporary settlements and small watercourses were calculated as Cost Accumulations using Tobler's Hiking Function, which is based on the anisotropic cost of moving across the topography with an additional isotropic cost surface to model the difficulty of crossing watercourses. The Distance Accumulations were classified using meaningful timespans and proximity to watercourses was additionally classified using Natural Breaks.

Due to its non-parametric nature, the Frequency Ratio (FR) was chosen to quantify the influence of the classes per site parameter: $FR(p,c)= Pix(KGAc)/\Sigma Pix(c) Pix(KGA)/\Sigma Pix(SA)$

After calculating the FR values in Microsoft Excel, they were normalised using the normalisation formula: $xnorm= x- xminRangex$

Weighted Overlay was used to calculate the predictive maps, using the normalised FR values as weights. The results were classified using equal intervals and validated by calculating Kvamme's Gain, which compares model accuracy to precision: $Kvamme's\ Gain$=1− % $Area\ of\ class\ very\ high$% $Sites\ within\ class\ very\ high$

Additionally, the models' predictive power was tested with a cross-validation variant, excluding one-third of the sites not discovered on aerial images in each iteration.

Results

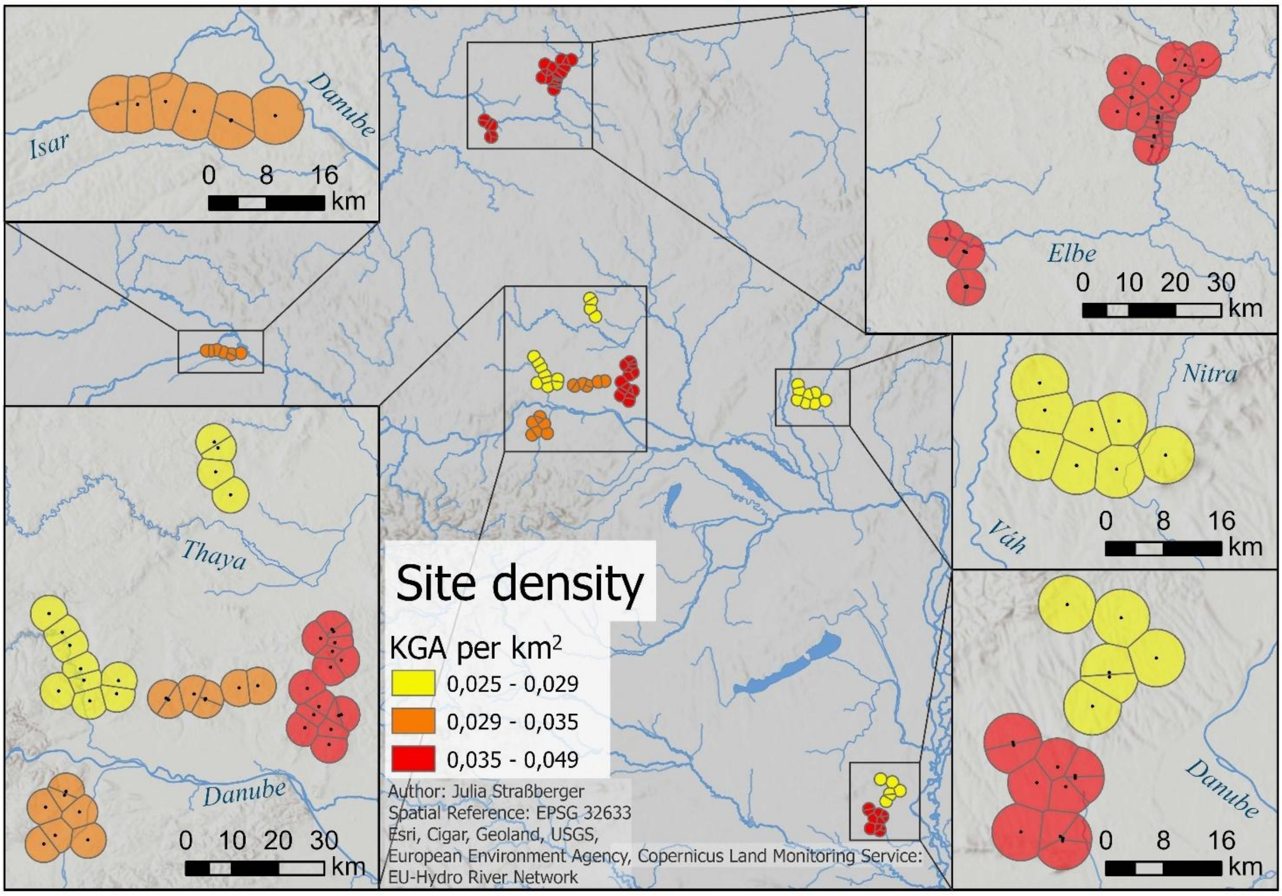
The analysis of all European KGAs identified 11 core regions, spread across the whole area, with densities between 0.025 and 0.490 KGAs/km^2. Within the study area, 4 core regions contain 60% of the Austrian KGAs. Significant clustering on a global scale was detected by Nearest Neighbour Analysis with a <1% likelihood of random distribution. Ripley's K-function test revealed significant local clustering, starting at distances greater than 500 m.

KGAs are usually found in dry areas, corresponding to gentle and moderate slopes, sometimes in fairly flat terrain. According to the Sky-View-Factor, very open terrain is clearly preferred. The Frequency Ratio of the Heat Load Index indicated a location in medium to warm areas. The assumption, that KGAs are located in highly visible areas was incorrect, as there was a significant correlation with medium visibility. In terms of soil type, there is a preference for moderately developed, fairly fertile soils originating from loose or calcareous sedimentary materials (e.g. loess). KGAs are generally located close to small watercourses, usually within a 10 min walk. Proximity to contemporary settlements proved to be very important, with most being less than 3 minutes away.

For the predictive model based solely on topographic and hydrographic parameters, two sites are entirely within the very high probability area, resulting in a Kvamme's Gain of 0.54. With a threshold of >80% of the site area in this class, the number of sites increases to 13. When proximity to settlements is included in the model, Kvamme's Gain increases to 0.96 (2 sites fully within class very high). In this case, 15 sites have more than 80% of their area classified as very highly probable. The models generated during Cross-Validation showed only minor differences to the originals, highlighting their accuracy.

Discussion

The wide distribution of the 11 core regions and the clustering tendency of KGAs suggest, that there is a high potential for future site discoveries in areas of rather low site density. This corresponds well with the results of the prediction maps, which indicate very high and high site probability even in areas with very few or no known KGAs. The initial observations on site placement were fully confirmed by the Frequency Ratio analysis on the influence of site parameters. The proximity to contemporary settlements, which is also a mandatory criterion for site classification, has been shown to be statistically evident. However, it should be noted that it may be slightly biased due to more intensive research in the vicinity of the KGAs. The difference in Kvamme's Gain was expected, as the model including the cultural parameters has a much higher precision due to its restriction to areas close to settlements. However, this makes the model more susceptible to bias, as the distribution of settlements depends on the state of research, leading to concentrations and empty areas. It is therefore recommended to compare the two models when using them to answer specific questions. The predictive maps serve as a basis for future research on KGAs, especially for targeted site prospection.



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20. Mapping the Lost City: Using Historical Texts and GIS to Rediscover Aqranus

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Aqranus is a magnificent city located on a high mountain", states the 12th-century Arab geographer Idrisi (Idr., 4, 4). Today, there is unanimous agreement among historians that Aqranus, as mentioned by Idrisi, refers to the mediaeval city of Kran (Κρηνοῦ/Κρουνὸν/Κρινῷ/Кръnъ). Kran is frequently mentioned in sources like Niketas Choniates, George Pachymeres, Manuel Philes, and the charter of Bulgarian Tsar Ivan Asen II. Located in the heart of mediaeval Bulgaria, Kran served as an administrative centre and, for a brief period, even became the capital of a breakaway state.

The exact location of mediaeval Kran has long intrigued Bulgarian scholars. Most researchers place it in the Kazanlak Valley in Central Bulgaria, associating it with the fortress near the modern-day town of Kran, close to Kazanlak (Stara Zagora Province). Others propose fortresses near the village of Tazha, west of Kazanlak. Recently Ivan Ivanov, Marina Minkova, and Nicolai Ovcharov suggested that the modern-day town of Kazanlak itself may have been the historic Kran. Meanwhile, a third group, including Dimitar Yankov, believes the city was located east of the Kazanlak Valley.

While the text-based debate increasingly leans toward the fortress above modern-day Kran, I test the existing propositions by modelling distances between Kran and its historical neighbours in GIS. Idrisi mentions that Aqranus is six days' march from Istibuni (modern-day Ihtiman, Western Bulgaria), 40 miles from Farui (modern-day Stara Zagora, Central Bulgaria), and four days' march from Lufisa (modern-day Lovech, Northern Bulgaria). It is generally accepted that 1 mile in Idrisi is approximately 1.5 kilometres, and a day's march is around 23-25 miles (Nedkov 1960, 17). I translate these measurements into GIS using three increasingly sophisticated methods. First, I create buffers representing distances from the respective cities and explore their intersection (Kran should be located where the three buffers intersect.) Second, I use the movecost package in R (Alberti 2022) to calculate accumulated anisotropic slope-dependent movement costs around the neighbouring cities and explore their intersections. Third, I explore the full length of these distances within a mediaeval road network between the three cities and see their intersection.

The initial results show that as the geographic models increase in realism, the possible location of Aqranus moves progressively closer from the east to the Kazanlak Valley.

Since any historian will emphasise that relying solely on one historical source is a critical mistake, I bring in additional sources for comparison. For instance, Niketas Choniates mentions that Krenos is located on the road between Tarnovo (modern-day Veliko Tarnovo, Central Northern Bulgaria) and Beroe (modern-day Stara Zagora). According to the charter of Bulgarian Tsar Ivan Asen II, the Kran region bordered on the territories of Borui (modern-day Stara Zagora) and Tarnovo. I incorporate these claims as additional guides for locating the city. The combination of all methods and historical references should bring us closer to the true location of Aqranus/Κρηνοῦ/Κρουνὸν/Κρινῷ/Кръnъ.

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473. Divisions and Connections in First Millennium BC Central Crete: A Geospatial Approach to Borderlands

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In central Crete, Greece, the emergence and development of the city-state organization during the first millennium BC shaped a highly compartmentalized landscape. This study explores the dynamics of borderlands – zones located on the edges of city-state territories – highlighting their dual role as areas of separation and connectivity. By integrating quantitative analyses and GIS-based modeling techniques, this research reconstructs the borders of ancient polities and investigates the role their adjacent borderlands played in the economic and social organization of ancient Crete, particularly in relation to agricultural and pastoral activities.

Because only very fragmentary epigraphic documentation is available on central Cretan borders, a modeling approach has been developed in this study. Out of the dataset of settlements occupied during the first millennium BC, settlements whose long-term history suggests an important role in the spatial structuration of the landscape have been extracted thanks to a State Sequence Analysis of their evolutionary trajectories based on Optimal Matching (Drillat 2022a). Around these central places, small territorial units have been modeled with Least-Cost Site Catchment Analysis, a method which already proved its efficiency in other Greek city-state contexts (Fachard 2016; Drillat 2022b). Around the borders thus modeled, borderlands are defined as buffer zones to which are excluded areas too close to important settlements in terms of cost-distance, to keep in the borderland definition an aspect of (spatial) marginality. Finally, the study of borderlands themselves is performed using terrain analyses and by studying the evolution of settlement patterns within borderlands over time.

The research identifies a dynamic evolution of borderlands across the first millennium BC. In central Crete, they appear to be mainly constituted of hilly or mountainous areas. During the Archaic period (600-480 BC), a peak in borderland cultivation is observed, evidenced by an increase in farmsteads and small villages concentrated in low-slope areas within the borderlands. However, in following the Classical (480-323) and Hellenistic (323-66) periods, a decline in cultivation and a transition to pastoralism is visible in borderland areas, as reflected in settlement patterns and epigraphic treaties documenting shared grazing rights between neighboring city-states. The presence of extra-urban sanctuaries along borders further underscores the role of borderlands as spaces of connection and interaction between polities.

The shift in the economic use of mountainous borderlands can be partly attributed to environmental changes. Paleoenvironmental studies and historical sources indicate that the Archaic period offered more favorable conditions for cultivation than later periods. Concurrently, the consolidation of city-state organization during the Archaic period likely motivated the expansion of settlements into borderlands as part of territorial control strategies.

By combining quantitative and spatial analyses of settlement patterns, land use, and terrain, this study highlights the complex nature of central Cretan borderlands during the first millennium BC. These areas functioned as zones of both cooperation and competition among neighboring city-states, shaped by the interplay of sociopolitical and environmental factors.

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498. Byzantine Landscapes: Mapping Trade, Defense, And Pilgrimage In The Peloponnese

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Introduction: The Byzantine Peloponnese, with its rich tapestry of urban centers, rural monasteries, and coastal fortifications, represented a complex and dynamic network of human activity. These networks played a crucial role in shaping the region's economy, defense, and religious practices, anchoring the Byzantine empire's foothold in southern Greece. Understanding these connections offers critical insights into Byzantine statecraft, the role of geography in settlement patterns, and the cultural integration of diverse communities through trade and pilgrimage. Yet, the spatial relationships between these nodes remain underexplored, particularly in their adaptation during periods of external pressure, such as Frankish conquest and shift-ing economic priorities.
This study investigates the spatial dynamics of these networks, focusing on key sites such as Mystras, Monemvasia, Geraki, as well as spiritual centers, monasteries, that linked rural hinterlands with urban centers. Through the application of Geographic Information Systems (GIS) and network analysis, this research attempts to address critical questions such as: How did geography shape the connectivity of Byzantine settlements? What role did trade and pilgrimage routes play in fostering regional cohesion? How did Frankish occupation alter Byzantine spatial networks? Computational tools are used to reimagine historical landscapes and their evolution over time, bridging the gap between academic analysis and public engagement. By employing interdisciplinary computational methods, this study reimagines the Peloponnese as a living network of interactions, offering a holistic view of its historical landscape. Beyond scholarly analysis, the project emphasizes the use of digital storytelling tools to make these connections accessible to wider audiences, providing a bridge between rigorous research and public engagement.

Methods and Materials: This study integrates archaeological, historical, and environmental datasets to reconstruct the Byzantine networks of the Peloponnese. Digital Elevation Models (DEMs) derived from publicly available sources (e.g., NASA's SRTM) provided the topo-graphic basis for spatial analysis. Data on settlements, monasteries, and castles were sourced from published ar-chaeological and historical data. Routes were digitized from georeferenced historical maps and supplemented by OpenStreetMap for modern comparisons.
GIS tools, ArcGIS Pro, were used to conduct spatial analysis, while network metrics such as centrality and clustering were computed using Python packages. Temporal mapping was employed to visualize the evolution between the Byzantine and Frankish occupation. Finally, ArcGIS StoryMaps was used for data visualization and storytelling enabling dynamic exploration of spatial patterns.

Results: The analysis reveals that Byzantine networks were heavily influenced by geography, with key nodes located near strategic passes, fertile plains, or along coastal trade routes. Monemvasia emerged as a central hub for maritime trade, while Mystras served as a key political and religious center. Pilgrimage routes connected rural monasteries to urban centers, reinforcing religious cohesion. Temporal mapping highlighted significant shifts during Frankish rule, including the adaptation of Byzantine networks to new economic and defensive priorities.

Preliminary visualizations include layered GIS maps of trade and pilgrimage routes, 3D models of key settlements, and animations depicting the dynamic evolution of the network over time. These outputs demonstrate the inter-play between geography, infrastructure, and human activity.

Discussion: The findings highlight the Byzantine Peloponnese as a highly interconnected landscape shaped by geography, resource availability, and socio-political factors. The spatial analysis emphasizes the strategic placement of key points, such as Mystras, Monemvasia, and coastal monasteries, which facilitated regional trade, defense, and religious cohesion. The network analysis re-veals a hierarchy of connectivity, with certain nodes exhibiting high centrality due to their geographic and functional importance. Comparisons between Byzantine and Frankish periods indicate that Frankish occupation introduced significant adaptations, such as new defensive priorities and shifts in trade routes, while still utilizing the existing Byzantine framework.

This research contributes to the broader understanding of Byzantine administrative and cultural systems, demonstrating how digital tools can provide new perspectives on historical landscapes. The integration of spatial analysis, network metrics, and digital storytelling not only enhances scholarly insight but also bridges the gap between academic research and public engagement.

The outputs, including interactive maps and temporal animations, offer practical applications for heritage management and education. These tools can inform site conservation strategies by identifying areas of historical significance and vulnerability. Moreover, the project under-scores the importance of computational archaeology in reconstructing complex historical systems, setting a framework for future studies to expand on with additional datasets, such as climate proxies or economic records.

Future research could apply similar methodologies to other regions, providing comparative insights into Byzantine connectivity across different landscapes. Additionally, the use of machine learning for pattern recognition in trade and settlement networks presents a promising avenue for advancing this field.

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360. A synthetic landscape characterization of monumental Anglo-Saxon funerary land use

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1.1 Introduction

In the late sixth century to the early eighth centuries AD, highly-furnished burial under isolated mounds became a hallmark of the 'Anglo-Saxon' furnished burial rite. These burial sites number approximately 125 and are found across the eastern and central areas of the modern country of England. Anglo-Saxon barrows are often accompanied by 'prestige' artefacts that demonstrate important connections with Early Medieval Europe, such as the garnet and gold-adorned helmet, swords, and shields from Sutton Hoo, or the ornate gold and garnet cross pendant from White Low. Most Anglo-Saxon barrows in the UK archaeological record were excavated in the nineteenth century by antiquarians interested primarily in their ornate grave goods. As a result, modern data mostly relates to grave goods and most research has reflected this data availability by focusing on grave goods, and the wider context of the barrows in the landscape has been neglected.

The grave goods, however, were sealed within the mounds soon after the funeral and the lasting artefact of the funeral became the mound itself. Phenomenological landscape research was undertaken in the 1990s at five prominent barrows, and it was suggested that the barrows may have been designed to act as landmarks, assembly places, and territorial markers (Williams 1999). In particular, it is thought the barrow builders selected prehistoric and Roman monuments to create a sense of place when constructing medieval Barrows, to claim legitimacy in a time where political stratification was emerging in England (ibid.). Significant questions remain about barrows' landscapes and whether the sites were truly isolated, or part of a larger 'funerary land use' space. This paper aims to answer these questions:

- What prehistoric and Roman monuments remaining in the Early Medieval period landscape were referenced, and was there a preference for certain monument types? Can certain features not observed by previous researchers be revealed by integrating ALS data and CRM/legacy datasets?
- Is there evidence for the engineering of past land use and preexisting monuments around Anglo-Saxon barrows to create a 'funerary arena'?

1.2 Data and Methodology

Addressing this project's research questions will require the use of three different data sources to construct the landscape context around the barrows. First, Airborne Laser Scanning (ALS) data from the Environment Agency's 1m LiDAR point cloud dataset will be used in 9 sq. km blocks around the barrows. Second, Cultural Resource Management (CRM) data relating to major UK infrastructure projects will be used to build the spatial context of land use, settlement, and preexisting monuments around the barrows. Third, legacy polygon data from the UK National Record for the Historic Environment (NRHE) and the Aerial Investigations and Mapping Project (AMP) will be matched to the surface expression of features observed in the ALS dataset. The project will start with an initial test series of three concentrations of barrows: Allington (Cambridgeshire), Lowbury (Oxfordshire), and Roundway Down (Wiltshire). These contain features in both upland and lowland landscapes and have good data availability for all three of the project datasets.

A synthetic quantitative methodology will be employed to enable the qualitative characterization of the Early Medieval period landscape. The methodology comprises four segments:

1. Filtering 1m Lidar data to create a hybrid raster that mitigates the chance of archaeologic features being filtered out during the DEM/DTM creation process.
2. Generation and segmentation of a stack of classified hybrid rasters that depict the surface expressions of known archaeological features.
3. Modelling ranked importance of preexisting features in the landscape around barrows.

The methodology will be scalable and will investigate the three project test areas listed above. The LiDAR creation process and spatial modelling will be undertaken in ArcPY and ArcGIS Pro. The 1m point cloud will be filtered to return codes 2 (Ground) and 6 (Building), with the addition of return values last, last of many, and single. This filtering process will minimize the chance of surface expression of archaeological features being removed. The resulting surface will be visualized with a series of standard techniques including Local Dominance, Sky View Factor, and Openness (Kokalj and Hesse 2017). The 'Segment Mean Shift' tool will be used to group continuous values of similar pixels. The ESRI 'Geomorphons Landforms' tool will also be applied to differentiate positive and negative features. These classifications will be related to known archaeology with the series of polygons based on UK CRM and legacy heritage data using the ESRI 'Forest-based and Boosted Classification and Regression' method. This process will use best of the series of visualizations to rank the known archaeology in terms of importance within a series of set distance bands from each barrow in the dataset.

1.3 Discussion

The resulting model output will be a series of regressions that rank the occurrence of different land use types in order of importance, with the closest monuments, settlements, and land uses being deemed more related (cf. Lucy 1999). This model will enable relationships between the barrows and the early medieval land use to be investigated in a qualitative manner. As a result of this research, future directions will be emphasized, including the 'scaling up' of the model for all known isolated barrow sites, and the possibility of including predictive modelling of landscapes without CRM/legacy training data.

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296. Leveraging AI for Enhanced Archaeological Data Extraction: Workflows for Textual and Image-Based Data

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The digitization of archaeological archives, particularly grey literature and archival photographs, holds immense potential for knowledge discovery. However, manual processing of such data is labour-intensive and often lacks consistency, making it a prime candidate for automation. This paper presents pilot implementation of re-usable digital research workflows that integrate text and image recognition technologies and AI models to streamline the analysis of archaeological documentation. These workflows are being developed for the purposes of enhancing (meta)data quality in the Archaeological Map of the Czech Republic (AMCR) digital repository and the ARIADNE Knowledge Base and discovery service.

Our approach to textual data leverages OCR/HTR and NLP tools to process archival reports, generating machine-readable text from a combination of manuscripts, typescripts, and printed materials. Through AI-driven information extraction techniques, we prepare models for automated segmentation and OCR/HTR processing of documents. These are implemented through the e-Scriptorium service and a newly developed dashboard. Based on the recognition outputs, LINDAT/CLARIAH-CZ open-source tools are applied for enhanced full-text search (tokenization, tagging, lemmatization, etc.; UDPipe), identification of keywords (KER), and named entities recognition (personal and place names, temporal data, AMCR vocabulary terms, identifiers, etc.; NameTag). The desired goal is to provide an integrated solution that will enable processing of legacy data and new uploads to the AMCR system and offer users more efficient services for searching and processing documents. A secondary objective is to simplify archival procedures by automating some of the steps involved in describing and archiving documents.

Simultaneously, we implement object recognition workflow for the detection and classification of archaeological objects, i.e. artefacts and other objects of interest, in archival photographs. By adapting and fine-tuning deep learning models (e.g., ResNet) for archaeology, we segment and annotate archival photographs according to AMCR controlled vocabularies. Two types of image datasets are used, firstly the images with single finds, photographed often on standardised backgrounds with scales, and secondly images with various content including photographs from fieldwork with trenches, burials, etc. Mappings of the vocabularies used across the datasets to the Getty AAT terms ensures interoperability in the context of ARIADNE infrastructure. This workflow streamlines the process of annotating archival photographs with terms from domain-specific controlled vocabularies and allows identification of archaeological artefacts and other objects of interest, which simplifies the otherwise time-consuming task of creating metadata and at the same time opens new doors for connecting and cross-referencing image data with textual data, e.g. the grey literature find reports.

The talk summarises the journey leading towards the implementation of both of the workflows, discusses what so far worked and what did not, including the dead ends we encountered and what we learned along the way. The current state of workflows' implementation will be demonstrated on pilot results based on the archival textual and image documents, showcasing how AI technologies can enhance archaeological archives processing and foster further research.

100. Digital Archaeology Data Archives as a Source of Creative Inspiration

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This paper examines the intersection of archaeology and non-archaeological audiences, analysing why and how creative professionals - such as artists, writers, and architects - seek access to digital archaeology data, heritage objects, and associated knowledge and materials. The research group adopted a quality-in-use conceptual approach for this study. The methodological model developed comprised: (i) interviews with non-archaeological professionals, (ii) eye-tracking experiments, and (iii) a post-experiment questionnaire.

The paper presents the research findings. In general, creative professionals are less interested in highly precise archaeological data; rather, they seek archaeological data as a source of new ideas, to understand common stylistic elements of prehistoric periods, and to experience the "spirit of the past." For this group, "inspiration" involves triggering a creative thought, discovering a new artistic direction, or stimulating a project. However, the archaeological objects or datasets themselves may not hold intrinsic significance beyond their initial inspirational impact. Members of this group may occasionally seek more detailed archaeological data for specific projects, transitioning from inspiration to improvisation. Despite this potential shift, their primary engagement with archaeological data remains sporadic, often unintentional, and driven by visual impressions or perceived creative potential. Typical comments from this group include: "I look first for where the eye falls"; "I reach for interesting shapes"; "the patterns of the fabrics led me to mould clay vessels"; "I was looking for a historical style"; "I saw a shard and started thinking of a story." They especially value digital archives that allow exploration of more complete archaeological sites rather than isolated artefacts.

The paper details (i) activities related to the use of archaeological data in creative work, (ii) specific data needs and types of reused data, (iii) various ways of accessing archaeological data through different types of digital archives, and (iv) the overall information behaviour of this target audience.

The main barriers to reusing digital archaeological data for this group are: (i) terminological barriers, naturally linked to the differences in activities among users of archaeological materials. Without formal training in archaeology, users may find specific terms, dating conventions, and cultural or regional attributions less accessible; (ii) search behaviour influenced by Google, favouring single-field searches or searches driven by visual material; (iii) a need for interpretative information, as "pure" archaeological metadata and data tend to feel somewhat "dry" for creative contexts; and (iv) a predominance of textual information over visual information.

This research was conducted as part of the TETRARCHs (Transforming Data Re-use in Archaeology) project.

36. Advancing reusable digital research workflows for built heritage conservation through Building Information Modelling

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The digitization of cultural heritage is increasingly recognized as a vital process in preserving, safeguarding, and valorising built heritage assets within contemporary cultural, societal and environmental frameworks. This is emphasized by initiatives such as the European Collaborative Cloud for Cultural Heritage and the New European Bauhaus, which promote interdisciplinary approaches to heritage management. Central to this process is the digitization and analysis of architectural, structural and materials data, which enables more informed and sustainable conservation decisions. With the development and enhanced availability of digital technologies like 3D scanning, Building Information Modelling (BIM), and data visualization tools, heritage professionals can now conduct more comprehensive analyses on the conservation condition of built heritage assets. These technologies foster interdisciplinary collaboration, optimizing maintenance and conservation strategies, and enhancing the integration and semantic enrichment of built heritage datasets.

One key advancement in this field is the integration of detailed digital representations, including digital twins and BIM, which incorporate data on material provenance, characteristics, and performance. This supports a comprehensive understanding of built heritage assets, facilitating more effective conservation, restoration, and rehabilitation efforts. However, a major challenge lies in the semantic structuring of heritage datasets, as emphasized in the literature (van der Heijden, 2023). Without effective structuring, it is difficult to ensure the meaningful use of the vast amounts of data generated through these processes, particularly in ensuring that datasets adhere to the FAIR principles (Findable, Accessible, Interoperable, and Reusable) and comply with existing technical standards. These standards are essential not only for interoperability between systems but also for enabling the long-term reuse of data across disciplines, including art history, archaeology, architecture, engineering, and conservation science.

In this context, state-of-the-art methods for characterizing materials properties, provenance, and performance play a critical role in the holistic management and valorisation of built heritage assets. When integrated into digital frameworks, these methods can enhance both the technical and historical understanding of built heritage. HBIM (Heritage BIM) serves as a key tool for the digital documentation, preservation, and conservation of built heritage, as it supports the incorporation of diverse datasets (Cursi et al., 2022), including metadata derived from historical investigations, as well as from in-situ observations and advanced sensing technologies. This multifaceted approach may improve the accuracy of digital representations and provide a more comprehensive overview of asset geometry, constituent materials, conservation state, and related contexts (e.g., social, environmental), which are crucial for informed conservation and management activities (Martinelli et al., 2022).

The aggregation of this diverse range of data into a single digital platform, offers a unique opportunity to foster multidisciplinary collaboration. For instance, data related to historical and architectural analysis, structural integrity assessments, materials' conservation state and durability and environmental performance analysis can be effectively integrated into a shared digital environment. This promotes not only a more cohesive understanding of the heritage asset but also facilitates a more effective collaboration across disciplines in the pursuit of a sustainably preserved, resilient and accessible heritage. Through this technical support, a holistic approach as HBIM can revolutionize the conservation workflow for heritage buildings, enhancing the diagnostic capacity and supporting more nuanced multi and cross disciplinary assessments.

This paper will present a comprehensive digital workflow, developed in the scope of the European Union project ATRIUM, which aims to address the challenge of integrating multi-disciplinary datasets into HBIM with the purpose of advancing heritage assessment, maintenance and conservation practices. The workflow builds upon existing standards and guidelines to ensure the quality and FAIRness of the diverse types of data for built heritage documentation required for assessment, maintenance, or conservation. It focuses on the integration of morphology analysis (3D geometry data) with conservation state analyses data, such as thermal, multispectral, and pulse measurements, along with archaeological data related to the built heritage asset construction and interventions. Social, environmental, and geospatial contexts are also considered, enhancing the depth and accuracy of digital representations.

The paper also discusses challenges faced in the development of the workflow, including the difficulties in harmonizing the practices, standards, and semantics for the digital information representations of built Heritage by the several implicated sciences. It addresses the scalability and sustainability of data repositories, especially given the large volumes of data generated during the digitization of heritage sites using advanced technologies like 3D scanning and HBIM. Strategies for data structuring, processing, and quality control are proposed to ensure long-term preservation and accessibility.

Based on a series of case studies, part of the ATRIUM project demonstrators, this paper will illustrate the application of the workflow in real-world settings. These demonstrators will include examples of heritage assessments and conservation projects where multidisciplinary expertise, including in sensing technologies, element modelling, and condition state assessment, have been employed. The workflow will be designed to facilitate the integration of analytical data related to materials, environmental characteristics, as well as provenance, and historical and cultural values, with the goal of creating comprehensive, accessible, and reusable digital representations of built heritage assets.

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258. 3D-Based Workflows for Archaeology and Built Heritage: the Case Study of the UNESCO World Heritage Site of the Ayios Ioannis Lampadistis Monastery, Cyprus

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Introduction

Despite advancements in 2D / 3D digitisation of historic structures (Chatzistamatis et al. 2023), and the democratisation of digital documentation and archiving, a remaining challenge is finding comprehensive, compatible, and reusable digital solutions that integrate heterogeneous, multi-disciplinary datasets in collaborative digital environments and enable their intelligent exploration. Such solutions should encompass Open Science practices, utilise large-scale research infrastructures compliant with the FAIR data principles, and employ digital tools capable of handling the complexities and peculiarities of built heritage (Lovell et al. 2023). Therefore, it is crucial to develop seamless workflows that are able to cope with the above, throughout the entire data-cycle process (acquisition, processing, archiving, interpreting and publishing) and aligned with specific heritage aims (conservation, restoration, interpretation, valorisation). In this context and within the ATRIUM project framework, we developed a 3D workflow for creating a collaborative open-access, web-based environment, enabling the integration and exploration of multi-disciplinary data and the 3D representation of Built Heritage assets, allowing a better understanding of their physical characteristics and cultural significance, for research-conservation-valorisation. The workflow was tested on a case study from Cyprus, the UNESCO World Heritage site of Ayios Ioannis Lampadistis monastery.

Methods and Materials

Located in the village of Kalopanagiotis in the Troodos Mountains (Cyprus), the Monastery is a historical landmark, still in use today, built in the 11th century and modified in the following centuries, which affected its form and elevated its cultural importance. Religious practicians, pilgrims and tourists visit the monument daily, posing additional challenges to its conservation and preservation.

When developing the workflow, our main constraints were the integration of multi-disciplinary, heterogeneous data sources, the provision of web access to such data and the facilitation of intelligent scientific visualisation to explore the heritage asset in all its intricate complexities. Consequently, we defined six main steps in the workflow: Project Preparation, Documentation, Data Processing, Asset Information Model (AIM) Authoring Process, Publication of the AIM in a collaborative web-based platform, and its Aggregation in large-scale research infrastructures. Each step comprises sub-actions involving the use of tools and the production of multi-format data, which need to be addressed when progressing through the workflow.

In the Project Preparation, the project's specific goals and desired outcomes are outlined, shaping the consequent roadmap. This process involves: assessment of the site, choosing suitable instrumentation, software applications, and methods, allocating resources, addressing legal requirements and authorisations, and creating protocols for data management and team collaboration. These preparatory steps are essential for creating a robust groundwork before commencing the Documentation Process, which involves multidisciplinary data collection, analysis, and archival research to decode the monument's identity and temporal development. Scientific fields like history, architecture, archaeology, geology, and environmental science provide contextual information, adding layers of cultural, historical, and spatial relevance. 3D documentation captures the monument's physical and aesthetic features, including textures, dimensions, and structural details. The captured data is processed (Data Processing phase) to create high-quality point cloud and mesh models that serve the generation of the 3D solid geometry. In the next phase, a knowledge database is developed, structuring historical, architectural, and conservation data obtained from the documentation process that contributes to the semantic definition of the building's structural and architectural components and the establishment of a hierarchical taxonomy of its systems. The AIM development requires the use of a software toolkit to increase the efficiency of the Documentation Process and address any interoperability or complex geometry issues. Once the AIM model is developed, the data enrichment process plays a key role in leveraging the model's potential by integrating heterogeneous information through tailor-made datasets for conservation and risk assessment purposes. The processed AIM is published on a collaborative web-based platform, utilising multiple scientific visualisation solutions answering the specific needs of experts in the monument's conservation, risk management, research or valorisation. The final Aggregation in large-scale data-sharing initiatives enables the advancement of heritage as an open-data-based collaborative discipline.

Results

Several digital tools and technologies have been employed in the 3D-based workflow. HBIM technology was employed to develop a multidimensional information model that integrates 3D geometry with crucial characteristics of the monument, such as historical records, conservation status, structural and architectural analysis. The AIM was published on the Inception Ice Core Engine, an open-standard semantic web platform, where the users can navigate the model's geometry, select building items or spaces, and query their metadata. The platform incorporates features such as the association of the building components to images, documents, and any studies related to the monument's conservation aspects and intangible heritage. BIM is effective for technically proficient users and therefore selected as a collaborative solution for those involved in the asset's architectural and structural conservation. Nevertheless, the selected BIM viewer, as the majority of its software, is proprietary, which entails limitations in data sharing, geometry editing, and compatibility with other software. These limitations highlighted the need to integrate open solutions during the 3D-based workflow implementation. Therefore, the model was also linked to other digital representations of the site, published on various web viewers (e.g., Potree, 3DHOP) embedded in EpHEMERA (Abate et al. 2017), a platform dedicated to heritage at risk. Currently, other open-source viewers for the site promotion (e.g., ATON framework) or the technical visualisation of BIM projects are under assessment for future integration.

Discussion

As the discussed case study demonstrates, a dynamic 3D workflow for research, conservation and valorisation of built heritage requires designing comprehensive, accessible, and collaborative steps throughout its pipeline. The selection of open data standards and software is instrumental in enabling transparent practices and seamless data integration. Consequently, the AIM is a dynamic tool that can be accommodated on various web platforms and constantly updated with new data, thus addressing the need for constant monitoring of a living monument like the Lampadistis monastery. Such a digital representation of the Heritage Assets is the base of the Digital Twin that together with the implemented 3D workflow, can serve as an adaptive and reusable methodology for diverse scientific purposes and promote the creation of new, collaboratively and multidisciplinary developed scientific knowledge within the future European Collaborative Cloud for Cultural Heritage (ECCCH).

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81. Creating a Knowledge Base of Research Methods from Archaeology Publications

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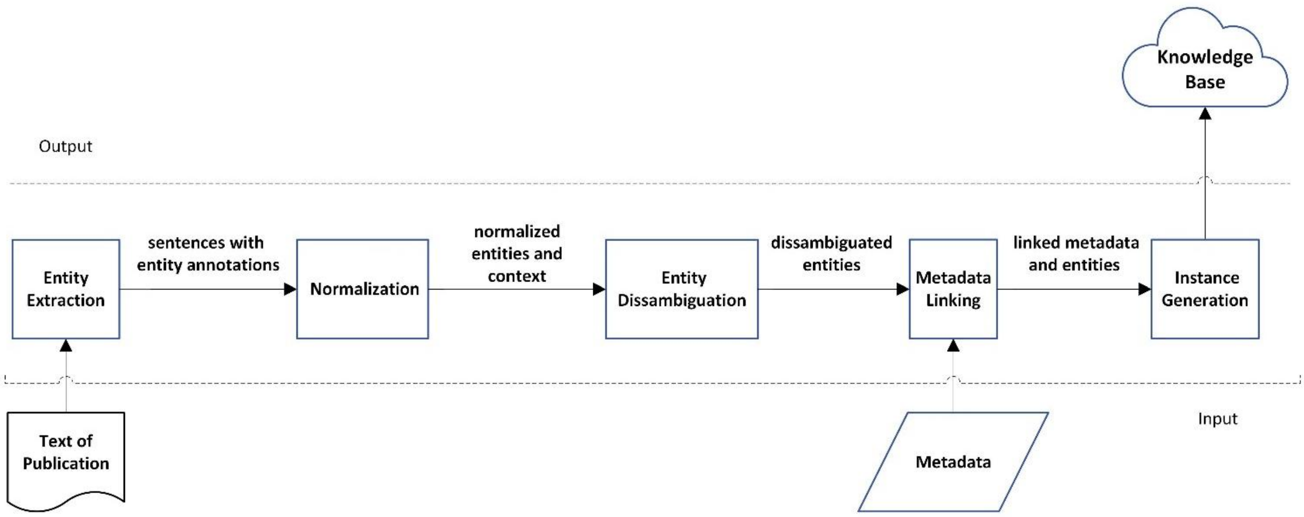
Access to knowledge captured in research publications constitutes a major information need of scholars across disciplines, a phenomenon dramatically exaggerated in the past decades due to the explosive growth rates of publications across scholarly domains. This situation calls for new strategic reading methods that transform the essence of knowledge encoded in textual form into structured formats like Knowledge Graphs (KG), thus changing the way researchers engage with literature [1]. This type of encoded information offered through Knowledge Bases (KB) can alleviate the task of maintaining a bird's-eye-view of research works across disciplines, something particularly useful for interdisciplinary fields like Digital Humanities, while keeping up to date with state-of-the-art methodologies in a specific domain such as Archaeology.

In this paper we present a digital workflow for creating such a KB of research methods in Archaeology, i.e. entities of variable length that appear in text with a proper name (e.g. “radiocarbon dating”, “stable isotope analysis”, etc.) and denote how research is conducted. Specifically, our workflow takes as input unstructured text from research articles' abstract and main body and through a series of steps that employ Deep Learning and LLM Prompting techniques in combination with inference rules: 1) identities and extracts textual spans denoting research methods; 2) normalizes them; 3) disambiguates them through Wikipedia and Wikidata; 4) links them with other entities extracted from publication metadata and 5) transforms the encoded knowledge into instances of a KB implemented in NEO4J . The following figure shows the modular architecture of the presented workflow. The entire process of KG creation is ontology driven, meaning that the definitions of the entity and relationship types that comprise the KB schema are provided from Scholarly Ontology (SO), a CIDOC-CRM compatible conceptual framework specifically designed for modeling and documenting scholarly work [2].

In the Entity Extraction step, we perform token classification using a pretrained transformer model (RoBERTa-base) for vector representation of text, in tandem with a transition-based parser for the NER task [3]. Both components are fine-tuned (transformer) and trained (NER) in a manually annotated dataset comprised of 10,000 sentences sampled from research articles from Humanities disciplines that were retrieved from JSTOR repository (years 2000-2021) and contained in total 5,450 textual spans labeled as Method. For the Normalization step we created a prompt template that uses as input the sentence context and the extracted label and prompts the LLM for a normalized label (i.e. expansion of acronyms, decomposition of composite phrases, etc.). For the Entity Disambiguation step, we employ the GENRE system that takes as input the normalized entity and context and yields the corresponding Wikipedia URL in the output. Then, from the related Wikidata page, we extract the method's description and alternate names. Evaluation of entity extraction and disambiguation modules was conducted using a dataset of 1,000 sentences sampled exclusively from 751 Archaeology papers that were manually annotated and disambiguated for the task at hand. The idea was to create a broad sample in order to test the ML models into as many writing styles as possible. Evaluation scores reached 82% and 81% (F1 measure), for the entity extraction and entity disambiguation respectively. In the Metadata Linking step we query ORCID through the provided API in order to link the authors of the paper with their corresponding author ID when available, while mapping the rest of the information extracted from publication metadata of the article into the corresponding SO entities and relationships, namely providing instances for the SO classes: Person (authorID -retrieved from ORCID), Organization (author affiliations – retrieved from ORCID), Article (articleID from the metadata), Topic (author keywords) and Aggregation (Journal / Conference Proceedings where the article was published). Finally, the KG Creation step handles the creation of an instance of KB in NEO4J, as well as the indexing of various methods' properties utilizing NEO4J's indexing technology for faster retrieval. Specifically, we examined more than 50 different cypher queries that can be utilized using this KB schema, by measuring retrieval times as well as the lexical characteristics and the frequency of appearance of each search term inside them. Evaluation showed that the optimum indexing strategy -in order to save resources while maintaining efficiency and fast retrieval speeds- is to create a text index for "name" property and a full-text index for "description" property of Methods nodes respectively. In the output, each created instance is inserted / merged into the KB after a series of duplicate checks based on its unique identifiers.

Through the presented digital workflow, unstructured text from research articles can be transformed into a structured form and knowledge regarding research methods can be extracted, disambiguated and encoded into a Knowledge Base capable of answering semantically complex queries such as "Given a specific Method, show similar ones - based on its description- that have been mentioned in articles concerning Anthropology, Archaeology and Paleontology" or "Show the top N methods in Archaeology and Paleontology that are referenced in articles by scholars affiliated to a specific Organisation (e.g. Oxford)". Future work includes the expansion of the presented digital workflow with modules -specifically finetuned and tested in Archaeology papers- that extract more entities and relationships from SO (i.e. research activities, denoting the actual research events -such as an archaeological excavation- or steps thereof, research goals, denoting the activities' objectives and research findings, denoting their results). In addition, we plan to leverage the NEO4J integration with LLM frameworks such as Langchain in order to employ advanced retrieval techniques such as graph-based Retrieval Augmented Generation.



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153. Toward a standardised workflow for the documentation of archaeological research projects

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The authors are employees of a FAIR repository for humanities data, which includes data publication. Its characteristic features are that the archived data of a (research) project are directly accessible and queryable on the repository's platform and that each resource within a project has its own persistent identifier, facilitating precise citations. Furthermore, the platform can be used as a virtual research environment already during the research project's lifespan. The platform is based on Linked Open Data (LOD) technologies, enabling data retrieval through a web application or an API, accessible to both humans and machines.

At present, 11 archaeological projects are either:

- already available on the platform and openly accessible for the public (5),
- being worked on directly on the platform but behind a firewall since the research project is still ongoing (2),
- in preparation on a test environment (4).

Several other ongoing archaeological research projects have expressed interest in archiving and publishing their data in the repository once the project has been completed.

Each of these projects employs a distinct data model comprising classes and properties on the platform, which is tailored to the particular requirements of the research project in question. This has both advantages and disadvantages. The flexibility afforded by the RDF-based system is particularly advantageous in the context of archaeological research, which is inherently versatile and requires a capacity for adaptation to the specific realities of the field. Moreover, the level of granularity can vary considerably between different projects, depending on the specific requirements and nature of the study in question. Object-oriented projects have the opportunity to refine the model with controlled vocabularies tailored to their specific field (e.g. numismatics, sculpture, ceramology, etc.). However, while the web-application enables cross-project queries in full-text search mode, this is not possible in advanced mode for single classes or properties, due to the lack of a common reference ontology in the background. This issue is further compounded when considering data retrieval via API.

In this context, we strive to enhance the discoverability of data by implementing three measures that facilitate semantic interoperability:

1. mapping all the existing data models to CIDOC-CRM and its extensions, as well as to other reference ontologies relevant for cultural heritage and archaeology, such as EDM or Nomisma,
2. outlining an "archaeology standard data model" with predefined mapping, which may be adapted by research projects to align with their specific requirements,
3. promote the re-use of pre-existing controlled vocabularies, also mapped (e.g. chronologies, materials, etc.), which can be adapted to meet particular demands.

A further crucial aspect to be taken into account when making research data openly accessible is the ability of the general public to comprehend it. The provision of a comprehensive documentation of the data and the data model as part of the archived data on the platform has so far been optional. As a result, very few research projects currently provide such documentation, which presents a barrier to the discoverability and the reuse of the data for non-project members. Despite the growing importance of data documentation for researchers, incentives to invest time in this area remain limited. This raises the question of how infrastructure providers can enhance the discoverability and accessibility of their services.

Some measures can be developed to achieve our goal. Several are not limited to the platform, but more broadly applicable and therefore worth sharing with others:

- The incorporation of a dedicated section on the platform will facilitate the integration of project metadata, thereby enhancing the visibility of project information.
- Making the documentation of project data mandatory. It is recommended that project data be documented in accordance with established standards. To facilitate the creation of such documentation for a range of projects, a checklist of essential elements should be provided, with an emphasis on the advantages of producing a comprehensive document.
- The provision of predefined documentation of data models in the field of archaeology, which can be adapted to specific project requirements, with visualisations.
- Providing a generic manual for searching the data model in a straightforward and efficient manner, which can be readily adapted to the specific requirements of the project (including the incorporation of specific examples, etc.).

The process of mapping a data model to a reference ontology such as CIDOC-CRM is not a straightforward endeavour. It is a significant challenge for research data specialists to achieve consistent and correct mappings. It may appear that providing researchers with guidance on the creation of an efficient data model, avoiding unnecessary repetition, and ensuring the provision of comprehensive, standardised documentation for their data and data structure would be a relatively straightforward task. Nevertheless, the challenge persists, particularly when research data specialists must convey to project researchers the intricacies of discoverability and interoperability at the machine level. Consequently, internal guidelines and workflows need to be developed:

- In parallel with the creation of a predefined and pre-mapped data model for archaeology, a documentation should be developed to assist in adapting it to specific requirements, thus ensuring consistency in the mapping, including the controlled vocabularies.
- Create a structure that allows the comparison of data models using the same predefined data model, so that consistency is maintained over time,
- Predefined scripts are to be created in order to facilitate the import of project data.
- Developing a protocol that has to be followed by each research data specialist from the beginning of the work process with the project team:

a. Apprehending the project data as they are and looking with researchers how the standard data model can be adapted to the data,
b. Creating the mapping,
c. Adapting the predefined import scripts,
d. Guiding the project through creating the documentation, providing canvas,
e. Uploading the mapped data onto the platform.

The principal challenge in developing such a workflow is to consider the inevitable evolutions that will occur over time. As the number of archived projects increases, it may become challenging to guarantee the consistency of a predefined but adaptable data model, as well as to maintain an overview of the controlled vocabularies to ensure their development remains within acceptable limits. At the level of mapping, the referencing of ontologies that are subject to constant evolution represents a further challenge that must be addressed. In each instance of adaptation over time, the question will be to maintain coherence between new projects and those that have already been archived.

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137. Towards a Collaborative Map Annotation Workflow: Annotating Ancient Places on Rigas' Charta of Greece

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Two-dimensional geospatial information has long been essential to archaeology, with the field being an early adopter of maps. Historical maps play a crucial role in archaeological research, serving as invaluable resources that deepen our understanding of past landscapes, settlements, and human activities, while enriching our historical perspective. Annotation, in turn, has emerged as a powerful tool in facilitating research, enabling scholarly communication and collaboration, and providing a foundation for further analysis and interpretation. Enriching the metadata of historical maps through semantic geo-annotation and linking place names to global authority records or gazetteers has proven to be an effective mechanism not only for geo-referencing primary sources but also for interlinking diverse datasets within and across disciplines (Rainer et al. 2019).

How can researchers carry out these activities in a systematic, effective, and reproducible way? What processes, tools, and methods should they adopt, and in what order? Creating a clear, reusable, and sustainable workflow for collaborative map annotation is a key component of the Geospatial Workflow being developed within the ATRIUM project (https://atrium-research.eu/). This endeavor focuses on enabling the ingestion and use of maps from repositories either via IIIF (when available) or by direct upload of image files into tools such as Recogito Studio (https://recogitostudio.org/) for collaborative annotation and geo-tagging of place names.The resulting information will then be accessible to services such as catalog enrichment pipelines and applications for interactive visualization of geospatial data. While initially tested in Recogito Studio, the workflow is designed to be adaptable to various annotation tools, making it applicable across different scenarios. Additionally, it will be accompanied by a demonstrator, which serves as an exemplary use case focused on a specific topic or dataset, to showcase the practical potential of the workflow. This paper outlines both the ongoing efforts to identify and establish a collaborative, reusable map annotation workflow as well as the development of a demonstrator focusing on the Charta of Greece by Rigas Velestinlis, a culturally rich map, with multifaceted historical and archaeological information.

The Charta (Map) of Greece (Pazarli 2014) is a landmark work of the Modern Greek Enlightenment and a key example of pre-revolutionary Greek cartography. Created by Rigas Velestinlis, a writer and revolutionary influenced by Enlightenment and French Revolutionary ideals, it serves as both a cartographic achievement and a symbol of Greece's late 18th-century cultural and political aspirations. Engraved by Franz Müller and published in Vienna between 1796 and 1797, the map consists of 12 sheets (each approximately 70cm x 50cm), depicting a region from the Danube River to the Libyan Sea, including parts of Asia Minor, the Aegean and Ionian islands, Crete, and the Dodecanese.

More than just a geographic document, the Charta promotes the vision of a unified and independent Greek state by emphasizing locations and events from Greek antiquity, Byzantine history, and the Ottoman period. This richly layered historical and cultural content is integral to the Charta's design and message, as it inspires hopes for liberation and democracy across the region. The Charta's complex, multi-layered composition supports this symbolic vision, containing over 5,800 place names, often including both ancient and modern versions, and various archaeological comments. It portrays important ancient cities, historical figures, and 162 ancient Greek, Roman, and Byzantine coins, represented as inserts within the map, sometimes filling in the space reserved for water or specific regions. Additionally, it includes a windrose, nine detailed city plans, mythological illustrations, a time scale, and a legend.

Annotating a map as rich in content and cartographic design as the Charta of Greece (Rēgas 1797), with interconnections to other cartographic products from the same period and its long-standing tradition, provides a valuable testbed for identifying the aspects and challenges associated with the in-depth exploration of a historical map. Addressing key questions—such as defining the goal of the annotation; identifying the types of places to be annotated; selecting suitable gazetteer(s) for geo-annotation; capturing place names from various historical periods; considering how to annotate objects, comments, and other features alongside places; determining the necessary level of detail for the tagging vocabulary; managing ambiguities; and incorporating a critical examination of the map—will yield valuable insights into the process and user needs. This understanding will, in turn, inform our workflow and ensure that all relevant aspects are taken into consideration.

Furthermore, various scenarios will be explored and tailored to meet the needs of identified stakeholders. To ensure sustainability and leverage BPMN's (Business Process Model and Notation, https://www.omg.org/bpmn/) ability to systematically represent complex processes, the resulting workflow will be formulated as a BPMN-style diagram. This diagram will illustrate the interconnections, iterations, and possible disjunctions among the various activities and steps within the process. Indeed, the workflow may sometimes not take the form of a strictly linear sequence of steps, but involve phases of mutual feedback and improvement between earlier and later stages of the process (for example, a tagging vocabulary may be revised based on feedback received during the actual annotation activity).

Additionally, the workflow will be transformed into a format compatible with the SSH Open Marketplace (https://sshopencloud.eu/ssh-open-marketplace), where it will be hosted, enhancing the findability, accessibility, and reusability of the workflow. A description of the demonstrator as well as the resulting output data will also be made available, to both validate the applicability of the workflow and share the outcomes yielded by the work on the Charta of Greece.

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427. The Infrastructure and Workflows of NFDI4Objects

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NFDI4Objects is a multidisciplinary consortium within the National Research Data Infrastructure (NFDI). It is designed for researchers, practitioners, and students whose focus lies in the material heritage spanning approximately three million years of human and environmental history, addressing the challenges posed by modern research data infrastructures.

The primary aim of the consortium is to develop a unified strategy for research data management and to foster close collaboration with related disciplines in other NFDI consortia. NFDI4Objects is both a consortium funded by the Federal-State Agreement on the NFDI and a constituent part of the National Research Data Infrastructure (NFDI) e.V. association.

The consortium's structure is organised into seven Task Areas, each managed by two co-applicant institutions, with the exception of Task Area 7, which, according to DFG guidelines, is overseen solely by the main applicant institution. These Task Areas are tailored to meet the scientific and infrastructural needs of the research community, ensuring long-term support for the challenges associated with research data management. Task-Related Activities for Implementation and Launch of Services (TRAILs) are implemented within these areas, bringing parts of the work programme to fruition.

The services offered by NFDI4Objects can be broadly categorised into two areas. On the one hand, the consortium serves as a platform for the research community to discuss the adoption of new standards and best practices. To facilitate these discussions, NFDI4Objects provides thematic Community Clusters and Temporary Working Groups. On the other hand, the consortium funds the development of various tools designed to simplify the application of these standards and best practices, thereby promoting sound research data management.

At the heart of our workflows related to research data is our Knowledge Graph (https://www.graph.nfdi4objects.net), a graph database based on Neo4J. Currently, data ingestion is facilitated through LIDO and CIDOC-CRM, with queries possible via SPARQL or Cypher APIs. The DANTE service (https://www.dante.gbv.de) serves as the central hub for terminologies and ontologies, while BARTOC (https://www.bartoc.org) provides a registry for these resources to increase their accessibility. Mappings between different vocabularies or ontologies can be achieved via Cocoda (https://www.coli-conc.gbv.de/cocoda/app/). These services are developed and provided by the VZG-GBV as part of Task Area 5 of NFDI4Objects and constitute the core of our infrastructure and workflows. All subsequent subject-specific standards and tools are designed to ultimately integrate into these resources.

Task Area 1 addresses data management challenges related to the field documentation of archaeological finds and features. To explore specific data management issues in this area, two Community Clusters have been established, namely "Field Documentation" and "Prospecting." Task Area 1 is also developing a QGIS plug-in called "Survey2GIS" (https://www.survey-tools.org/) to simplify the import of survey data into QGIS, as well as an R-package for deriving vegetation indices from multispectral aerial images (https://github.com/bcdhbonn/multispectral).

Task Area 2 focuses on collection-related data. In addition to developing collection-specific vocabularies and ontologies, the Task Area is working extensively on exporting data from existing providers, such as WikiData, FactGrid, and several collection-specific platforms, to the NFDI4Objects Knowledge Graph. Key tools developed by Task Area 2 include the “Academic Meta Tool” (https://academic-meta-tool.xyz/), which assists users in modelling uncertainties in SPARQL queries, and “re3dragon” (https://tools.leiza.de/re3dragon/), a catalogue for Linked Open Data resources.

Task Area 3 is responsible for experimental and analytical data. To support this, the Task Area provides three platforms: GlobaLID (https://archmetaldbm.github.io/Globalid/), a database with an Rshiny-based web frontend for lead isotope data from ores and objects in archaeological contexts; ArbotDat+ (http://arbodat.info/), a software package for registering and importing archaeobotanical analysis data, along with evaluation tools such as those for preparing publication tables; and POSEIDON 2.0 (https://www.poseidon-adna.org/#/), a database for ancient genomic data in archaeological contexts, which has recently surpassed 10,000 individuals. ArboDat+ will also contribute data to PANGEAU (https://www.pangaea.de/), a major data publisher in the Earth and environmental sciences.

Task Area 4 focuses on the protection and conservation of objects. A key aspect of this work is moderating discussions regarding common standards for the cultural heritage community in Germany. Current efforts centre on the development of standards for site and monument data, particularly concerning their legal status, as well as citizen science. The development of specific tools to support these processes is currently in the planning stage.

Task Area 5 is responsible for the development of the aforementioned central infrastructures and also oversees the IANUS project (https://ianus-fdz.de/), which provides recommendations and infrastructure for the long-term storage of research data.

In summary, NFDI4Objects is developing a comprehensive array of tools, standards, and workflows across various fields of archaeology, ranging from the documentation of field data from surveys and excavations, to collection data, conservation, preservation, and scientific data from archaeological contexts to the long term storage of this data. While the NFDI4Objects infrastructure is primarily designed to meet the needs of German researchers, many of the workflows and resources developed are applicable on a global scale.

482. Go with the flow - workflows as a recipe for reproducible results

Ceri Binding (University of South Wales)*; Douglas Tudhope (University of South Wales)

The cultural heritage domain (and others) has experienced a movement towards open data and FAIR data principles with the aim of improving the visibility and reusability of datasets. These principles could and should extend to documenting paradata on the methodology and versioned tools and dependencies used in the creation of datasets, to allow them to be reproduced (or adjusted, using different input parameters) and to improve the provenance and credibility of the dataset giving greater confidence it can be reused.
Recent years have seen increasing calls to address the “replication crisis” in research, emphasising a need for the detailed documentation of methodologies and datasets. A methodology overview as described in a published paper may not be presented at a sufficient level of granularity - e.g. precise versioning of tools, and dependencies used. Instead, or additionally, workflows and associated datasets can be published and formally referenced - thereby providing concise, clear and objective instructions (a recipe) for sourcing data and reproducing the results as described in a publication. This approach also potentially facilitates incremental improvement of results by forking and revising particular steps.
We describe initial versions of workflows created as part of the ATRIUM project for the task of performing vocabulary-driven Named Entity Recognition (NER) on archaeological texts. The main purpose of this processing is to enable semantic enrichment of existing subject metadata, building on and extending work previously undertaken in the ARIADNE project on KOS based enrichment of archaeological fieldwork reports [1]. Identifying instances of vocabulary concepts within the text as candidates for subject indexing can contribute towards greater semantic integration of the reports being processed [2].

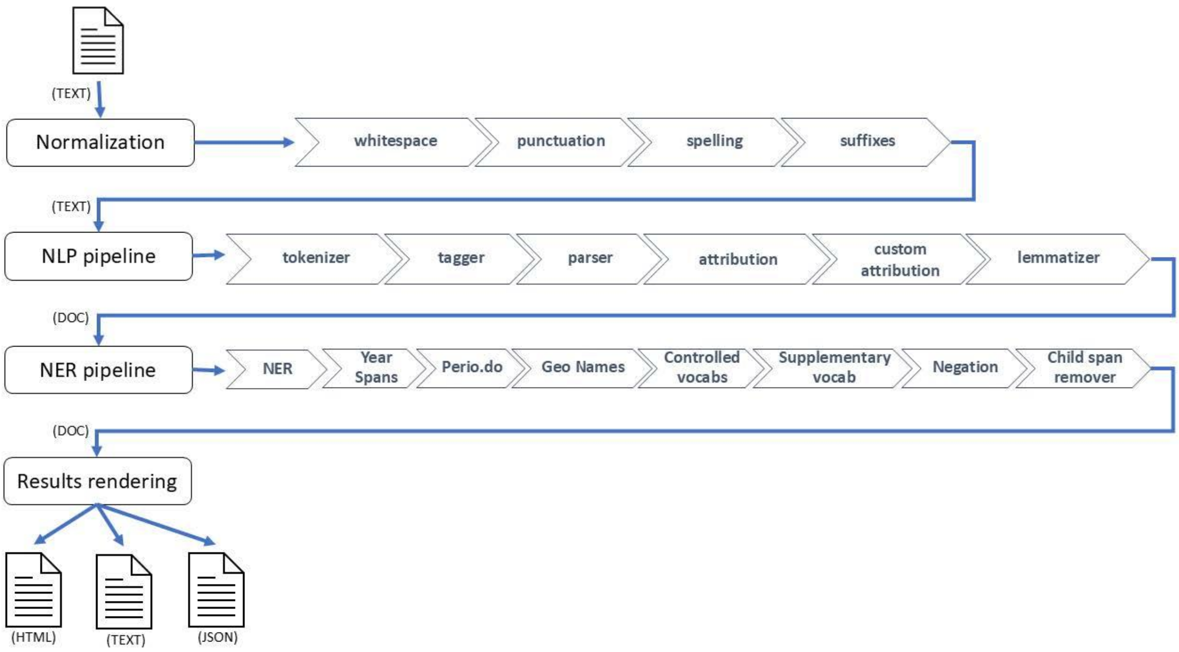

Figure 1 ATRIUM NER processing pipeline

The main steps are to:
• Extract pertinent text from a supplied set of published reports or grey literature describing archaeological interventions.
• Apply a vocabulary-driven NER process using a pipeline architecture to annotate the text extracts - identifying named entities (year spans, named periods, object and monument types, place names, activities etc.) within the input text, based on a set of pre-defined chosen controlled vocabularies and a combination of general and bespoke supplementary rules.
• Produce output in various formats including listings of span entities locating the character positions of the named entities within the text, reconciled to vocabulary concept identifiers wherever possible.
The individual steps described above can be formulated in terms of a workflow. A modular approach means workflows may be nested - so each step may be described within another (more granular) workflow, which could be produced and/or performed by another party. Workflows are not necessarily a linear sequence of steps; the next step may branch depending on some condition being met. Our aim for the workflow is that it is:

• Modular - each step of a workflow may itself be a standalone workflow. In the steps described above, the first step is a separate workflow undertaken by project members in a separate organisation.

• Reusable - modular workflows (and the resources they reference) may be reused within other workflows. Some steps in our own workflow are shared among multiple
workflows.
This can create synergy savings where there may be some overlap of requirements in multiple work package tasks in a project.

• Actionable – the aim is to exceed traditional technical documentation by including working source code examples to illustrate functionality. We achieve this using Python notebooks published in a public GitHub repository. These notebooks contain commented and executable step-by-step source code examples illustrating precisely how the input data input is obtained and processed, and what the resultant output will be.
The process of formulating and documenting a workflow is itself beneficial as an aid to clarifying understanding (and perhaps rethinking) the work being undertaken and the methodology adopted. In addition to I/O formats, data types & structures, tools & dependencies, documentation could address and describe any specific observed scalability limitations and an appraisal of any advantages/deficiencies of the approach taken that may be revisited and perhaps improved in subsequent versions.
The final workflows are intended to be published via the Social Sciences and Humanities (SSH) Open Marketplace to provide a suite of openly available, referenceable and reusable resources. Once published mutual referencing may be performed, whereby a dataset references the workflow employed to produce it, and the workflow can reference the resultant dataset as an output. Any associated source code and examples will be published via public GitHub repositories.

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283. Pioneering Preventive Preservation: the role of remote sensing in Cultural Heritage

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In Europe, and particularly in Greece, the preventive preservation of cultural heritage sites has emerged as a pressing priority in response to the escalating challenges posed by climate change. The current climate crisis, marked by unprecedented temperature fluctuations and a surge in severe climate-related impacts (European Commission 2024), poses serious risks to these cultural landmarks. Factors such as rising temperatures, extreme weather events, sea level rises, and shifting precipitation patterns accelerate degradation, heighten erosion and flooding risks, compromise the static integrity of monuments, and foster the growth of biodeterioration agents that can further burden these landmarks. In this context it is recognized that remote sensing as a means of preventive preservation can be a critical tool for proactive heritage preservation, ensuring that these invaluable sites endure for future generations.

While substantial strides have been made in addressing the effects of climate change on cultural heritage in Europe and Greece, there remains a critical need for coordinated actions, investments, and collaborative efforts regarding applications such as remote sensing. Strengthening preventive preservation measures and ensuring the sustainability of cultural heritage requires integrating monitoring systems, updating management plans, and raising awareness among stakeholders as integral components of effective adaptation strategies.

This paper aims to present the current state of the art regarding remote sensing in cultural heritage through relevant case studies and projects, including those that integrate remote sensing into the creation of digital twins. Through a comparative analysis, it will also aim to explore the existing limitations and challenges in employing remote sensing technologies for the proactive conservation of cultural heritage sites. Despite advancements in remote sensing, several persistent barriers continue to hinder their full potential for cultural heritage preservation. These challenges include restricted spatial and temporal resolution, insufficient integration with supplementary data, high costs, and operational difficulties such as access to remote or sensitive locations.

Another key aim of this paper is to emphasize the critical importance of interdisciplinary collaboration among conservation experts, technologists, heritage stakeholders, and policymakers. Such partnerships are vital for addressing existing gaps and driving innovation in cultural heritage preservation. Significant progress has already been made at the European level, fostering initiatives that unite diverse projects into a collaborative ecosystem. These consortiums facilitate the exchange of knowledge and best practices, identify opportunities for joint dissemination and communication efforts, and provide cohesive, actionable recommendations to policymakers within the European Union and beyond. (Gerakis et al. 2024)

In conclusion, this paper examines the potential of integrating remote sensing technologies into the proactive preservation of cultural heritage in response to the escalating challenges of climate change. By tackling these issues, it aspires to outline a multi-faceted approach that combines advancements in remote sensing with robust interdisciplinary collaboration and targeted policy recommendations. Ultimately, the goal is to provide actionable insights that can enhance the resilience and sustainability of cultural heritage sites ensuring their protection for future generations in an increasingly vulnerable environmental context.

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188. Towards an Easy-to-Use Machine learning Framework for Cultural Heritage Scientists

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Cultural heritage artefacts are invaluable records of human history and identity, offering unique insights into past societies, traditions, and innovations that shape our understanding of cultural evolution and continuity. Over the years, numerous factors have led to their deterioration and damage, highlighting the critical need for assessment and protective strategies to guarantee their continued preservation. As breakthroughs in Machine Learning and other ICT technologies continue to advance, there is a growing potential for such tools to support cultural heritage scientists (conservators, archaeologists, museologists, etc.). A framework encompassing a suite of tools may enable complex data analysis and preservation tasks, making them accessible to researchers across disciplines including those with limited technical expertise.

Our contribution is an open-source framework offering a user-friendly interface that allows users to upload, process and manage their machine learning projects, with no prior technical knowledge needed. The under-development framework and tools are preliminary work of TEXTaiLES, a Horizon Europe funded project. Providing such a framework to cultural heritage scientists gives them the ability to operate more independently, run more experiments with real-time access to their results, simplifying machine learning technologies integration into their research. This work aims towards bridging the gap between Cultural Heritage sciences and ICT technologies, offering significant benefits.

Using state-of-the-art infrastructures and Machine Learning Operations (MLOps) techniques, the framework can support the full lifecycle of a machine learning enabled project, from data annotation to training and eventually deployment (Kreuzberger, Kühl, and Hirschl 2023). Each stage is specialised and customised to better fit the needs of cultural heritage scientists. The framework will comprise a suite of essential services, starting with various annotation tools options (Aljabri et al. 2022) enabling users to process and store diverse data types including among others 2D images and 3D objects. By leveraging distributed computing approaches based on Kubernetes technologies, dockerised services (i.e. software bundled with the necessary environment for execution), allows our framework to seamlessly integrate and interact with different tools to match the requirements of each use-case. Following the same principles, our framework includes an environment to manage the training of different machine learning models, offering services like experiment tracking and hyperparameter tuning. Moreover, the automated deployment procedure of the results will be offered as a one-click solution. To conclude, the suggested Kubernetes based architecture enables seamless scalability by automatically adjusting resources to match the varying workload demands. Such a dynamic resource allocation scheme will ensure consistent performance, while allowing researchers to efficiently process large datasets, regardless of current user loads.

This framework is currently under early development, with its requirements and architecture designed being tailored to real-world use cases and challenges met in the TEXTaiLES project.

Alongside this framework, we integrate machine learning-based models designed to precisely detect damaged areas in archaeological findings through the application of semantic segmentation. Furthermore, the morphology of artefact surfaces can be analysed, allowing for categorisation based on their structural and material properties. It is important to note that this framework is flexible and can be adapted to be used in other tasks such as object detection and points-of-interest based segmentation. Deep learning architectures with a focus on Convolutional Neural Networks (CNNs) and Transformer networks will be utilised for the above tasks. In order to achieve optimal performance, techniques such as transfer learning and data augmentation will be applied where possible given the diversity of the data (Gaber, Youssef, and Fathalla 2023).

Integrating machine learning into cultural heritage research significantly broadens investigative possibilities by speeding up large datasets analysis. This integration bridges cultural heritage and machine learning, through an easy-of-use framework, opening new avenues for discovery and preservation. As a result of the contribution of machine learning in cultural heritage is the automation of the serial process of evaluating the characteristics of findings. Moreover, since there is a variety in the morphology of the surface of the objects, collecting data with tools that offer additional features makes machine learning models particularly useful as they can detect patterns that are not visible to humans. In conclusion, this framework opens up new perspectives in the documentation, analysis, management and conservation of cultural heritage, empowering non-expert users to engage effectively with advanced machine learning related tools and methods. By accurately assessing the condition of archaeological artefacts, the decision-making process of cultural heritage scientists is enhanced.

In summary, the main contributions of this work are:

- Provide a no-code, open-source framework for cultural heritage scientists to exploit machine learning approaches without technical skills.
- Enable end-to-end project management from data annotation to deployment, tailored for cultural heritage scientists.
- A framework that can handle various data types like 2D images and 3D objects.
- Utilise machine learning to examine artefacts, such as identifying damage and analysing structural features.
- Easily adaptable for challenging tasks, enhancing non-expert (in terms of technical background) accessibility to machine learning in cultural heritage studies.

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Keywords: Non-expert User Accessibility, Machine Learning Framework, Cultural Heritage Scientist, MLOps.

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389. Future-Proofing Heritage with ARGUS: A Multimodal Digital Twin Approach for Sustainable Preservation

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Introduction

The preservation of cultural heritage faces increasing challenges from environmental, climatic, and anthropogenic pressures. The ARGUS Horizon Europe project addresses these challenges by proposing an innovative approach leveraging AI-driven digital twins and multimodal data fusion to assess and mitigate risks to heritage sites. Our research focuses on developing a sustainable, dynamic decision support system (DSS) that integrates multi-scale on-site and remote sensing data, enabling holistic heritage management. The primary research question is: How can digital twins incorporating multi-dimensional data enhance the preservation and adaptive management of cultural heritage in a changing environment?

Methods and Materials

The ARGUS digital twin integrates diverse datasets, including (a) pre-existing GIS and remote sensing data from five pilot sites (Delos Island, Greece, Multi Lucretilli, Italy, Sant' Antonio di Ranverso Abbey, Italy, Cellar Town at Baltanas, Spain, and Schenkenberg Castle, Switzerland); (b) early-stage sensor measurements (e.g., temperature, humidity, seismic, radiation) tested during initial implementations; (c) spatial and spectral data layers hosted in a GIS-based platform under development, which will form the digital twin’s core.

The methodologies include (i) designing a multimodal, GIS-compatible data hosting system to store and manage spatiotemporal datasets; (ii) developing pipelines for sensor integration and remote sensing data visualization; (iii) initial AI tests for identifying patterns and potential vulnerabilities in heritage structures.

Results

Although at an early stage, ARGUS has established (1) A unified GIS framework for hosting spatial and non-spatial data across pilot sites, allowing seamless integration of multi-scale datasets; (2) Tested data pipelines for sensor connectivity, showcasing the potential for remote real-time monitoring; (3) Preliminary visualizations of heritage assets, laying the foundation for the ARGUS decision support system. These developments demonstrate the feasibility of integrating pre-existing data with live sensor input into a dynamic, scalable model.

Discussion

The ARGUS framework represents a pivotal step toward future-proofing heritage management. By focusing on sustainability, interoperability, and real-time adaptability, the project aligns with broader goals of digital heritage preservation in response to climate change and societal shifts. Future work includes extending the GIS platform into a fully operational digital twin, integrating AI-driven analytics, and refining multimodal visualizations to support conservation planning and public engagement. ARGUS highlights the importance of embracing emerging technologies to protect and promote cultural heritage for generations to come.

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38. The impact of normal mapping on the geometric simplification of archaeological 3D data

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Problem statement

A great challenge in 3D digitization and modelling lies in striking a balance between surface detail and model size. Large models severely impact storage requirements, data transmission and 3D rendering. It is therefore typical for high-resolution digitized objects and modelled assets alike to produce sub-sampled and simplified versions (levels of detail – LODs), to match the requirements of the intended applications. By doing so however, geometric detail is lost, affecting visual fidelity during 3D visualization.

An established computer graphics method for the preservation of visual fidelity of LOD versions is the estimation and transfer of the local surface orientation (the "normal" direction) variation of the high-resolution mesh onto a texture image (Theoharis et al., 2008). The "baked" local surface detail is then applied during rendering to the low-resolution version, simulating details via the illumination computation.

In this work, we explore the robustness of detail transfer via normal mapping on decimated 3D digitized archaeological objects and sites, by evaluating the technique with a diverse set of test cases and user groups of different familiarity to 3D content and expertise.

Background

Normal mapping is a well-known technique for the visual enhancement of 3D surfaces, during rendering. The primary factor affecting the detailed appearance of a surface during visualization is the local surface orientation, as determined by the vector pointing directly outwards from the surface (the normal vector). The normal vector is directly used for the determination of local shading. When rendering any three-dimensional surface, we can artificially substitute the true (or interpolated) normal of the surface with one computed or supplied at runtime. The replacement normal vectors are usually defined in local tangent space of the surface and provided in a pre-computed texture image. Most of the time, the indexing of the texture is performed via a precomputed bijective mapping of surface locations to the (2D) parametric domain of the image. Starting from a high-resolution surface, it is possible to decimate this to produce simplified versions and transfer the differential geometric detail that is lost to the low-resolution surface via texture mapping. In essence, the lost detail manifests as a deviation in the elevation of the resulting model, registered in a displacement map. However, adapting the relief of the simplified mesh during rendering is rather expensive. On the other hand, using only the locally bent normal of the displaced, high-resolution original surface without actually displacing it, can mimic the correct illumination and preserve the appearance of the detailed surface, to a certain extent. It is known that the effect breaks when observing the silhouettes of objects or very oblique, as the lack of true geometric detail produces rougher edges and no detailed self-occlusion.

Once a texture parameterization of the surface of the geometry is established, computing the normal map is straightforward. Rays are cast from the low-resolution object perpendicular to the surface, both outwards and inwards. These are intersected with the high-definition surface and the normal vector at the closest intersection is registered, expressed in local tangent-space coordinates of the simplified surface and stored as an image, properly encoding Cartesian coordinates as color values. During rendering the normal map is indexed and the resulting vector coordinates trivially replace the true local normal.

Evaluation Methodology

We performed our evaluation using a variety of digitized material, ranging from small objects to entire archaeological monuments from the archaeological site and museum of Ilida, Greece. Using aerial and ground-based photographs, we reconstructed high-detail meshes with structure from motion photogrammetry (Agisoft Metashape software). The reference high-resolution reconstructed meshes were then processed in Meshlab to aggressively decimate them down to 2-20% of the original triangle count and produce the simplified surface models (Garland and Heckbert, 1998).

Normal map baking was subsequently performed via the corresponding functionality available in Adobe Substance 3D Painter texture authoring software, due to its high-performance and parameterization, although similar texture baking facilities are available in many other 3D modelling and asset processing tools.

For the evaluation, 80 participants with varying levels of experience were involved. Participants were asked to pinpoint the high-resolution rendered model among the randomly shuffled images of a) the true high-resolution mesh, b) the low-resolution mesh and c) the normal-mapped low-resolution mesh. 13 sets of images were presented, showing different views of the test models. All models were fully textured and rendered with high-quality, consistent lighting in Unity. Participants were then asked to vote for the criterial they employed, when judging the images, such as texture clarity, color accuracy, detail preservation, lighting and silhouettes.

Evaluation Results

In all the test cases, most of the participants consistently reported the normal-mapped simplified version to be the high-fidelity model (~60%). Interestingly, experts with professional experience in the handling of 3D content constituted the group with the highest false-positive response (63%). It is important however to also correlate this result with the factors that biased their response: local detail preservation (51.2%) and lighting (52.5%) were the dominant factors, which are exactly the traits that normal-mapping excels at preserving and accentuating. It is also worth noting that 53% had trouble distinguishing between the high-resolution models and the simplified ones. Interestingly, object silhouettes, which can more readily identify a low-resolution mesh, were only considered by 15% of the participants.

In light of the findings, the results have successfully demonstrated that the low-resolution model with normal maps can effectively stand in for the high-resolution models for many data visualization applications, as the use of normal maps effectively preserve key visual characteristics, while reducing resource demands.

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377. From Temple to Church: Leveraging Digital Twins and HBIM for the Preservation of San Nicola in Carcere

Karol Argasiński (Warsaw University of Technology)*; Yannick Ley (RWTH Aachen University)

Introduction
The transformation of San Nicola in Carcere in Rome, from a Roman temple to a church, spans centuries of cultural and architectural evolution. Preserving such historically layered structures requires innovative methodologies that integrate architectural history with digital technologies. Our research focuses on creating a Heritage Building Information Model (HBIM) for San Nicola in Carcere, leveraging high-precision laser scanning and data integration to document and analyze its architectural transformation. By employing openBIM standards like IFC (Industry Foundation Classes), bSDD (buildingSMART Data Dicitonary, buildingSMART International, 2024), widely renowned in the construction industry, and CIDOC-CRM frameworks, we aim to establish a digital twin that not only preserves the site's historical integrity but also offers predictive insights for future conservation (Argasiński and Kuroczyński 2023).

Methods and Materials
Our approach combines data from high-resolution laser scans with a detailed historical analysis to build a comprehensive HBIM and reconstruction layers embedded into archive (Kuroczyński et al, 2023). The data was collected using FARO & Riegl terrestrial laser scanners (TLS), capturing minute details of the building's current state. Our interdisciplinary team integrates expertise from architectural historians, who provide insight into the church's historical layers, with digitalization specialists skilled in HBIM, openBIM, and semantic data structures. By aligning our model with the bSDD and CIDOC-CRM, we ensure standardized data integration, facilitating seamless interoperability and enhanced usability.

Results
The preliminary HBIM model reveals intricate details of San Nicola in Carcere's structural transitions over centuries, highlighting the adaptive reuse of architectural elements. Our digital twin integrates geometric data with metadata, historical records, and environmental parameters, creating a dynamic model that reflects both the physical and historical attributes of the site. This approach has enabled a deeper understanding of how different building phases interact and offers insights into potential vulnerabilities. Additionally, the model serves as a foundation for future conservation efforts, providing a virtual environment for predictive analysis and risk management.

Discussion & Conclusion
The creation of a digital twin for San Nicola in Carcere illustrates the transformative potential of integrating HBIM with advanced digitization techniques and standardized data frameworks. Our approach facilitates non-destructive, multimodal monitoring that can adapt to future technological advancements. By embedding architectural history into the digital model, we ensure that the conservation of the site is informed by a holistic understanding of its past. Moreover, the use of AI-driven tools for threat identification and scenario modeling opens new avenues for sustainable preservation, allowing stakeholders to anticipate and mitigate risks posed by environmental and anthropogenic factors.

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Figure 1 Section of the texturized model of San Nicola in Carcere utilized with different technologies and further research openBIM-based methodologies

35. Safeguarding Buddhist heritage, Digital Preservation of Gandhara Buddhist Sites in Khyber Pakhtunkhwa Pakistan.

Numan Anwar (Directorate of Archaeology and Museum Govt of Khyber Pakhtunkhwa Pakistan)*

Abstact
The Khyber Pakhtunkhwa province of Pakistan boasts a rich cultural heritage, with numerous archaeological sites showcasing the region's significance in the ancient Gandhara civilization. However, prevailing security concerns have led to a decline in tourism, emphasizing the need for alternative methods to promote these heritage sites.

Research Objectives and Methodology
This study explores the potential of digital preservation in promoting the cultural heritage of Khyber Pakhtunkhwa. We employed 3D scanning technology to digitally preserve select sculptures in Peshawar Museum, including the famous "Dying Buddha" sculpture at Bhamala in Haripur, Buddhist Stupas at Jualian in Haripur, and Takht-i-Bahi UNESCO World Heritage site. The scanned data was processed to produce high-detail 3D models, which can be utilized for online promotion of museums and heritage sites.

Academic and Practical Implications
This digital preservation project contributes to the academic discourse on cultural heritage preservation and promotion. By leveraging digital technologies, we can increase global accessibility to these heritage sites, fostering cultural exchange and education. Furthermore, this project demonstrates the potential for digital preservation to support sustainable tourism development in regions with limited tourism infrastructure.

Significance and Future Directions
This study highlights the importance of digital preservation in promoting cultural heritage sites in Khyber Pakhtunkhwa. Future research directions include exploring the application of digital preservation technologies in other cultural heritage contexts and investigating the impact of digital preservation on tourism development and community engagement.

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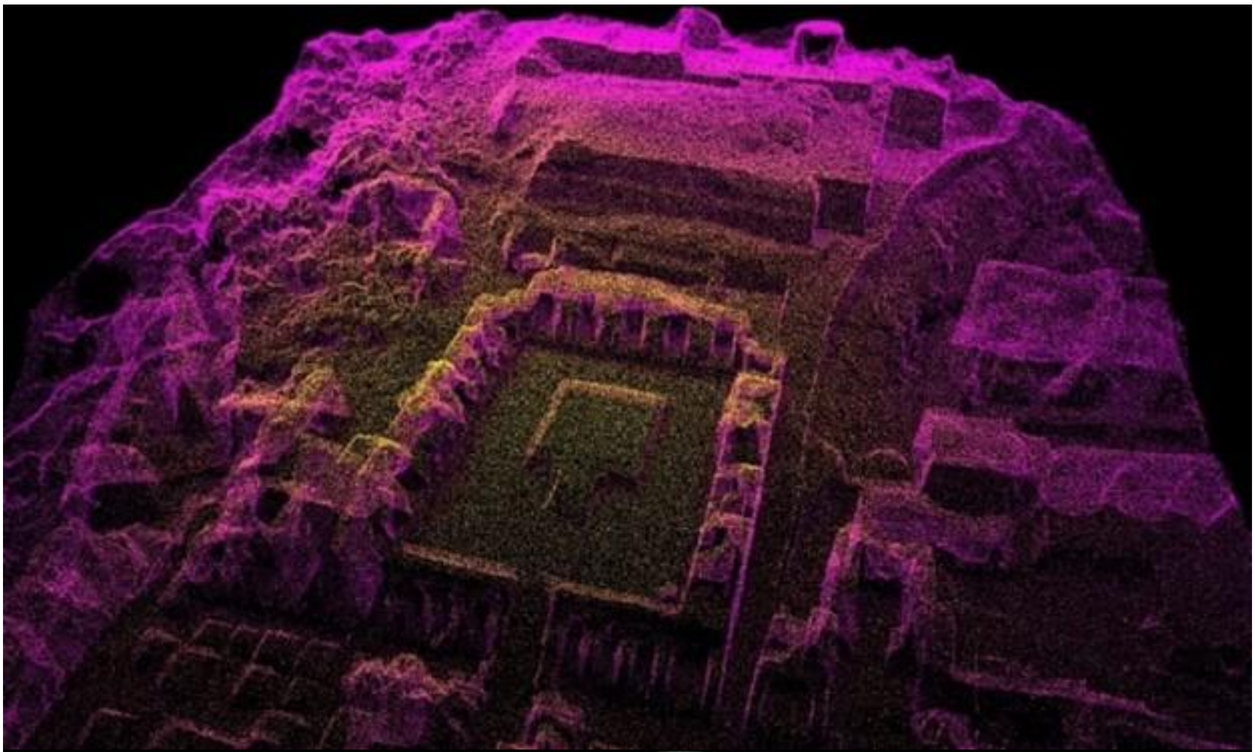

243. A future-proof digital deposit model for the City of York, UK.

Kristina Krawiec (York Archaeology)*; Virgil Yendell (AOC Archaeology); Phil Stastney (Independant)

The city of York is known for its deeply buried waterlogged archaeological deposits which contain some of the best preserved early Medieval structures in the UK. The continuing survival of these deposits is now at risk from a number of factors affecting the stability of the burial environment (Holden et al 2009). These range from climate and hydrology changes (Watts et al 2015), microplastics and redevelopment of sites. In order to respond to these challenges the City of York Council and Historic England commissioned York Archaeology and AOC Archaeology to undertake a three year project to create a fit for purpose deposit model for the entire unitary authority area.

This was not without precedent as the original York Deposit Model, created in 1991, sought to map the disposition of archaeological strata of different periods - 'natural'; 'Roman'; 'Anglian'; 'Anglo-Scandinavian'; 'Medieval' - across the city centre. This model was a static output and represented the understanding of the nature and extent of the deposits within the city at that time. However, since 1991, the way in which archaeologists and geoarchaeologists use and create Deposit Models has changed substantially due in part to the release of Historic England Guidance (2019). In addition, the City of York's boundaries have expanded, and many more archaeological investigations have also taken place the results of which are recorded in the HER and were unable to be integrated into the 1991 model. Given that Deposit Modelling is now a common request as part of archaeological heritage management in the UK, the decision was made to update the format and data of the existing Deposit Model as held within the Historic Environment Record (HER).

The project is moving toward its final stages and the new dataset is now populated with both archaeological records generated over the last thirty (30) years and data held by the British Geological Survey (BGS). The model is structured in a way that aims to make future updates simple and effective to facilitate the management of the archaeological resource in the City of York. The new Deposit Model maps archaeological remains, deposits with palaeoenvironmental potential, waterlogging and/or organic-preservation and pre-urban 'natural' topography from a collection of data sources so that nationally important heritage assets can be appropriately managed. The model can also be used for decision-making, development design, and past landscape reconstruction.

In addition to the model as a tool for heritage management, the data can be shared with researchers and archaeological contractors working within the city to allow resources to be targeted and to frame the research questions for the city. In this way the data recovered from commercial and research-led investigations is accessible to a wider audience and on a much shorter timescale. This is critical given the rapid nature of modern archaeological investigations. It also addresses issues of data access and dissemination within a sector under increasing pressure to deliver on ever shorter timescales with diminishing budgets.

The deposit model data has been used to create three-dimensional representations of the distribution of data across a given area, such as a proposed development. This allows the city archaeologist to issue a targeted brief to archaeological contractors to ensure that resources are allocated to address outstanding research questions. The system also allows for areas of predicted waterlogged deposition and preservation to be tested and the model updated. This is especially critical when considering the impacts and changes to the burial environment. The model can also store other information such as absolute chronology and environmental data. Again, this can be disseminated to other investigators working on adjacent sites to ensure a holistic approach to fieldwork methodologies.

Although many of the final outputs of the projects are not yet ready to be shared, as part of the earlier stages of the project a qualitative assessment of the HER and BGS data for this city was undertaken. Assessing archaeological reports (and borehole data) as to the usefulness of the quantitative location information and the qualitative deposit descriptions and interpretations contained within. A byproduct of this work has been identifying the benefits and pitfalls of changing report styles and methods over the years in respect to the potential research or commercial reuse of archaeological grey literature data. Conclusions from this part of the project may be used to inform future standards and guidance for the investigations carried out in York to ensure consistency in data collection.

The underlying data standard and data entry guidance has already been utilised as part of research-led projects, namely the AHRC-funded Roman York-Beneath the Streets project led by Professor Martin Millett (University of Cambridge) and Dr John Creighton (University of Reading), which focused on the data within and surrounding the fortress walls, providing detail on the Roman period deposits. The results of this project will be able to be integrated into the city model ensuring the data can be reused by other researchers and to ensure the city archaeologist has access to the results of this work.

The work carried out as part of this project will help to shape future standards within archaeological fieldwork as well as data collection and dissemination. This approach combines multiple data sources to create a coherent understanding of preservation baselines and distribution of archaeological deposits.

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515. Transition to digital, intelligent, and preventive preservation based on hard data from the field: A view from the Côa Valley

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While offering us a poignant testimony of the earliest human genius, prehistoric rock-art sites (notably those classified as UNESCO World Heritage) constitute a scarce, unrepeatable symbolic resource, requiring special attention because of its fragility and exposition to anthropogenic and natural hazards.

The Côa Valley's inclusion on the UNESCO World Heritage list in 1998 (following the "Battle of the Côa") imposed on the Portuguese State the responsibility for the conservation of this open-air rock art of "outstanding universal value". This responsibility constitutes the core of the Fundação Côa Parque's (FCP) mission statement: "safeguard, conservation, investigation, dissemination, and valorisation of rock art of the Côa Valley".

To accomplish this mission, the FCP has progressively tested and improved documentation and conservation practices for this heritage whose inherent characteristics (fragility, spatial dispersion in remote and vulnerable locations, and irremovability) impose extremely complex challenges due to its physical nature and dispersion in the territory. Such challenges become ever more demanding because of the present accelerated degradation of climatic stability, exposing the Côa Valley rock-art heritage to multiple increased environmental risks.

The impact of these growing environmental challenges is further aggravated by direct anthropogenic factors, such as intensive agriculture/vineyards, mining industry, forest fires, and hydrographic network artificialization. As an example, the persistence of the Côa dam's cofferdam (the major active degradation factor of the Côa engravings), left intact since the dam's construction halt in 1996 and completely exempt of any maintenance since, causes artificial flood events of an unpredicted frequency and magnitude: the twenty hydrological years between 1996 and 2016 delivered 65 distinct flood occurrences with an average of two flood days per occurrence, leading to a severe aggravation of deterioration risks due to physical and chemical erosion, sedimentary accumulation, and subsequent bio-colonization and gravitational movements. In the last ten years, the situation got even worse, with climate change increasing impacts on rainfall concentration causing almost every year the occurrence of flows above 21.23 m3/s, which causes the upstream cofferdam to overtop and, consequently, a ~7.5M m3 flooding over 9 km of the riverbed, affecting 57 engraved rocks, including some of the most emblematic Côa prehistoric panels.

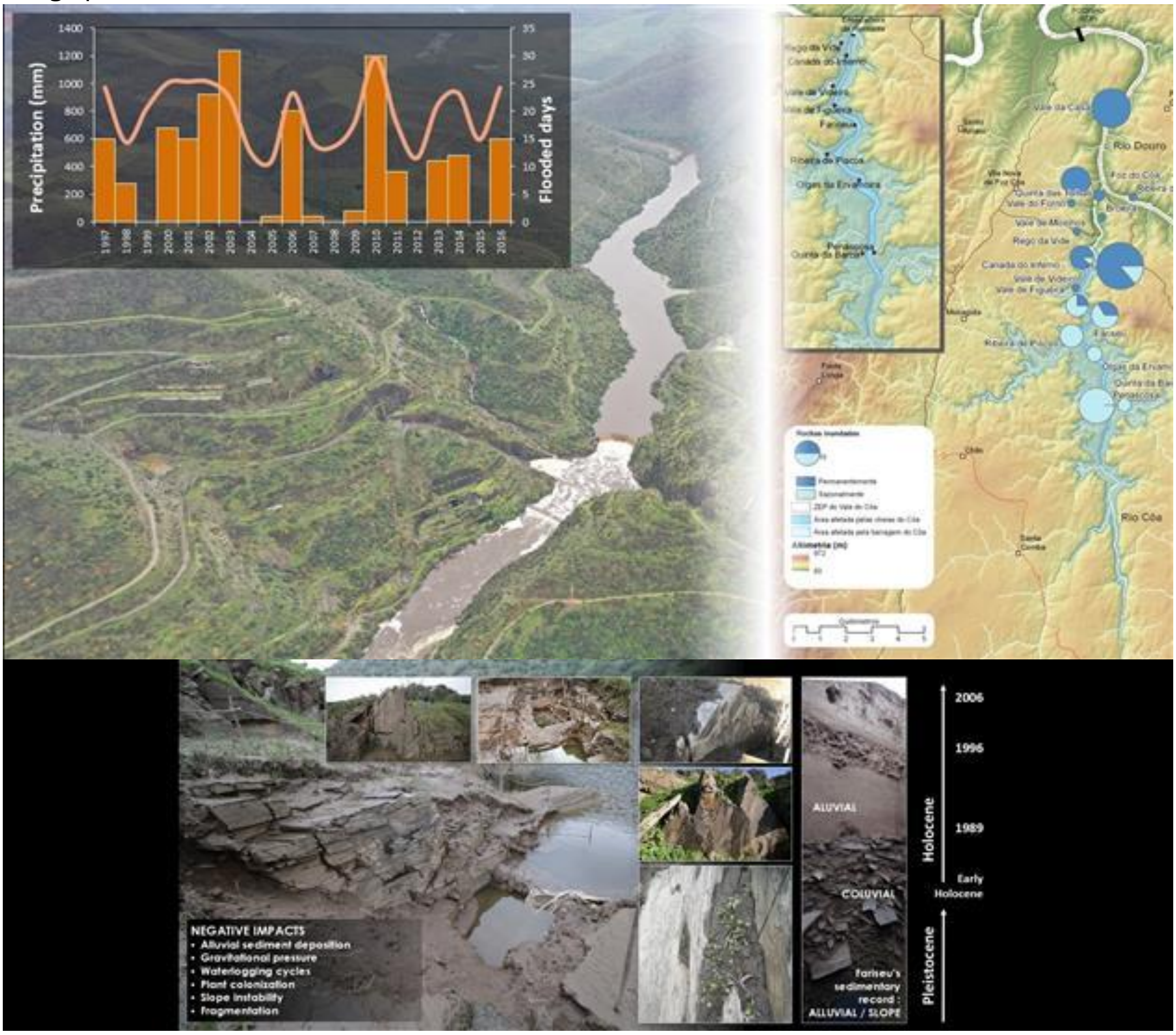
Consequently, present management procedures struggle with the herculean task of curating this fragile heritage in such difficult and uncontrolled conditions. Moreover, when degradations occur, the lack of extensive documentation protocols exploiting the full potential of new technological solutions, usually results in significant losses of invaluable historical information.

This called for the development of an advanced cultural heritage preservation strategy based on an ambitious digital transition programme intended to improve our response capacity through remote real-time monitoring using a technological combination of contextual data, remote sensing, digital modelling, IoT, and artificial intelligence.

Nonetheless, it should be stressed that the simple consideration of the above-mentioned example of the cofferdam impact on the specific conditions of rock-art preservation in the Côa Valley demonstrates that no technological development or digital transition will be effective unless strongly anchored on the previous research experience and a detailed knowledge of the territory, geologic structure, geomorphological dynamics, petrological characteristics of the

rock-art supports, cultural settlement criteria, engraving techniques, biological colonization of the engraved panels, impacts of human actions, etc.
Accordingly, the strategic assessment supporting the innovative "Kassandra conservation strategy" restated the need for continued study of the natural and cultural aspects of the prehistoric engravings as the first critical factor in the success of conserving the Côa heritage, as is the distinctive mark of the Côa Cultural Heritage management since the early stages of the "Battle of Côa". This pre-requisite called for an extended program of collaborative research, combining the Côa Parque Foundation's internal research capacity and a wide network of partner entities from the academic and professional sectors.
In this general framework, the Kassandra@Côa project was designed to study the former conservation program and identify opportunities for improvement through the integration of new available technologies and the renewal of monitoring and maintenance protocols for this heritage, aiming to surpass present inefficiencies and minimize the negative impact on the prehistoric art of both environmental and anthropogenic hazards by thoroughly testing a wide range of available technologies able to improve the current rock-art study, preservation, and dissemination practices and further develop innovative management protocols combining state-of-the-art inspection and monitoring equipment with ICT's advanced technology in augmented reality, big data processing, artificial intelligence, alarmistics, and communication networks.
The resulting "Kassandra strategy" proposes a digital transition towards an intelligent conservation paradigm of the Côa cultural landscape, based on the continuous remote monitoring of the territory and its cultural and natural resources, favoring the adoption of a preferably preventive - rather than reactive - conservation perspective, supported by sustained collaborative and multidisciplinary research about the engravings, their physical supports, and the environmental and geochemical dynamic processes of its preservation/decay.
As a result, the path for the intended digital transition of the Côa valley rock-art preservation program requires:
- Expanding our understanding of the territory and heritage, focusing on the engravings' rock-supports and their degenerative processes (geochemical, biogenic, and anthropogenic).
- Testing the wide range of nowadays cutting-edge remote sensing and 3d digital technologies, to evaluate its relevance for Prehistoric research, rock-art documentation, study, and dissemination and introducing advanced digitization techniques to enhance the accuracy and detail of digital representations of rock-art panels.
- Introducing innovative enhancements of the existent technological equipment, favouring its use for Prehistoric art documentation in harsh out-of-the-lab conditions.
- Developing seamless precise as-is 3d global models of the studied territories derived from the combination of non-invasive multi-sensor geometric and Geophysics terrestrial and airborne surveys through data fusion protocols.
- Developing new rock-art documentation methods combining the classic relevé methods with 3D digital modelling and other geometric and imaging technologies into seamless multi-source 3d digital models with augmented reality and embedded predictive tools.
- Creating 4d Paleogeographic and Paleoenvironmental reconstruction protocols based on the above technologies.
- Building digital twins of the Côa territory integrating diverse data sources such as geometric, spectral, geographic, remote sensing, and environmental data.
- Designing, producing (by addictive production), and implementing in the field a set of multi-parametric sensors for continuous monitoring of the rock art distributed in the territory.
- Creating the remote monitoring and alarmistics software for the central management unit.
- Designing and implementing an unstructured, wireless communication's infra-structure able to continuously stream the field sensors data in real-time.

- Implementing a decision support system including preventive and mitigation algorithms against predictable or verified threats, thus promoting preventive preservation and enabling proactive damage prevention.



420. Comparison of large-scale magnetometry measurements with excavation datasets in Eastern Hungary. Feature detectability and identification possibilities

Gábor Mesterházy (Hungarian National Museum)*; Mihály Pethe (Hungarian National Museum)

In 2009, David Jordan highlighted the half-century track record of archaeological geophysics' effectiveness. Since then, the adoption of non-invasive geophysical methods in scientific and development-led archaeological research in Europe has gradually increased. Despite the widespread use of geophysical measurements for various archaeological objectives. Many studies often focus solely on processing and interpreting data without adequately addressing feature detection probabilities, identifiable feature types, and undetectable archaeological features.

This study examines two sections of motorway in Jász-Nagykun-Szolnok county, Eastern Hungary: the 19 km M4 section between Abony and Fegyvernek, and the 33 km M44 section between Tiszaug and Szarvas. Geophysical surveys, conducted in 2013 and 2014 across 67 hectares using magnetometry, were complemented by trial trenching and full-scale excavations in subsequent years, yielding a significant dataset for comparison. The presentation aims to analyze the physical and cultural properties of archaeological phenomena by comparing features from magnetometry, survey interpretation, and excavation. Each method has its limitations and biases: magnetometer surveys are influenced by measurement settings and soil properties; survey interpretation depends on the expertise of the interpreter; and the success of excavations is impacted by the archaeologists' skills.

The data processing was aided by a developed ArcGIS toolbox, which offers shorter scripts and models to standardize the input data out of the excavation’s AutoCAD files. Original elevation values, humus-level points, archaeological features depth points, polygons of archaeological features with feature type and chronological data, polygon of excavation area was supplemented with geophysical survey area polygons and polygons of the geophysical interpretation, as primary and standardized input data. Further data processing was carried out in an automated black-box solution and the results were summarized in a single shape file. Our approach not only offers an overview of detection rates but also delves into the analysis of detection and misinterpretation rates by feature type, chronological categories, and properties (size, depth, topsoil depth).

On both motorways altogether 1,500 excavated and measured archaeological features were analysed from the Neolithic to the Middle Ages. Large, high response features (burnt houses, sunken buildings, kilns) had the most successful identifications rates, meanwhile small and shallow features (postholes, small pits) remained mostly undetected on the magnetic surveys. Due to the size variations of the pits, it only got mediocre detectability.

Through this comprehensive examination of large-scale datasets, we have enhanced our understanding of regional feature detection capabilities, which varies by feature type and location. By developing a system, which focuses on the misidentification causes, regional strengths and weaknesses of the applied geophysical method could have been analysed. And meanwhile the scientific geophysical surveys are mostly not followed by a large-scale excavations, development-led archaeological projects could offer vast datasets to improve our understanding of the regional feature detection possibilities.

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79. Using AI interpretability techniques as a method for origin determination of prehistoric green phosphate

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Introduction:
Since the discovery of the main prehistoric sources of variscite [$AlPO_4 \cdot 2H_2O$] in the 1970s, several models have been proposed to determine the provenance of personal adornment made from this mineral or mixtures of different green phosphates. The number of empirical data used in them totals n=192 to date. The insufficient data on which such approximations are based considerably limits their generalisability as they fail to accurately represent the complexity of chemical compositions within different sources.
In this work, we leverage the information of ca. 1800 geoarchaeological samples of known origin to ask whether it is possible to use supervised machine learning techniques to geochemically profile the main sources of green phosphates in Western Europe, so that the provenance of prehistoric beads can be reliably established.
Our hypothesis is that provenance determination can be effectively modeled as a classification task. In this framework, we use compositional data obtained by p-XRF as our feature space, corresponding to a response variable with three classes representing the three main european deposits.
We trained a supervised model [Random Forest(RF)] to infer a sample's belonging to one of the three classes. Subsequently, we evaluated its decision-making process using entropy (Shannon 1948) and Shapley values (Lundberg y Lee 2017; Shapley 2016) as we were interested in identifying critical elements that discriminate between classes and not only in achieving good model performance.
As a use case, we have used an external test of (n=159) beads from four Portuguese sites whose provenance was previously determined using some previous chemometric models (Carvalho 2019) as a baseline to compare results.
Methods and materials:
The dataset has been built from the recorded elemental composition of a set of geological reference material of known origin measured with a portable energy dispersive X-ray fluorescence spectrometer (p-EDX). The data accounts for n=1778 samples from surveys and excavations in Aliste outcrops (n=511), Terena and Pico Centeno mining complex (n=439), and Can Tintorer mining complex (n=828). The samples were randomly selected from the material collected during fieldwork, so the sample has no mineralogical bias. Any green phosphate mixture that resembled variscite, as determined by XRD, was analyzed. A 5-mm sample thickness was used as the only selection criterion to avoid analyzing crust or veinlets which could not be worked to make beads, pendants or charms.
Chemical composition was measured by an Oxford Instrument XMET-7500 p-EDX equipped with a Rh tube, a silicon drift detector (SDD), and an automatic 5-position filter changer. Quantification was obtained using the SOILS-LE program based on fundamental parameter (FP) method.
For model building, a standard splitting procedure was performed using 80% for training. We assess model performance by 10-fold cross-validation tests of 10 iterations with the remaining 20% of the data. Ten percent of the original data (n=178) was reserved as an out-of-sample final validation set to ensure that any data leakage would not affect the model development and lead to overestimation of the model's performance. To investigate the discriminants within each source we explore the importance of the features selected by our model. We unpack feature

importance computing information gain based on entropy reduction and Shapley values, a game-theoretic technique frequently applied in machine learning to interpret predictions that is defined as the average marginal effect of including a certain feature over all possible feature combinations.

Results:

The results suggest an alternative way of interpreting the influence of different elements within the geochemical compositions of green phosphates. Contrary to previous proposals, we find that a slightly different set of elements play crucial roles in differentiating between sources, while others traditionally considered as key discriminants appear to be of marginal importance. For instance, it seems that Fe's inclusion may introduce noise, and potentially compromise accurate source discrimination. Additionally, P, Al and Si, previously highlighted, also showed limited significance in our analysis and contribute minimally to source differentiation.

On the other hand, elements included in previous models as Ca, Cr, As or V have been found to be among the most influential in discriminating between sources, but others such as Sr, Mo, Ta or K emerge as unexpectedly important discriminators, and should be taken into account despite having been overlooked in previous studies.

Our findings show that the discriminant elements are not necessarily those present in the highest concentrations within the deposits, but those that contribute most effectively to the systematic ordering of the data. This represents an important shift in the analysis of archaeometric data that exploits the use of information as a quantitative measure.

Used in archaeological settings, the results reveal new insights into the structure of the distribution networks of these materials, suggesting that Catalan materials reached regions as far away as the Portuguese Estremadura in the Chalcolithic period.

Discussion:

Our proposal enables the visualization of the feature space in a manner that surpasses the capabilities of traditional techniques, particularly when dealing with high-dimensional data. While previous chemometric models have attempted to reduce the number of discriminant elements to a limited set that can be represented in successive ternary diagrams, such approaches often fail in oversimplification of the complexity of the phosphate chemistry. In contrast, our method leverages the dimensionality of the data, offering a more comprehensive and flexible analysis. Furthermore, this approach allows for the integration of the chemical complexity inherent in various green phosphates, extending beyond variscites to encompass a broader range of mineralogical mixtures that enhances the model's applicability and robustness in provenance determination.

A final set of 14 elements has proved to be the most important in addressing provenance analysis. The trained model, fully reproducible can be used for new predictions.

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339. Besieging the fortress. Challenges and experiences with integration and analysis of diverse datasets in the study of the early medieval fort in Spycimierz (central Poland).

Jerzy Sikora (University of Lodz)*; Piotr Wroniecki (Montefortino Prospection & Digitalisation)

The medieval (11th – 14th century) fortress at Spycimierz (Łódź Voivodeship, central Poland) is an interesting case study of the problem of integrating diverse data sets from both non-invasive and invasive archaeological investigations. The exceptionally poorly preserved remnant of a former timber fortress is located east of the present village of Spycimierz, in a bend of an old river channel, at the bottom of the Warta valley. Its present shape is largely the result of natural processes (numerous floods recorded in the archaeological record) as well as anthropogenic processes (traces of repeated extensions and transformations, destruction and later agro-technical processes), which have almost obliterated the original relief of the site. Despite its poor state of preservation, the site has been of interest to archaeologists since the 1920s. The first excavations were carried out here in 1962-1963, accompanied by an electrical resistivity survey, which was pioneering in Poland at the time (Nadolski 1966). This resulted in extensive drawing and photographic documentation of a standard typical of the 1960s. Unfortunately, the results of these surveys have not been fully published. In 2014 and 2016 we carried out an extensive programme of non-invasive research in Spycimierz, including analytical surface surveys, geophysical surveys (magnetic, electrical resistivity, GPR), aerial photography (which was repeated in subsequent years using UAVs), LiDAR data analysis and preliminary geochemical probing using the phosphate method. In addition, archival cartographic material was collected, including archival orthophotos from the 1940s. The results of this work have been published (Sikora et al. 2017). A small-scale verification excavation was carried out in 2022 and 2023. This time, digital photogrammetry-based documentation combined with detailed RTK and total station surveying was used in place of traditional drawing documentation. A methodology similar to that previously used at another similar site in Rozprza (Sikora and Kittel 2018) was employed, supported by the use of UAVs.

During the course of the 2014-2016 non-invasive surveys and the recent excavations, the need to integrate their results emerged. For this purpose, the GIS environment and Qgis software were used, as they allow fast, efficient and accurate integration. In 2022 and 2023, photogrammetric techniques were used extensively to document the excavations, but the results of these activities, in the form of 2-dimensional georeferenced plans, were exported to Qgis software. Such 2D documentation visualised in Qgis meets the expectations of the Polish Monuments Protection Offices, which still require paper-based documentation. Planning of the excavations was directly guided by the results of the geophysical survey, and excavations were established on specific anomalies in order to obtain further excavation data for their interpretation. Ultimately, the stratigraphic situation revealed by the excavations proved to be more complex than the interpretation of the geophysical data, which become an additional challenge for archaeologists. The procedures used to integrate the results of both archival and current research had come up against the heterogeneous nature of the datasets used. While the survey methods used in recent years, both non-intrusive and intrusive, were relatively easy to incorporate into the system, as they were directly created with GIS systems in mind and had accurate georeferencing based on the results of geodetic measurements, the data produced in the 1960s posed a significant challenge. The drawing documentation was based solely on relative measurements made in relation to the edges of the archaeological trenches. The edges of the trenches themselves, measured with tapes and simple optical instruments, were only plotted on a composite plan.

Unfortunately, this was drawn in a local reference system that could not be accurately aligned with the national coordinate system we use. In addition, the situation depicted on this plan hardly reflects the actual situation of the poorly preserved object. It was only after a thorough analysis of the terrain using LiDAR data and archival photos that the locations of the 1960s excavations could be approximated. Only then was it possible to georeference the digitised plans. Despite our best efforts, some documentation, such as electrical resistivity surveys from the 1960s, could not be imported into our GIS system because there was insufficient data to allow georeferencing. Finally, by bringing together the results of archival and current research, within a single GIS system, it has been possible to build a bridge leading to a more complete interpretation of the results obtained over the years of research. It has made it possible to provide an interpretation of the wooden structures excavated in the 1960s, which were unclear to researchers at the time. At the time, they were dated to the 14th century and their purpose was described as unknown. By comparing their characteristics with those of the structures uncovered in 2023, which have been precisely dated using dendrochronology and radiocarbon, it has been possible to determine which are the remains of the 11th-century rampart and which are most likely related to the wooden buildings inside the ring-fort.
The digitisation and integration of the Spycimierz datasets into a unified GIS environment could be an interesting case study, not only because of the bridging of non-invasive and invasive archaeology, but also because of the use of very diverse data, including pre-digital archival data. It also illustrates that the effort to digitise such older data is worthwhile, as it allows entirely new interpretations, resulting from a better understanding of the spatial context through the use of a GIS environment.

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318. Enhancing Archaeological Interpretation with Anomalyzer - A Tool for Non-Invasive Data Analysis

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Introduction

The increasing reliance on non-invasive archaeological techniques, such as geophysical (Gaffney & Gater, 2003), ALS/LiDAR (Opitz & Cowley, 2013), and remote sensing surveys, has produced an abundance of complex datasets. These data sources offer significant potential for understanding archaeological sites before excavation, but their scale and complexity often require advanced tools for interpretation. This paper introduces a computational tool, Anomalyzer, as part of the broader, in-house developed, Py2DGeoBatch framework. Designed to support archaeological interpretation, Anomalyzer applies statistical analysis and anomaly detection techniques to identify features of interest, thereby aiding excavation planning and contributing to the implementation of geophysical data into archaeological workflows.

Methodological Framework

The Anomalyzer tool operates as a key component of Py2DGeoBatch, a Python-based framework for the analysis and visualization of geophysical datasets. The design of the tool emphasizes adaptability, enabling it to process various data types, including magnetic, GPR, resistivity, and topograpical (LiDAR-derived) datasets. Anomalyzer uses a combination of data preprocessing, statistical modeling, and spatial analysis to identify anomalies that could indicate archaeological features. The tool is built around integrating core principles of statistical thresholding, which identify data points that deviate significantly from the norm, coupled with clustering algorithms that group these anomalies into spatially meaningful patterns.

Central to the methodology is the use of Gaussian smoothing and edge detection to filter noise while preserving critical features within the data. This preprocessing step ensures that the analysis focuses on relevant anomalies without being skewed by extraneous fluctuations. Anomalyzer applies unsupervised machine learning methods such as Balanced Iterative Reducing and Clustering using Hierarchies (Zhang et. al, 1996), which allow for the organization of detected anomalies into interpretable groups. These outputs are subsequently visualized in formats suitable for Geographic Information Systems (GIS), enabling archaeologists to overlay anomaly maps onto other spatial datasets for comprehensive site analysis and further qualitative interpretation.

Applications and Case Studies

The development and application of Anomalyzer have been guided by real-world archaeological projects. One illustrative case involves the analysis of magnetic data from fortified and enclosed sites from various chronological periods. The tool was able to identify clusters of subsurface anomalies consistent with defensive structures, which were later validated through comparison with excavation findings. In another case, Anomalyzer was applied to airborne LiDAR-derived data to detect microtopographical features indicative of prehistoric earthworks.

These case studies show the utility of Anomalyzer in bridging the gap between non-invasive data collection and actionable insights. By automating aspects of data analysis, the tool not only reduces the time required for interpretation but also ensures consistency compared to manual mapping in the identification of archaeological features across diverse datasets.

Challenges and Future Directions

As a proof-of-concept, Anomalyzer has demonstrated significant potential but also revealed areas for improvement. One ongoing challenge is the tool's scalability when applied to extremely large datasets, which can strain computational resources and slow processing times. Future development efforts will focus on refining the clustering algorithms and similar techniques to enhance the accuracy of feature classification. Real-time data processing capabilities are also being considered to support field-based workflows.

Development Status

The Anomalyzer tool and the Py2DGeoBatch framework have been developed in-house as part of a proof-of-concept initiative. The primary objective is to experiment with and refine solutions in the vast landscape of non-invasive field techniques and available computational methods. The focus remains on testing the effectiveness of various approaches, with an emphasis on identifying best practices and methodologies that can later aid the tool's development.

Conclusion

The Anomalyzer tool marks a significant advancement in applying computational techniques to non-invasive archaeological research. By automating the detection of anomalies within complex datasets, it offers archaeologists a powerful resource for streamlining interpretation. While still under development, the tool has already demonstrated its utility through various case studies. Its continued refinement holds the potential to revolutionize the use of non-invasive data in excavation planning and heritage management. By addressing the challenges posed by the differing expertise required for archaeological interpretation and geophysical analysis, The aim of Anomalyzer is to bridge gaps in communication and improve integration of available non-invasive datasets into archaeological workflows, both in rescue and scientific contexts. This process, often complex and nuanced, can otherwise lead to misunderstandings or even the abandonment of non-invasive data in projects.

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250. Using Augmented Reality for 3D-Reconstruction in Building Archaeology Interdisciplinary XR-Development at the Roman World Heritage Sites of Trier

Clemens Brünenberg (TU Darmstadt, Department of Architecture); Martin Kim (University of Applied Sciences Mannheim)*

Architecture is three-dimensional. As such, three-dimensional models showing the state of preservation and reconstruction of lost buildings are regarded as a heuristic tool in historical building research. These models not only allow us to convey certain visual concepts, but also to clarify our understanding of building processes, construction phases, spatial design or constructive interrelationships, right down to detailed solutions. The meaning and significance of these models is closely related to the actual object, but their development process is usually independent of it.

In this project, the process of creating these reconstruction models will be directly linked to the object under investigation for the first time, with the help of the technical capabilities of augmented reality (AR), thus redefining the reconstruction methodology. The immersive effect of augmented reality alone, i.e. the superimposition of real surroundings and virtual content, makes it possible to work on the reconstruction directly on the object in three planes of reality. The existing building stock (first level) is linked with the digitally recorded building stock (second level) in order to build the virtual reconstruction directly on the object (third level).

An integral part of this innovative approach to implementing and testing working hypotheses, architectonic possibilities and preliminary reconstruction approaches is the networking of all those involved in the reconstruction process at the object. It is possible to broaden their expertise through a broad , interdisciplinary and transdisciplinary discussion and to directly apply the results of this collaborative work in the reconstruction. The aim of the project was to develop a tool for the methodical application of this new approach. The testing and development of this tool has been carried out within the framework of this project using the example of the imperial Barbara Baths in Trier.

The expected outcome of the project was the development of a digital application tool that allows users to reconstruct on objects of interest in an AR environment, with the possibility to extend the tool as needed.

537. Motion Capture and Augmented Reality in the Reconstruction of the Intangible in Cultural Heritage and Archaeology.

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Introduction

Archaeology is fundamentally and in its original form a discipline dealing with material and tangible subject matters. This is a challenge if the purpose is to reconstruct the practices that once gave meaning and cultural context to what today may only be disintegrated physical remains. While the documentation and conservation of intangible cultural heritage has been given a lot of attention over the past decades, the reconstruction of the intangible and immaterial context of artefacts and sites from the distant past have been given less attention. All our cultural forms and practices involve human action. And once human actions are lost they are difficult to reconstruct or reenact in a purely digital environment. This is where Motion Capture becomes important. Earlier motion capture was limited to large scale film, animation and game productions. Now it is emerging as an affordable technology even for academic research & development purposes.

Methods and materials

The presentation will focus on the use of Motion Capture as a tool to analyse and understand actions and cultural heritage in settings of early historic buildings, surroundings and landscapes. More specifically, we will focus on the design and development of several augmented reality applications from archaeological and cultural heritage sites: religious rituals in ancient Greek culture, reconstruction of a historical event in ancient Rome, a Viking/Medieval farm mound, and most importantly the augmentation of a Mesolithic rock carving site in Oslo. The applications will present suggestions on how to construct prehistoric landscapes as well as buildings in order to give the users a deeper understanding of the events and places.

Discussion

The presentation will discuss experiences and designs as well as describe various solutions for different purposes and needs. It involves both the development of new technological possibilities and an understanding of the historic and prehistoric events, The applications integrates all available sources, both documentation of the remaining cultural heritage and, for the historic periods, written sources. The main focus is academic research, but the results will also be valuable assets in teaching students in university courses that include these periods and geographic areas. The results can also be used to teach lower grade students and in public outreach, as they will deepen the immediate understanding of the remains experienced by visitors to the sites today.

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82. Menodora: A Metahuman Model created with Mixed-Reality in Sillyon Excavation Project

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Sillyon, within the ancient region of Pamphylia, is located in Serik district in Antalya province Türkiye. The cite is a prominent ancient city with its archaeological cultural assets and multi-layered texture with its historical and cultural assets. Throughout history, at the point of unification-conflict of cultures and civilizations, Sillyon bears the traces of many civilizations.
Menodora, the metahuman project that is planned to be advanced, embodies an innovative study made with the goal of digitally reconstructing ancient sites (Taşkıran 2021, 1-3). This study concentrates on 3D modeling of Menodora, a benefactress, a notable person in the 2nd century Sillyon (Adak 2024, 59). It is aimed to model the envisaged physical properties, gestures and motions of this Luwian origined, ill fated Anatolian woman with highest accuracy through the software that has been developed within the excavation project. Historical sources and the archeological and epigraphical finds discovered in the city have been guides to this modeling. Our project is going to apply the methods of mixed reality and gamification, and the model being developed is going to be integrated with the Virtual Reality (VR) goggles technology; eventually the simulation which is closest to the reality will be provided. Furthermore, an interactive fiction will be created by placing the metahuman Menodora in the virtualised ancient city. Thus, visitors are going to have the opportunity to explore the city interactively through Menodora. This experience which is presented to visitors, is not only limited to a virtual tour, it also provides a connection with the historical cite through their dialogue with Menodora. Thereby visitors having this experience, are going to have a better understanding of the social and cultural dynamics of the city (Ioannides, Magnenat-Thalmann, and Papagiannakis 2017, 371).
The metahuman study, will be accomplished with the help of video games, virtual reality, augmented reality, simulation and other game engines used for other virtual applications. It is foreseen that the softwares which are the most realistic and powerful graphic engines of the time, are going to add the project high quality visuality and realism. With the potentials of this software engines, detailed graphics and dynamic simulations will be done in order to take the visitors experience to the highest level. A full and comprehensive experience to the visitor, both technically and artistically is the bottommost aim of this project.
To conclude, the Metahuman project is not only a historical reconstruction work, but also an innovative approach which is going to provide the visitors to get into interaction with the historical environment. The Menodora project is going to make the elements of the antique era more accessible, attract the visitors attention through being fun and educating on one side, and on the other side it is going to contribute to digital technology used in archaeology with an innovative modeling system.

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464. Developing an AR application for self-exploration at the Roman Temple in Antiochia ad Cragum, Turkey.

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Introduction

The so-called “NE Temple” in Antiochia ad Cragum, a Roman city on the south coast of Turkey, has been excavated since 2005. The excavations have uncovered the remains of the city, developed in terraces on the slopes of the mountain, that included monumental colonnaded agora, a main street with a gate, a theater, two bathing complexes, and temples. Among the building remains, the most intriguing and the earliest to be studied was a tetrastyle prostyle podium temple, perched over the Roman city at its northeastern side. This was a highly-visibly temple, which over the course of its history was repurposed into a burial ground in the Byzantine period, later into a wine press and which also collapsed completely till the level of its stylobate due to an earthquake. The course of the excavations uncovered the building remains of the temple, cleaned and positioned more than 600 building blocks on the surrounding field, that are estimated to constitute about the 80% of the building materials of the temple.

Despite initial interest from local authorities, a complete or near complete reconstruction of the Temple back to its authentic architecture of the early Roman era is ultimately not recommended by the architectural, engineering and conservation team (Erdogmus et al. 2019) for two reasons: First, since the building had several uses and reconfigurations over its history, no single reconstruction can bring it back to life accurately and ethically. For instance, if it were to be restored to the state of a brand-new pagan Roman temple, the history of the burial and wine press periods would be lost. Second, given the condition of the existing platform and blocks; and the number of missing elements, any major reconstruction would have to incorporate new materials (e.g. pieces carved from new marble that is compatible) as well as significant structural interventions on the existing materials (e.g. reinforcement, mechanical connectors, pinning) for a structurally safe reconstruction. Such an extensive reconstruction is not likely within the boundaries of ICOMOS standards for anastylosis as well as the budgetary constraints of this project. Therefore, a unique multi-era digital augmented reality reconstruction has been proposed that will synthesize the evidence on site with the proposed reconstruction, according to the principles established by the Charter of London for digital reconstructions (Denard 2021). Visitors to the temple will be able to access the application via a QR code with their phones and will be able to navigate the site and participate in the research argument made thus being active readers and learners of the material record, and not passive recipients of ready-made information, in a similar manner to the VR application for the Library of Nysa (Mamoli et al. 2007).

Methodology

The methodology we are following for this project has distinct stages: 1. Lidar scanning of the in-site building remains of the temple as well as of a sample of 30 building blocks, on which the reconstruction of the temple is based. These blocks are placed in the field, one next to the other and come from different architectural members of the temple, such as column, antae and pilaster bases, capitals, entablature blocks including architrave, frieze, and geison blocks, the tympanon of the pediment, etc.

2. The 3d modeling of these sample blocks based on the captured blocks and the drawings of the state of preservation made over the years by the archaeologists.

3. The 3d modeling of the state of reconstruction of the temple, as it was probably designed in the 2nd – 3rd centuries CE, based on the restored geometry of the sample blocks built in stage 2 and the reconstruction of the in-situ building remains of the temple.
4. The synthesis of the point cloud of the in-situ remains and the state of reconstruction (built in stage 3) of the temple in a virtual environment, in which the reconstruction will be with 50% opacity to allow for the visibility of the evidence (state of preservation) within the hypothesis (state of reconstruction). Additionally, the point clouds of the sample building blocks will be placed in their corresponding reconstruction parts following the same aesthetic and principles.
5. In the future, we plan on further developing the application to include the history of the building, and the different phases of its use over the subsequent centuries until its abandonment.

Results

The output of this project is VR/AR application that the visitors will access with a QR code through their phones on site as well as renderings to be included on information boards on site as well as the Alanya Museum, in the galleries that include findings from the temple. According to our timeline, these will be installed on site this coming May, at which point we will be able to collect user feedback and data. At this point, our intention is that this application will combat the typical non-expert visitors' perception that archaeological remains are "all stones" and demystify the methodology that archaeologist use in the reconstruction process.
By putting QR codes to different curated spots around the temple, we make this VR application part of the circulation path of the archaeological site and enable the visitors to access the reconstruction from multiple points of view, experiencing the reconstructed temple within its ruins and the landscape. Additionally, by putting QR codes in select building blocks we extend the visitors' experience to the whole uncovered archaeological record and make the field of building blocks part of the destination, not just an area necessary to cross to reach the destination, which is the temple.

Discussion

In making this application, the major challenges we need to resolve are issues of ownership, maintenance and accessibility as technology constantly evolves. Questions like who is going to host the application, who is going to be responsible for its maintenance and the maintenance of proprietary software are very critical to the longevity of the project. For example, proprietary software (zapworks) that makes the development, hosting and use of such products seamless exists, however, issues of ownership of the model and accessibility without being hostage to an outside company might require the development of open-source software, such as unity.

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165. Augmented Reality as a Tool in Cultural Heritage Communication - Experiences from the ARGO Augmented Archaeology and BelginumAR Projects

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The project ARGO Augmented Archaeology aims to enhance visitor experiences at archaeological sites through augmented reality (AR), allowing users to view 3D reconstructions of historical structures in their original size and locations. This immersive approach deepens visitors' understanding of these sites.

The project began with a feasibility study at the Department of Classical Archaeology at the University of Trier in 2015. Initially, the team tested marker-based AR systems but found them inadequate for their goals, leading to the development of a GPS-based solution. From 2017 to 2020, the project received funding through the EU’s LEADER program, which promotes rural areas. By collaborating with experts from fields like geoinformatics, geoarchaeology, history, and intermedia design, the team developed an AR-based guidance system that includes an app, a web route planner (ar-route.eu), and information boards, linking and visualizing 110 sites across Rhineland-Palatinate and Luxembourg.

Since its launch at the end of 2020, the project has continued to expand, incorporating additional sites and new features. To present and communicate various aspects of the Roman site Belginum, including buildings and significant finds through multiple AR experiences, a technically independent app was also developed.

3D Reconstruction

The creation of 3D reconstructions began with an extensive literature review. Given the scope of primary documentation, the team primarily relied on published resources, although collaborations with ongoing archaeological projects provided deeper insights. However, two main challenges emerged: since AR overlays digital objects onto the real environment, high-resolution models of the terrain and the environment in general were needed to properly integrate virtual objects. This proved particularly challenging at sites where large portions of the structure had been preserved or rebuilt, such as castles.

To meet these challenges, the team used LiDAR scans for terrain modeling through CloudCompare. Also drone surveys of over 20 significant sites were conducted, documenting their current state of preservation in 3D via Structure-from-Motion technology. The actual 3D reconstruction was done using Blender, combining 3D-documentation and archaeological features with plans, cross-sections from literature, and the team’s sketches.

Using techniques from game development, the team improved modeling efficiency by creating a library of prefabricated assets like doors and windows, which not only sped up the modeling process but also optimized app performance and reduced storage demands on mobile devices. Substance Painter was used to apply PBR (Physically Based Rendering) textures, which included not just color but also material properties, gloss, and height details.

Challenges and Observations

Through the use of 3D reconstructions and AR, ARGO addresses a common problem in presenting archaeological sites: while excavations generate interest, conveying their historical context and past appearance remains challenging. Often, visitors are limited to basic information boards that may not fully capture the imagination required to envision the site's past appearance. Traditional physical reconstructions have been used to provide visual context, but they come with significant drawbacks. They are expensive to build and maintain, and they can compromise the integrity of the original archaeological site, potentially hindering further research. Moreover, visitors may struggle to distinguish between authentic reconstructions and practical modifications made for reasons like safety or cost.

The ARGO project utilizes augmented reality to achieve the visual benefits of structural reconstructions without these drawbacks. However, uncertainties in visual reconstructions—both digital and physical—pose a challenge: how should uncertain elements be represented? The team tested several strategies, such as leaving uncertain areas untextured or, in some cases, opting for hypothetical full reconstructions when leaving elements out seemed “more wrong.” Another approach was to visualize objects as ruins, so that uncertain aspects didn’t need detailed representation. Further research is needed to understand how these strategies affect viewers' impressions.

A sensitive aspect of the project involved stakeholder management. Since the LEADER program follows a bottom-up approach, site selections were made in consultation with local communities, with input from historical societies and interested individuals. This required substantial organizational coordination across 92 municipalities. In a few cases, implementing the proposed reconstructions was difficult, as long-held local beliefs didn’t align with current research approaches. This was further complicated by the fact that local institutions contributed to the project’s funding and sometimes saw it as a paid service rather than a research initiative.

Results and further Development

The AR app serves as the systems core, incorporating the AR feature alongside options for users to capture, collect, and share photos. The project also includes an online route planner that maps AR-enabled objects, offering additional information and visuals. Information boards at sites promote app usage, and promotional materials have been developed for tourism organizations. Since the app’s launch in late 2020, it has evolved with new features: a location library lets users download only selected items, optimizing data usage and storage. A preview function allows to view selected objects at a 1:100 scale from any location, and for certain sites, users can switch between different historical phases. New locations, such as the Romanesque abbey church in Prüm and the Gallo-Roman sanctuary of Pelm, have been added.

The project has also expanded into special applications, including a dedicated app for the 20th anniversary of the Belginum Archaeological Park. This app allows users to interact with exhibition highlights, such as a gladiator’s cup, providing detailed information through AR. The app later expanded into a comprehensive guide featuring an interactive map and additional AR content, including a multi-phase site model at a 1:100 scale and a walkable Roman house. A new tracking method using a combination of markers and SLAM (Simultaneous Localization and Mapping) was implemented.

Conclusion

The ARGO Augmented Archaeology and BelginumAR projects explore new ways in how archaeological information is communicated to the public. By integrating cutting-edge technology with innovative approaches to historical representation, ARGO makes archaeology accessible, engaging, and educational for visitors. The project not only preserves the integrity of archaeological sites but also fosters a deeper appreciation for history, allowing people to explore the past dynamically and interactively.

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176. Immersed in traditional places: an investigation of connection to land, lifeways and language in 360-degrees

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As humanity moves deeper into the 21st century, risks to heritage are increasing in quantity and severity. Cultural landscapes are impacted by climate change, natural disasters, modern development and human conflict. In the Canadian north, there is evidence that youth are not participating to the same degree as their ancestors in the traditional modes of skill transmission, including "on-the-land education [and] hands-on, practical engagement with the environment", due to being raised "exclusively in the context of fixed settlements and Eurocentric education" (Pearce et al. 2011, 271-272). Existing approaches in heritage engagement and management in North America are dominated by the use of 2D assets including documents, photographs and maps. 360-degree Virtual Tours and 3D models should continue to be tested within indigenous knowledge management contexts to ensure culturally sensitive methodologies are established and "can assist indigenous communities in fulfilling their own visions of heritage preservation" (DeHass & Taitt 2018, 120). Dawson et al. noted that while indigenous youth are already engaged with emerging digital technologies through mobile applications and video games, we as researchers still "need to better understand how indigenous users perceive the digital replicas we create, and under what conditions meanings are transferred, either in whole or in part, from the real object to its digital 'replicant'" (2011, 399).

The study presented in our paper was carried out in support of Carcross/Tagish First Nations' (C/TFN) interest in the digitization of cultural sites, landscapes and features in their traditional territory for dissemination to community members both local and distant. This research was conducted with three objectives:

to provide a roadmap for the adoption of accessible, engaging and user-friendly emerging technologies by heritage practitioners and concerned entities in preservation of sensitive sites that are threatened by human activity and climate pressures, and in particular for the valorization of sites that are not protected;

to describe the benefits and disadvantages of the aforementioned tools in site visualization and communication with the purpose to increase engagement of indigenous youth and communities with traditional places in their traditional territory;

to explore the benefit of accessing digital assets of survey documentations enriched with existing written, recorded, drawn and archived information through immersive interfaces on the expansion of a knowledge classification system.

The paper presents the 360-degree virtual tours (VTs) and 3D representations (3D models) of sites that were chosen as easy-to-use emerging technologies for the recording, interpretation, and dissemination of land-based language and cultural knowledge. Information from C/TFN's internal GIS database, the Yukon Territory's public-facing GIS program GeoYukon, excerpts and verbiage from prior C/TFN language and archaeological publications, and the collected 3D models were integrated with the VTs for presentation with the nation's Land Management Board (LMB), the decision-making body for all land management matters. The LMB selected two traditional places for the creation of VTs and provided logistics and personnel support for on-the-land data collection and training at the remote locations of Chílíh Dzé£e'/Tsálgi Shaayi and the Désdélé

Méne’ watershed. 360-degree imagery was recorded with an Insta360 One X2 and 3D models were collected with the Scaniverse mobile application utilizing the camera and LiDAR sensors on an iPhone 12 Pro. VTs were created and presented to C/TFN utilizing the Pano2VR software.

Two virtual tours and twelve 3D models were created during this study. Findings from this research show that the presentation of traditional language in Virtual Tours highly benefits the communities engaged. Additional preferences identified include the intentional selection of location for virtual transportation of community members to places of traditional significance and for the educational opportunities those choices provide to indigenous youth. Reflective discussions with the LMB indicated a preference for virtual representation of landscapes as they are without people or equipment, integration of VTs and 3D models with traditional GIS programs, and the need for further research around the diverse application opportunities of these emerging technological tools. The paper presents the workflow we developed to incorporate these tools as options for indigenous communities to utilize throughout efforts to safeguard cultural heritage.

This research claims that adaptation and standardization of digital tools to facilitate the visualization and dissemination of the diversity of human experience and beliefs must be guided by the respective knowledge holders of the local communities. The paper aims to inform the adoption of immersive heritage management systems to promote indigenous perspectives and priorities in accessible mediums which provide an intuitive understanding of tangible and intangible cultural heritage and the risks they face. Reflections of this study’s participants suggest that the integration of gamification methods with immersive 360 visualization (VT) dissemination may prove to support youth engagement with traditional and archaeological sites and places regardless of their location or access issues. As a result of the research presented, the C/TFN are considering implementation of the recommendations of this research to guide new forms of consultation deliverables from industries requesting to develop projects in their traditional territory, respond to information requests from the government, and/or to develop guidance procedures for trail crews working around sensitive sites, as a visually-based information dissemination method.

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105. Immersive Analytics in Virtual Archaeology Applications

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Virtual Archaeology (VA) develops and uses computer science methods and technologies in archaeology to innovatively experience and analyse the past.

This is driven by the tremendous technological advancements in terms of availability, usability and capability of technologies such as hardware for data acquisition and for creating immersive experiences, software ecosystems for model creation, and improvements in computational power for analysis and rendering.

Those advances lead to higher-quality virtual environments, a reduction in the effort required by experts to produce them, and novel ways of analysis and interpretation.

With those advances, we can address the rather extensive spectrum of requirements that emerge from the goals of VA of making the past accessible and preserve historical artefacts digitally.

Thanks to recent developments in technologies that allow the recording of cultural heritage (CH) objects, such as laser scans or photogrammetry software, digitised objects can be made accessible in virtual environments faster and in greater variety than ever.

Furthermore, the progress of extended reality (XR) developments helps to engage experts and a broad audience with our cultural heritage.

Therefore, 3D modelling and visualisation innovations that utilise XR technologies in various ways have become very popular, leading to many applications where CH objects can be seen, interacted with or represented in a specific way in immersive environments.

Those applications, in the form of digital recreations, try and need to use precise, compelling, and exhaustive ways to represent existing heritages and their historical backgrounds.

While multi-modal experiences can help with that and are also broadly applied, there seems to be a lack of systematic categorisation and exploration of actual design spaces in such VA applications.

Design spaces for multi-modality in immersive environments, such as immersive virtual reality (iVR), are the exact research that is happening in Immersive Analytics (IA), which builds upon Visual Analytics, Human-Computer Interaction, and Computer Graphics, among others.

IA utilises engaging and embodied tools to improve the users' understanding of a, in this works context, CH object.

We can use those tools to facilitate a researcher's capability of making decisions about questions related to digitised objects and, by extension, further the scholarly discourse by unveiling new aspects.

Multisensory analytics, for instance, explicitly examines utilising multi-modal interaction technologies to convey information to users via visual, auditory, haptic, or even olfactory channels.

Even the interaction with the environment can be enhanced through multi-modal input.

Apart from multi-modality, IA explores further related topics of interest to VA, such as (stereoscopic) 3D visualisation, multisensory immersive analytics, situated analytics, collaboration, and immersive storytelling.

As can be seen in the work of Rodriguez-Garcia et al., who provide a detailed review of works in iVR applications for 3D virtual reconstructions (Rodriguez-Garcia et al. 2024), despite frequent usage, there seems to be no explicit specification for multi-modal designs, even though they are available as, for example, in the book Immersive Analytics by Marriott et al. (Marriott et al. 2018), who explicitly address a design framework for multisensory immersive analytics.

One example Rodriguez-Garcia and colleagues point out is that auditory experiences were broadly included in the virtual experiences they encountered in the sample for their review, which, despite their popularity, lack the mentioning of a clear pattern for the actual audio design.
Since audio has evidence to improve immersion (Kern and Ellermeier 2020) and is part of the multi-modal experience, the indication of missing clear design patterns raises the question of whether this is due to existing established practices or missing interplay between related research.
The latter would imply unused potential for building immersive environments in VA contexts.
As a consequence, in this work, we look into the multi-modal design as well as a selection of further topics that pose an intersection between fields of interest for IA and VA.
We explore current research related to that intersection and discuss how existing results can be used to give immersive environments in VA an improved design frame.
Our work aims to further the discourse about best practices in VA applications by assessing the potential of IA findings and how they can contribute to the workflow for creating immersive experiences for museums, teaching, and research applications.
We put them into the context of Virtual Archaeology and map out their applicability to the field to contribute to the synergy between related research directions.

428. From FAIR principles to FAIR practices in archaeo-geophysics – a position paper.

Agnes Schneider (Leiden University)*

Context
The practice of large-scale data collection has long been integral to Archaeological Remote Sensing. Increasingly, air- and space-borne sensors contribute a significant portion of datasets, and in the past decade, geophysical prospection has also embraced large-scale data collection. The growing volume and diversity of these data sources necessitate analytical approaches, such as (semi-)automated analysis methods, to manage and interpret this information effectively. While established workflows and methodologies exist for processing air- and space-borne imagery, similar workflows are largely absent for geophysical datasets due to their unique complexity and characteristics.
Main argument Over the past two decades, the application of semi-automated methods to large-scale archaeological remote sensing has shown continuous progress, often influenced by advancements in Remote Sensing and Computer Science. This period has seen the development of diverse solutions tailored to specific research questions. However, such efforts frequently lack published data, code, or workflows in a form that supports transferability or reproducibility, with workflows often presented in a highly generalized manner. The introduction of the FAIR principles in 2014 marked a turning point, highlighting the importance of making data Findable, Accessible, Interoperable, and Reusable. Recently, research data management has gained prominence as a core element of scientific practice. Despite this, the absence of widely adopted research standards continues to hinder transparency, transferability, and the establishment of best practices.
Applications or implications Specifically in the case of archaeo-geophysics, transparent and transferable workflows require certain desiderata to be successful. Although, as presented above, such kind of workflows are absent (with a few exceptions) for geophysical data sets, it is important to bring forward and establish what is needed. Although the following desiderata are rather specific for archeo-geophysics, they are also valid in general to archaeological remote sensing. First, the availability of standard benchmark data sets (collected in open data bases) in a common data standard is needed (including documentation and metadata). Secondly, annotated reference benchmark data sets with documentation and metadata are required. In addition, FAIR models for machine learning, trained on archaeological benchmark datasets are also required, and/or models transfer learned on archaeological data. Further the mindful creation of training datasets is essential, making use of consistent
ontologies to transform and formalize expert knowledge into context information and thus computer readable. At last, but not least, common evaluation metrics used in machine learning must be adjusted and tailored to archaeological data sets given their different and complex nature compared to those for which e.g. IoU was established.
To conclude it must be said, that evidently, there’s a long way to go and fundamental research is needed with regard to FAIR practices applied to archeo-geophysical data processing. A good starting point is a bottom-up approach of incorporating FAIR and CARE principles and practices into the teaching curriculum.

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493. Rethinking Reproducibility

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In the realm of fair and open science, the ability to reproduce the results of others is crucial for verification and validation. However, not all results are easily reproducible, particularly in fields like archaeology, where data often relies on outliers rather than repeatable experiments. Archaeology frequently adopts methods from other scientific disciplines that may not be entirely applicable, such as the emphasis on experimental repeatability and the scope of available data. With the advent of artificial intelligence, deviations due to optimization have become commonplace, necessitating a reevaluation of our understanding of reproducibility.

This reevaluation highlights that while the results themselves may not always be reproducible, the underlying information can still be valid. In the context of "The Turing Way," this distinction is framed as generalisability versus reproducibility. The central question becomes: when and how can we consider a result, and more importantly, a statement, as generalisable? The ultimate goal of reproducibility is to ensure that the insights gained from research are verifiable, valid, and applicable, at least within the context of the given experiment or study.

As reproducibility becomes increasingly challenging to achieve, maintain, and sustain, it is essential to reassess its cost and benefit. Even if results can be reproduced, this does not necessarily mean that generally relevant insights can be derived from the data, methods, or results. Therefore, the focus should shift to understanding what we truly aim to achieve with reproducibility.

In this presentation, we will explore what is fundamentally important about scientific research results, how the stability of results can indicate generalisability, and how insights can potentially be measured. By addressing these aspects, we aim to provide a nuanced perspective on the role and significance of reproducibility in scientific research, particularly in fields where traditional methods may not fully apply.

Reproducibility in scientific research is a cornerstone of fair and open science, ensuring that results can be verified and validated by others (Committee on Reproducibility and Replicability in Science et al., 2019). However, the challenge of reproducibility is particularly pronounced in archaeology, where data often hinges on outliers rather than repeatable experiments. This field frequently borrows methods from other scientific areas, which may not always be suitable, such as the emphasis on repeatability and the scope of available data. The advent of artificial intelligence has further complicated this issue, as deviations due to optimization have become the norm, prompting a need to rethink our approach to reproducibility.

The key insight from this reevaluation is that while reproducibility of results may be difficult, the validity of the underlying information remains intact. In the context of "The Turing Way," (Turing Way Community, 2022) this is articulated as the difference between generalisability and reproducibility. The critical question is: when and how can we deem a result, and more importantly, a statement, as generalisable? The primary objective of reproducibility is to ensure that the insights derived from research are verifiable, valid, and applicable within the context of the specific experiment or study.

Given the increasing difficulty in achieving, maintaining, and sustaining reproducibility, it is crucial to reassess its cost and benefit. The ability to reproduce results does not automatically imply that the data, methods, or results will yield generally relevant insights. Therefore, it is important to clarify what we aim to achieve with reproducibility.

This presentation will delve into the essential aspects of scientific research results, the role of result stability as an indicator of generalisability, and the potential methods for measuring insights. By examining these factors, we seek to offer a comprehensive view of the importance and implications of reproducibility in scientific research, especially in disciplines where conventional methods may not be entirely applicable.

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478. Reproducibility in the age of AI and beyond: a position paper.

Nadine Alpino (Schleswig-Holstein State Library)*; Lutz Schubert (Universität Köln); Agnes Schneider (Leiden University)

Context
Nowadays FAIR, - Findable, Accessible, Interpretable, Reproducible (and Replicable) are concepts which are supposed to be critical pillars of rigorous scientific research, which should facilitate the reliability and utility for future use. But does this always depict reality? Are FAIR principles translated into FAIR practices, and do they work as they are supposed to? So, what are the challenges of translating FAIR principles into FAIR practices and how to overcome them? How can every single of the multifaceted aspects be respected and fulfilled? These incorporate multiple agents with different responsibilities, so it is essential to distinguish and split the responsibilities. Individuals, groups and organisations have different needs and constraints. Until 2023 there was not a singular approach to implementing FAIR practices (Nicholson et al. 2023).

Main argument
It's time to look at the problem from a different angle: the different levels incorporate the creator of the data, the analyst of the data (using different computational environments) up to every level of adding or changing the data, the publishers (in scientific works), and the storage of the data (either at an institution or at a platform). It must be established what responsibilities lie with each level and agents.

One significant barrier is the rapid evolution of computational environments. Software, operating systems, and dependencies are subject to frequent updates, which can render code that worked flawlessly one day, incompatible the next. This issue is especially pronounced when research relies on external libraries or modules, as updates by third parties may disrupt previously functioning pipelines, leading to unverifiable results. Addressing this often necessitates preserving entire computational environments, such as via virtual machines or containerization. However, this approach raises further questions regarding sustainability, storage requirements, and practical feasibility.
There have been calls for publishers to take a more active role in verifying research, including reproducing results prior to publication. While this could improve the reliability of published findings, it also imposes substantial resource demands, requiring teams of experts and incurring significant costs. Additionally, reproducibility at the time of publication does not guarantee future replicability (as opposed to reproduced (Community, 2022)), particularly as methodologies evolve or as original datasets and computational environments become inaccessible over time.

The challenges of reproducibility are further compounded in the era of artificial intelligence (AI). Techniques such as large language models (LLMs) and generative adversarial networks (GANs) introduce unique complexities. While storing model parameters, seeds, and hyperparameters may enable reproduction of outputs under controlled conditions (Reddy, 2024), these results often lack robustness. AI-generated results are also sensitive to contextual factors, such as variations in input queries or additional training data, which can lead to divergent outcomes even under seemingly identical conditions. Moreover, the storage of all contextual information, including computation environments, increases both complexity and storage demands, creating further challenges.

Applications or implications
Given these complexities, it is neither practical nor efficient to adopt a universal ""store everything"" approach. For instance, simple computational tasks, such as calculating an average from a dataset, require the retention of data and the algorithm, but not the entire software environment. Similarly, preserving complex code is insufficient without proper documentation of the underlying algorithms and methodologies. Identifying which information is essential for reproducibility and determining sustainable strategies for its preservation remain key challenges.

This raises critical questions: What information is truly necessary for reproducibility and replicability? How can it be effectively preserved over the long term? And who bears responsibility for this effort—authors, publishers, or hosting institutions? Furthermore, what level of commitment can realistically be expected from authors years or even decades after publication?

This session explores these questions with a focus on reproducibility and sustainability of research results in archaeology, emphasising three core dimensions: What, How, and Who.

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448. Archiving in the age of Artificial Intelligence: a Report

Stefan Wesner (Universität Köln); Agnes Schneider (Leiden University); Lutz Schubert (Universität Köln)*

Reproducibility is a cornerstone of modern Open Science and the FAIR (Findable, Accessible, Interoperable, Reusable) principles, ensuring that scientific findings can be consistently replicated and validated. Traditionally, reproducibility and replicability hinge on the assumption that the algorithms and mathematical functions generating the data are deterministic and unequivocal. This implies that identical calculations should yield identical results each time they are performed. However, this ideal scenario often diverges from reality, particularly in methods that incorporate random factors to enhance performance and avoid local minima, such as optimization techniques.

Monte Carlo simulations and Artificial Intelligence (AI) clustering methods exemplify approaches that depend on random “seeds” to function effectively. Parameters like seed, temperature, and fidelity are crucial in guiding the output of modern Large Language Models (LLMs). Within the framework of the AI Act, ensuring a certain level of reproducibility is mandated, raising questions about the sufficiency of these parameters in guaranteeing replicability (“EU Artificial Intelligence Act,” 2024).

This presentation delves into the reproducibility of LLM outputs by examining various use cases and the controllable criteria that influence these results. We examine the impact of parameter variations on critical research outcomes, interpreting the deviations that arise from changes in these settings. The issue of non-reproducibility poses significant challenges for the archiving of scientific data, as deviations in AI-generated results can undermine the stability and reliability of AI systems (IBM, 2023).

Our presentation will address the implications of AI deviations, emphasizing their potential impact on the preservation and integrity of research findings. By exploring the nuances of reproducibility in AI, we aim to highlight the importance of robust parameter control and the need for comprehensive strategies to mitigate the effects of non-reproducibility in scientific research. This discussion is pivotal for advancing the reliability of AI applications in scientific inquiry and ensuring the long-term validity of archived research data.

Reproducibility is not merely a technical requirement but a fundamental aspect of scientific integrity. The deterministic nature of traditional algorithms provides a clear pathway to achieving reproducibility. However, the introduction of stochastic elements in modern computational methods, such as Monte Carlo simulations and AI clustering, complicates this landscape. These methods rely on random seeds to initiate processes, which can lead to variations in outcomes even under identical conditions.

The parameters that influence LLM outputs, including seed, temperature, and fidelity, are designed to control variability and enhance the model's ability to generate diverse and contextually appropriate responses, but also to achieving reproducibility. The AI Act's requirement also necessitates a closer examination of these parameters to ensure that AI-generated results can be reliably replicated (Baker, 2016; National Academies, 2019).

Through a series of use cases, this presentation explores the extent to which LLM outputs can be reproduced by controlling these parameters. We analyze the impact of different parameter settings on the consistency of results, highlighting the potential deviations that can occur. These deviations are particularly concerning in the context of scientific research, where the reliability of data is paramount.

The variation in (non-)reproducibility are essential in the broader context of data archiving. Inconsistent AI-generated results can compromise the stability of archived data, posing long-

term challenges for scientific inquiry. Addressing these issues requires a comprehensive approach that includes robust parameter control and the development of standardized practices for documenting and replicating AI processes.
In conclusion, the reproducibility of AI-generated results is a critical issue that intersects with the principles of Open Science and the FAIR guidelines. Ensuring reproducibility in the face of stochastic elements requires careful consideration of the parameters that influence AI outputs. By addressing these challenges, we can enhance the reliability of AI applications in scientific research and safeguard the integrity of archived data. This presentation underscores the importance of reproducibility in maintaining scientific rigor and advancing the field of AI.

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91. From Interdisciplinary Data Management to Reproducible Research in Practice

Steffen Strohm (Kiel University)*; Mattis thor Straten (Kiel University); Andrea Göhring (Kiel University); Peer Kröger (Christian-Albrechst-University Kiel); Matthias Renz (University of Kiel)

Interdisciplinary research environments often aim to provide answers to broader research questions regarding complex phenomena, large geographical distributions, long time horizons and combinations of the former. In order to pursue these goals a large variety of backgrounds, research interests, perspectives, methodologies and heterogeneous research data are intertwined in scientific collaborations. Based on experiences gathered over the course of several years in two larger interdisciplinary research projects with an archaeological focus and ongoing research as well as implementations, we want to propose and discuss a project-centric but generalized approach for effective research data management (RDM) for FAIR research outcomes.

FAIR research data alone is insufficient to make research reproducible and allow the community thorough evaluation with the adequate scientific skepticism, e. g., when assessing the analytical methods and their implementations used to process the given research data. In order to enable researchers to perform such assessments, the preparational and analytical workflows leading to certain results and states of research data need to become available in a form that allows interested researcher to rebuild an analytical pipeline in a time-efficient manner. In short: We believe that reproducible research needs FAIR research data and (easily) executable research workflow documentation.

In the first part of this work, the proposed framework generalizes core elements focusing to implement FAIR research data management and its relation to identified main functionalities a research project requires. Selected functionalities for an RDM solution to become a crucial or supportive tool are:

- Adherence to FAIR requirements
- Visibility and representation of project progression
- Support of early (internal) exchange
- Integrated information search space

Most of the challenges in RDM are of socio-technical nature and originate from three major sources. Firstly, the project itself comes with constraints regarding time frame, resources, staffing and research goals. Secondly, researchers involved in a project come with individual skill sets, prioritizations, (technical) affinities and comfort zones. The third factor is interdisciplinary collaboration itself which - in order to be successful - comes with certain necessities regarding trust, common understanding and the will to explore non-traditional methodologies.

Designing, implementing and maintaining an RDM solution relies on early and effective decision-making, taking organizational and technical preconditions seriously. This can be embedded into a research project in an early stage, like the proposal or research data management plans and policies. While formulating (likely incomplete) project goals, these declarations of intent need to be filled with life through structural precautions over (and in some cases beyond) the project life span. We believe that, after identifying the necessary environmental constraints and challenges, this is achieved through identifying and adequately staffing roles, establishing effective and efficient processes and aiming for a usable, maintainable and sustainable software solution. All these aspects need to be tackled through a hybrid approach of enabling bottom-up activity on the one hand (interdisciplinary exchange, training, division of labor) and firm top-down demands on the other hand (agreement on

realistic goals, milestones, deliverables). In our experience, such bi-directional approaches have proven to be more successful in practical RDM over the last years.
With these before-mentioned complexities in mind and building upon an existing RDM solution, we want to get closer to providing an answer on how to actually provide researchers with comprehensible research documentation, where analytical subtasks become replicable and therefore scientific results (data, publications, workflows) may be assessed. This ability for evaluation (within the project and beyond) is also a more reliable and sustainable basis for finding similarities, comparing method applications, methodological advancement and synergetic effects for later studies on different spatial or temporal contexts.
We tackle this far stretched goal by using the existing RDM solution as a source for research data versioning and deconstruct analytical workflows on the individual (research endeavor) level, the subproject level, and the project level. On the individual level, the deconstructed processes can be modelled as pipelines along iterations of the research data life cycle, strongly related to Knowledge Discovery in Databases (KDD). Interconnecting these deconstructions to each other on the subproject and project level yields cases such as:
- Re-usage of data for another analysis
- Re-usage of an analytical pipeline on another or larger data set
- Integration of data to create larger or richer data sets
- Step-wise integration of information from several data sources to enrich analyses (Cross-Domain Data Fusion)
Our goal is to expand the generalized framework based on new experiences towards a more complete understanding of FAIR research outcomes, not just including data sets but also reproducible workflows in an interdisciplinary setting.

507. Ensuring Reproducibility and Sustainability in Archaeological Research Software: A FAIR4RS Approach by the Research Squirrels

Tom Noack (Universität zu Köln); Lutz Schubert (Universität Köln)*; Florian Thiery (LEIZA)

The increasing reliance on computational workflows in archaeological research underscores the importance of aligning research software with the FAIR4RS Principles. The Research Squirrel Engineers Network, a volunteer-driven initiative, addresses the challenges of reproducibility and sustainability in research software through four interrelated use cases focusing on Linked Open Data (LOD) generation and geospatial analysis for Ogham inscriptions. These projects, leveraging Python, Java, and R, illustrate the complexities of aligning with FAIR4RS while operating without dedicated funding or institutional support. Applying the FAIR4RS principles, these grassroots efforts aim to produce high-quality, reusable software outputs that integrate seamlessly into broader archaeological research contexts.

The use cases are divided into data transformation and data science. The data transformation workflows include a Python project that converts CSV files into RDF for LOD publication and a Java project that processes TEI EpiDoc XML inscriptions into RDF. These workflows produce FAIR-compliant data outputs that align with CIDOC CRM and can be integrated into larger knowledge graphs such as the NFDI4Objects Knowledge Graph. The data science workflows include R scripts for geospatial analysis, such as density mapping of Ogham inscriptions, and Python Jupyter Notebooks for querying and analysing data from Wikidata and NFDI4Objects via SPARQL. These Python-based notebooks, developed within the Research Squirrel Engineers repository for Jupyter Notebooks and Linked Open Data, serve as modular examples for integrating data retrieval, analysis, and visualisation into a reproducible framework.

The FAIR4RS principles are systematically addressed in the following ways:

Findable (F):

Research software outputs, including Jupyter Notebooks, are hosted on GitHub with metadata provided via Citation File Format (CFF) files. CFF files ensures software is discoverable and citeable, with links to Zenodo archives where each release is assigned a DOI.
Software components and scripts are documented with README files that outline their functionality, purpose, and usage, making them easier for new users to locate and understand.
The workflows produce FAIR-compliant data outputs (e.g., RDF files) with persistent URIs, linking the software tools to the resulting datasets for traceability.

Accessible (A):

All software and accompanying outputs are openly accessible under permissive licenses, with code licensed under MIT and data under CC BY 4.0. These licenses ensure both software and data can be freely used, adapted, and shared.
The Jupyter Notebooks are archived in Zenodo alongside metadata to describe dependencies and provide usage instructions. This ensures long-term access to both the code and its computational context.

GitHub repositories are linked with continuous integration workflows (via GitHub Actions) to automate accessibility aspects, such as generating HTML documentation of RDF outputs for human-readable access.

Interoperable (I):

The workflows adopt standards for software development and data integration. For instance, the Python and R scripts are modular and use widely adopted libraries (e.g., Pandas, SPARQLWrapper, ggplot2) to ensure compatibility across computational environments.
Software outputs align with the CIDOC CRM ontology and standards such as OWL and GeoSPARQL, ensuring semantic consistency and enabling integration with other archaeological datasets and tools.
By developing Jupyter Notebooks as reusable modules, the software outputs are designed to interoperate with both human and machine workflows, bridging analytical processes with data integration systems.

Reusable (R):

Each software tool and script includes usage instructions, detailed examples, and references to the standards they implement (e.g., RDF for Linked Data, SPARQL for querying knowledge graphs). This documentation supports reusability across different research contexts.
The Jupyter Notebooks are mainly focused on reproducibility and reusability. They capture not just the logic of the workflows but also the execution environments and dependencies, ensuring future researchers can adapt them.
Data science workflows for querying and visualising Ogham inscriptions demonstrate the software's practical applications while also serving as templates for expanding analyses to other archaeological datasets.

Central to ensuring sustainability and reproducibility is the involvement of communities that contribute domain-specific expertise, infrastructural support, and advocacy for research software engineering best practices. Volunteer-driven initiatives like the Research Squirrel Engineers exemplify grassroots efforts to advance computational archaeology. At the national level, infrastructures such as the German NFDI provide platforms and consortia to support software sustainability. In particular, the NFDI Section Common Infrastructures and its Research Software Engineering working group contribute to fostering reproducible and interoperable research outputs across disciplines. Associations like the UK Society of Research Software Engineering (SocRSE), deRSE in Germany, and the UK's Sustainability Institute also provide vital expertise on maintaining and sustaining research software. Together, these networks strengthen collaboration and ensure that reproducible research outputs can extend beyond individual projects or funding cycles.

Sustainability is further ensured through open contribution models. All GitHub repositories are open to contributions via pull requests, enabling external collaborators to extend and adapt the tools. Software releases are archived in Zenodo with DOIs to guarantee accessibility and citability over time. Expanding upon these measures, future improvements will focus on developing more comprehensive documentation, enhancing metadata, and integrating containerisation strategies such as Docker to improve reproducibility across diverse environments.

The interconnection between workflows demonstrates the potential for FAIR4RS-aligned outputs to integrate seamlessly into larger research ecosystems. The RDF produced by Python and Java workflows is intended to serve as direct input for data science projects, enabling smooth transitions between data transformation and analysis. For example, the Python Jupyter Notebooks querying Wikidata and NFDI4Objects demonstrate how external knowledge graphs can provide enriched data for further analysis and visualisation. Similarly, the SPARQLing Unicorn QGIS Plugin allows the resulting RDF data to be integrated into geospatial workflows, bridging the gap between LOD and the practical needs of archaeologists. These connections exemplify the potential for interoperability and reusability across diverse software tools and data sources.

Through collaboration with initiatives like Jupyter4NFDI in the Base4NFDI consortium, additional tools and services are being developed to support reproducibility in research, such as automated reproducibility assessments integrated with knowledge graphs. These efforts provide a scalable framework for sustainable research software practices. Despite these advances, challenges still need to be solved in resource-constrained environments. Java-based workflows, for example, still need a viable Jupyter-based solution, relying instead on Maven for dependency management and enhanced documentation to address reproducibility gaps.

By aligning with FAIR4RS principles, the Research Squirrel Engineers demonstrate that even grassroots initiatives can significantly contribute to reproducibility and sustainability in computational archaeology. The integration of Jupyter Notebooks, combined with robust RDF outputs and tools like the SPARQLing Unicorn QGIS Plugin, provides a scalable model for achieving these goals. Through partnerships with national research infrastructures, international organisations, and volunteer networks, this work offers actionable pathways for addressing the pressing challenges of reproducibility and sustainability in research software.

216. Re-excavating the past: digital tools for accessible, reusable archaeological workflows

Benedict Dyson (Griffith University)*

Archaeological data's complexity and unique spatiotemporal context make it challenging to reuse effectively. 3D models, though visually compelling, remain difficult to work with in accessible formats. By presenting an archaeological 3D segmentation toolset in Blender (ArchSV) and an interactive multi-data interface in Unreal Engine (VEx), I aim to demonstrate how reusable digital tools can make complex archaeological workflows more accessible, with far-reaching implications for data reuse and public engagement.

Most archaeology is a finite resource, making data reuse essential. This reuse is often complicated by multiple recording formats and variable archiving standards, usually mitigated through standardised reports. While these are essential resources for providing a high-level interpretation of a site or collection of sites, they complicate the critical re-examination and re-interpretation of primary data. An over-reliance on reusing interpretation rather than primary data could lead to an increasingly flawed interpretation of the wider archaeology. However, archaeological primary data can be difficult to handle. Efforts to standardise data through the use of common ontologies such as CIDOC-CRM aim to make data interoperable and more easily reusable. These approaches can be highly successful and are becoming widely adopted across the heritage sector (e.g., Binding, May, and Tudhope 2008). However, while this is an important first step in making data FAIR, I argue it does not go far enough in addressing the unique issues of reusing archaeological data.

The most familiar and fundamental record of archaeology is a data collection sheet comprising a mix of quantitative and qualitative data. The richest information in these records is arguably the qualitative fields, such as descriptions and interpretation. While these fields are important for empowering the archaeologist (Eddisford and Morgan 2018), they also have the potential to fossilise interpretation and be detrimental to reflexive and polyvocal practices. 3D models have become increasingly cheap, reliable, and accessible to create. They provide an infinite number of views and are not as constrained as typical 2D formats, while also offering high levels of geometric accuracy and visual authenticity. These models could be used to make an archaeologist's decisions more transparent, increase the amount of qualitative data gathered at the context level, and facilitate reuse through a more interactive form of data interaction.

Archaeology Segmentation and Volumetric Tools (ArchSV) is a toolset developed in Blender, an open-source 3D software, that allows for the segmentation of contexts within 3D models using semi-automated methods. It works by sampling points within a context and extending the selection based on variation in coordinates from these points. Additional filtering allows for refinement of selection, taking into consideration factors such as slope. This creates a segmented 3D model of a context that is defined by a set of quantifiable criteria. In the future, this could be extended to variations in colour or surface roughness, which would typically be discussed qualitatively. With this data, additional processing can be performed, such as the automated creation of volumetric meshes that can make analytical methods, such as finds distribution, more reliable. The outputs of these tools are interoperable and can be georeferenced and integrated into a GIS.

Where ArchSV quantifies interpretation and aids analysis, the Virtual Excavator (VEx) enables an immersive, interpretive experience that further expands the scope of archaeological data reuse. VEx is an interactive data interface created using Unreal Engine. Using segmented 3D models of contexts, a reconstructed site can be "re-excavated" and navigated in a game environment (see Figure 1). By adopting an object-oriented data approach and utilising common data organisation formats such as CSVs, this system can rapidly integrate multiple data types. This is an intuitive method for an archaeologist to explore data and provides any user with an immersive context in which to understand the archaeology. Furthermore, while VEx is currently not bound by ontologies such as CIDOC-CRM, if it were, with the addition of formats such as USD, an interoperable network of tools is achievable. Building this level of interoperability will enable the integration of further data types from sources such as remote surveys or other sites, creating a dynamically linked system that is interactive, engaging, and contextual, with the potential to produce polyvocal, reflexive environments for interpretation.

The implications of digital methods, properly applied, are wide-ranging and will be beneficial to data reuse. While it could be argued that further applications of automated methods disempower the archaeologist in interpretation, I suggest that they could provide archaeologists with more tools to make their interpretation more robust and transparent. Additionally, increasing the amount and diversity of qualitative data allows for easier, more accurate, and more varied analysis of large archaeological datasets. Providing users with an interface for complex data allows for the re-examination, re-interpretation, and re-mixing of archaeology within a more authentic context. This system could have wide-ranging uses, such as: a polyvocal multiplayer mode where specialists can discuss interpretation virtually; reconstructions “built” in-game and other visual means of communicating interpretation; teaching students about recording practices; and engaging the wider public through virtual tours. While VEx is still limited in its flexibility, with further development, it could become a powerful tool not just for visualisation but analysis as well.

A game engine approach provides an interactive, playful environment to visualise archaeology. Feeling as if you are present within the archaeology and allowing for its adaptation to your needs should facilitate reuse from a wide range of users. ArchSV enables the segmentation of contexts within 3D models and allows for more quantitative analytical methods. Designing these tools to be reusable by other archaeologists and the wider public will ensure they do not become one-time experiments but instead serve as valuable additions to the growing digital tool bag. VEx and ArchSV represent a step towards an integrated approach to polyvocal data use and reuse.

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57. Unlocking landscapes. How data reuse shapes Shared Archaeological Landscapes.

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The Shared Archaeological Landscapes PhD research aims to develop protocols for sharing and reusing data to address, in a collaborative way, the reconstruction of the diachronic history of human landscapes. Using an interdisciplinary approach and analyzing various types of available data, the research promotes a more effective and inclusive data use, aligned with the FAIR (Findable, Accessible, Interoperable, Reusable) principles.

One of the central goals of the broader project, within which the PhD research is active, is the development of a participatory and open GEO-server infrastructure to facilitate data sharing and reuse creating a community of practice able to foster collaboration and continuous learning. The primary goal is to engage the student community, enabling them to share and reuse data produced during their final essays in Landscape Archaeology. These works give, in fact, a significant contribution to the reorganization and systematization of often fragmented and sporadic data, as well as to the updating and enhancement of legacy data through the acquisition of new field data.

Furthermore, the project has educational aims, training students in using the infrastructure and understanding the vocabularies and ontologies related to the database. These aspects are aligned with the National Geoportal for Archaeology (GNA) and the Italian standards of the Central Institute for Catalogue and Documentation (ICCD), while also taking into account leading international practices, like the CIDOC-CRM. Additionally, the project aims to train a generation of archaeologists who are willing to share their work and to reuse those of others - essential for advancing research. To ensure quality and relevance, evaluation methods for the platform and data will be integrated throughout the research process.

Thus, this approach aims not only to facilitate knowledge sharing among young researchers but also to ensure that data are structured and interoperable, for effective reuse by the scientific community and the public. Moreover, by adopting established standards, the research contributes to create a digital ecosystem in which archaeological and environmental data can be easily found, accessed, and reused by everyone at different levels.

In conclusion, this paper will present the progress made in developing the infrastructure during the initial stages of research, the sharing protocols adopted, and the challenges faced in implementing data reuse at the student level. Therefore, starting with the student community, this research aims to implement data reuse practices to foster academic innovation and public engagement. The Shared Archaeological Landscapes PhD research is thus proposed as a practical example of promoting the polyvocality and democratisation of archaeological knowledge, in line with the FAIR principles.

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293. Beyond the Standard: Integrating Children's Voices into Archaeological Data Models

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The increasing availability of open archaeological data and the existing standards are contributing to ensuring that both legacy and new archaeological data remain FAIR. The Semantic Web allows us to express complex, multi-layered concepts without compromising scientific accuracy. However, at the data level, there is a risk of replicating the same rigid social structures that determine who holds knowledge and who does not, who can contribute and who cannot, and whose opinions matter (D'Ignazio 2017). Starting from this premise, this research explores new ways to involve a broader audience in the creation and interpretation of heritage-related knowledge. It focuses especially on enriching archaeological records with insights from children's perspectives, presenting an integrated data model that creates space for their views on heritage to stand alongside those of specialists. The aim of this research is not to achieve a clearer understanding, but to develop a deeper, more complex perspective on the archaeological record and the practice of archaeology.

The study collected 103 items, including maps, descriptive forms, and drawings, produced by children aged 6–14. These activities were conducted in an area already surveyed by specialists, for which a comprehensive archaeological database (already mapped for the Semantic Web) exists. The children's contributions were analyzed using grounded theory methodologies (Charmaz, 2014). The data were annotated with tags from the pre-existing archaeological database, enabling the identification of elements that could fit into its standard and highlighting what is left behind (Hacıgüzeller, Taylor, and Perry 2021). These “leftovers” represent the children's unique perspectives—elements not yet captured because they don't align with the objectives of the current standard. This set of data was examined in greater depth to build the theoretical basis for a new data model. From it, key themes emerged concerning the relationships children established with the material record, the landscape, and other humans during fieldwork.

The challenge is to model this type of information to enable semantic interoperability. By integrating these new insights into data models, the study aims to create additional access points to archaeological data, fostering inclusivity and enhancing reuse potential, thereby encouraging deeper public engagement with archaeology. Moreover, this approach challenges traditional hierarchies in data representation, advocating for an interdisciplinary and participatory framework that expands the interpretive possibilities of archaeological practice.

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400. Modelling for different audiences: a storytelling data model for archaeological data reuse

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Archaeology has grappled with the FAIR data principles long before they were first introduced in 2016 (Wilkinson et al., 2016), and while a lot of research these past 20 years has been addressing findability, accessibility, and interoperability, it appears reusability is yet to be fully understood (Wright and Richards, 2018). In the context of the Transforming data rE-use in ARCHaeology (TETRARCHs) project, the aim is to increase the reusability of archaeological data. As heritage sites are not merely places of knowledge, but also places of emotions, the optimisation of archaeological data for a more impactful expression represents another goal. As such, archaeological data reuse is explored through the lens of storytelling, a powerful tool which fosters interaction between people who find or interpret heritage assets, and people for whom they might generate value and meaning. Using a methodology rooted in grounded theory, the goal is developing alternative data models to support reuse of archaeological data by different audiences, specifically archaeology professionals, creative practitioners, or partners from memory institutions, organisations and platforms. By conducting surveys, focus groups, as well as annotation and reuse experiments, elements which these audiences find essential to tell stories using archaeological data, which ones are already recorded, and which ones are not, become clearer. Several of these experiments have been organised throughout the past two years, their results have been coded and analysed and from that the Storytelling Data Model is crafted. More experiments are still to be organised, especially ones involving testing the data model itself.

This paper presents a possible methodology for the creation of data models for archaeology as well as preliminary results for a Storytelling Data Model, focusing on elements which are deeply intertwined with archaeological practice but often left out of the record, such as feelings, emotions, sensations, already emerging as stable categories throughout the experiments and with all the different audiences.

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44. Advancing CRMarchaeo: A Refined Approach to Modeling Archaeological Observations and Intellectual Processes

Anna Aslanoglou (Athena Research Center)*; Panos Constantopoulos (Athens University of Economics and Business); Vicky Dritsou (Athena Research Center)

The CIDOC Conceptual Reference Model (CRM) (https://www.cidoc-crm.org/) is a formal ontology that supports the interpretation, integration, querying, and exploration of diverse cultural heritage data, as well as reasoning with it. The CRMsci (https://cidoc-crm.org/crmsci/home-1) extension focuses on scientific observations, while the CRMarchaeo (https://www.cidoc-crm.org/crmarchaeo/home-3) extension is specifically designed to support the documentation of archaeological excavation processes. In the first author's master's thesis, a new archaeological documentation model was proposed based on existing data from the excavation of the ancient site of Sikyon, utilizing the CIDOC CRM ontology along with its extensions, CRMsci and CRMarchaeo. The model was tailored to meet the documentation needs of Sikyon and was tested through the development of a database, with a set of specifically designed queries assessing and validating the expressive power of the model.

That study identified a gap within the CRMarchaeo model, suggesting the need to enhance the representation framework by incorporating archaeological observations. Specifically, while CRMarchaeo plays a crucial role in organizing and documenting archaeological processes—particularly focusing on stratigraphy and stratigraphic relationships—it tends to merge the excavation processes with the intellectual processes. This paper highlights the importance of distinguishing between these two aspects and, furthering the line of work in, suggests refinements to the CRMarchaeo to better articulate these distinctions, ultimately proposing a more precise classification. The central research question focuses on how to effectively model the intellectual processes separately from excavation activities, ensuring a clear distinction between these two facets of archaeological work. Building upon the CIDOC CRM and it's extensions, we define and classify properties and processes relevant to archaeological observations, as illustrated in the attached figure. The data from the Sikyon excavation, on which our analysis is grounded, serves as a practical case study to demonstrate the effectiveness of the model in real-world applications. This excavation is rich in data, documented in accordance with the guidelines in the Corinth Excavation Manual (Sanders et al. 2017).

CRMarchaeo focuses on stratigraphy, on stratigraphic genesis, and their relationships. It also defines classes related to excavation and excavation processes (A1 Excavation Processing Unit and A9 Archaeological Excavation) and provides the basis for their documentation (Hiebel et al. 2014). However, most of the fieldwork carried out during an excavation involves recording the properties observed within the stratigraphic layers. These features are identified through archaeological observation before being documented. Although archaeological observation is part of the excavation process, it should be distinguished from the physical activities represented by A1 Excavation Processing Unit which is defined as resulting “in the production of a set of recorded data and is an intellectual process”. Since archaeological observation is an intellectual process, it should be separated from a class that describes a physical process.

To this end we introduce a separate class, AE1 Archaeological Observation, representing this kind of intellectual processes, not to be viewed as a subclass of A1 Excavation Process Unit. This distinction is necessary because A1 Excavation Process Unit is a subclass of both S1 Matter Removal and E64 End of Existence. Archaeological observation arises from excavation processes but does not always involve S1 Matter Removal. For instance, the characterization and observation of a layer identified as a cut (introduced class AE5 Cut) exemplify this distinction. Archaeological observations occur during excavation but also continue afterwards, e.g. assigning dates based on the analysis of pottery and findings, as well as attributing properties to units. These activities continue even after the respective instances of A1 Excavation Processing Unit, which is categorized as a subclass of E64 End of Existence.

The introduced AE8 Archaeological Documentation class represents the results of archaeological observations, covering both in-field and post-excavation activities. Furthermore the model introduces three main excavation elements: AE3 Deposit, AE4 Structure, and AE5 Cut, each representing different types of stratigraphic units. Specifically, AE3 Deposit refers to soil deposits, AE4 Structure to build features, e.g. walls, and AE5 Cut to negative features, e.g. pits. These three elements form the core of archaeological observations. They are what excavators observe, describe, and record, serving as the focus for data collection throughout the excavation. The model introduces specific classes and properties to document the data surrounding these stratigraphic units, including soil color, elevation, masonry style, and more. These properties are incorporated into the model to systematically capture essential details about the stratigraphic units and findings, enabling comprehensive documentation of key activities like soil sampling and sieving. Such processes are crucial for understanding the characteristics of a unit and for ensuring that the archaeological record accurately reflects both excavation processes and archaeological observations.

In conclusion, this research underscores the importance of distinguishing between excavation processes and the intellectual processes involved in archaeological work. CIDOC CRM and its extensions provide a flexible framework that can be adapted to different excavation contexts and integrated with other cultural heritage documentation models. With the proposed refinement to the CRMarchaeo framework, this work enhances the ability of archaeologists to accurately record and analyze excavation data, contributing to a deeper understanding of stratigraphy, material culture, and the archaeological process as a whole.

The model also provides an impetus for future advancements in archaeological documentation. For instance, the introduced AE2 Study Process Unit can serve as a basis for further specialization to describe post-excavation activities such as conservation. By incorporating key archaeological concepts and familiar terminology into the proposed model, we expect that the documentation produced during excavation will be more accessible, consistent, and capable of supporting long-term research and analysis.

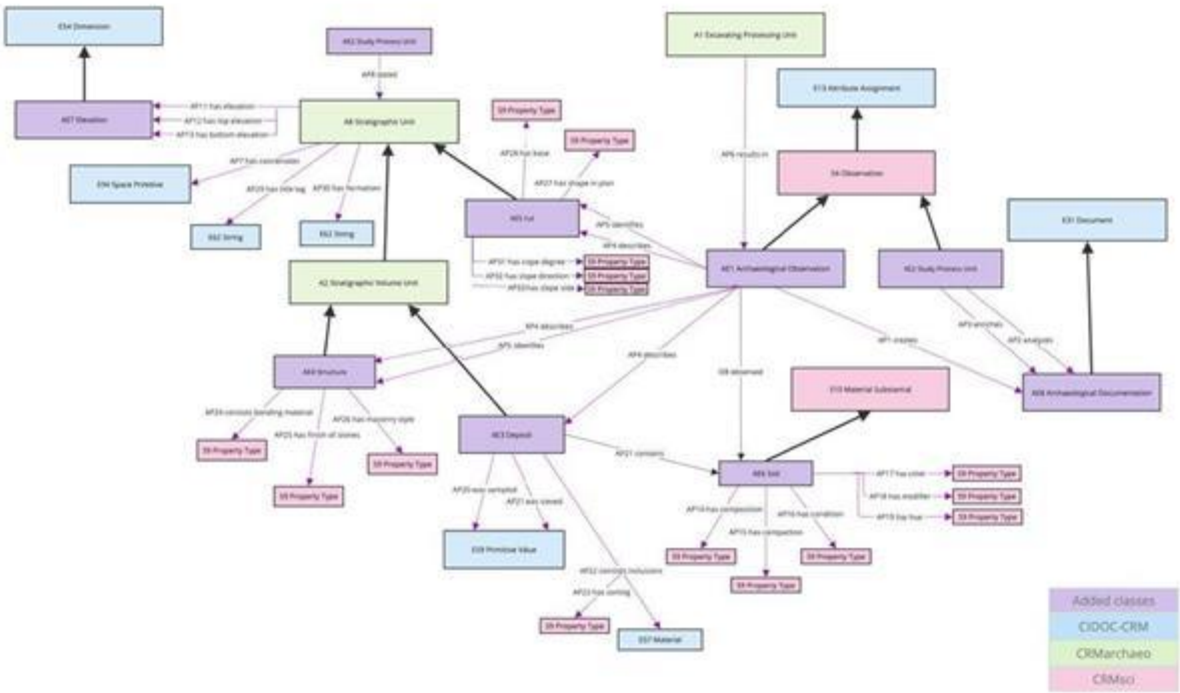

Figure 1. Ontological model.

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295. Modelling Space-Time Uncertainty in Archaeological Excavation Information: From Relational Databases to Semantically Rich Graphs

Natalie De Schuytener (University of Antwerp)*

Traditional data models in archaeological excavations often rely on relational databases, capturing information specifically designed to accommodate the data elements expected to be collected. As a result, some of the information that could be generated during excavations may not conform to predetermined data collection models, schemas or other templates. These datasets are then often captured as unstructured or semi-structured information in the form of text, images, or videos, or may not be collected at all, with significant consequences for the formation of archaeological knowledge (Hacıgüzeller et al. 2021). In this talk, I present my reflections and preliminary research on a specific type of information related to space and time uncertainty. This research is carried out as part of my doctoral project entitled: “Modelling Space-Time Uncertainty in Archaeological Excavation Information: From Relational Databases to Semantically Rich Graphs.” The primary objective of this project is to improve the representation of space- and time-related uncertainties encountered during archaeological excavations as structured data, primarily through semantically rich graphs, since both these uncertainties and structured datasets are crucial to the production of archaeological knowledge.

My talk aims to provide a framework for understanding space- and time-related uncertainties encountered in the archaeological excavation fieldwork in a multidisciplinary context. I first examine how such uncertainty emerges as a phenomenon across different fields (including not only archaeology, but also computer sciences, sociology, cultural geography, ecology, and history). The key findings emphasise that every research field is affected by or involved with uncertainty, which is often organised in terms of accuracy (including location, attribute, and temporal components), precision, completeness, credibility, or subjectiveness (Schäfer 2018). They further illustrate the range of approaches currently used to express uncertainty across multiple fields, whether as a consistent format adhering to standard structured data conventions or as methods tailored for the requirements of specific domains. Drawing on this multidisciplinary framework, I present a taxonomy involving a set of criteria to identify and categorise space- and time-related uncertainties observed in archaeological excavation information with a particular focus on archaeological notebooks. Archaeological notebooks or diaries, in both their analogue and digital forms, are the most common tool of recording the archaeological excavation fieldwork process and provide personalised, contextualised, and human-oriented insights into that process. These notebooks facilitate the recording of various types of information during archaeological excavations, including interpretive uncertainties that emerge during the process of data collection (Mickel 2015).

This taxonomy of archaeological space-time-related uncertainties informed by human language forms the foundation of my doctoral research, aiming to further model them as rich semantic graphs. This paper seeks to provide a framework for understanding uncertainties encountered in archaeological fieldwork in relation to other disciplines, together with developing broad categories of archaeological uncertainties encountered during excavation processes.

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373. Towards integrating diverse archaeological collections.

Sveta Matskevich (IAA)*

The problem of archiving and integrating archaeological raw data has received considerable attention in the past two decades from institutions and international collaboration projects (Richards 2021; Richards et al. 2021). It is not completely solved, but we can be sure this data will not be completely lost for future research. With all its seeming diversity, the field data can be brought to a common ground via mapping to an ontology like CIDOC-CRM or one of its extensions. In the worst case, they can be indexed at a site level and fit into almost any digital archaeological archive or repository.
From the point of view of an archaeological archivist, the problem starts where the field records (especially of the last four decades) end. The two case-study archives I would like to present here contain several collections. The archival cataloging system allows for the management of boxes, folders, and subjects. Each collection has its indexing template that attempts to capture the essence of its content, allowing a future user to find the documents, even if – as often happens – we search for a topic quite remote from their official subject. Yet, the abilities of indexing and the tabular metadata created are limiting the scope of the content of the archive (Hacıgüzeller et al. 2021).
I would like to present some not-yet-implemented ideas about linking the collections within an archive. The proposed solution is based on layering the indexing schemata and using ontological modeling (or one of its layers) as a means of connecting discrete collections. This additional network can increase the findability of documents that don't fall into a common pattern of archaeological documentation.

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275. True integration: the journey to present archaeological documentation with the CRM family

Jane Jansen (Statens Historiska Museer Arkeologerna)*; Stephen Steads (Paveprime Ltd)

This continuing integration study considers how the body of archaeological excavation databases of The Archaeologists (a department within the National Historical Museums of Sweden) is being prepared for integration utilising the CRMarchaeo and other extensions of the CIDOC Conceptual Reference Model (CRM). New details on how this will be done will be presented in this paper. We will show how CRMarchaeo will be applied on the Intrasis data model and how we will implement it on thousands of databases.

The Archaeologists create many new Intrasis-databases each year and the project is looking at making the full richness of both observations and interpretations available as a queryable resource. In addition, the para-data of how the transformation from the internal Intrasis data-structure to the CRMarchaeo representation is being performed, is being modelled using the CRM family of ontologies. This enables the full digital provenance of any individual element of the full data-set to be assessed as well as understand the evolution of techniques used. This will allow scholars to consider both the archaeologically investigated past and the techniques used to manage the documentation of this past: the history of the discipline so to speak.

There is one further areas of interest. It is the documentation of competing interpretations of primary evidence and the reasons for the selection of one interpretation over another. This is being done using CRMinf.

The presentation showcases the work undertaken by Intrasis and Paveprime to make the original site archive data accessible without resource hungry recasting and harmonisation. The most recent phase of the work has concentrated on allowing multiple interpretations to be made accessible to researchers and the linking of oral history and traditions to site archives. Technical innovation has concentrated on presenting the material using the enhanced functionality possible with RDFS*.

444. Unlocking the Potential: Advancing the Implementation of FAIR Principles in Geospatial Data Management within Hungarian Commercial Archaeology

Árpád Balogh (Hungarian National Museum Public Collections Centre; Budapest University of Technology and Economics)*; Attila Juhász (Budapest University of Technology and Economics)

With the advancement of data collection technologies, the collection of born-digital data has gained significant importance in archaeology. However, data management practices have not evolved at the same pace, as the mindset shaped by traditional paper-based records continues to strongly influence the approach to the digital realm.
As the volume of data increases, efficient information extraction cannot be achieved solely through the introduction of new tools, technologies, or by expanding human resources. Instead, a paradigm shift and a rethinking of related workflows are necessary. The first step in this process is to move away from disintegrated data sets and towards the creation of flexible, interoperable, and long-term sustainable data structures that facilitate seamless integration across various digital procedures.
In our presentation, following a general introduction to the issue with a focus on geoinformatics, we examine the situation in Hungary, particularly in the domain of commercial archaeology, where the demand for efficient, standardized workflows is especially high. We seek answers to how a data structure representing a shared minimum standard can be developed. Our goal is to ensure that this data structure not only preserves the freedom of archaeologists to choose tools and methods but also aligns with the FAIR principles. By doing so, we aim to establish a more sustainable and inclusive digital framework that supports research and facilitates the broader dissemination of results within and beyond the archaeological community.

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198. The Swiss Example in FAIRification of Archaeological Data: Chronicles Online Powered by ArcheoBase

Emmanuel Clivaz (ArcheoBase)*

Switzerland has reached a significant milestone in archaeological data management with the launch of Chronicles Online (December 2024), a digital platform powered by ArcheoBase, which provides open access to comprehensive archaeological records in line with FAIR data principles. Developed through collaboration with Swiss Archaeology and cantonal archaeological services, Chronicles Online offers seamless access to over 6,000 excavation reports from Swiss heritage sites since 1987, making data not only findable and accessible but also interoperable across diverse heritage databases.

This platform enhances public accessibility and fosters interoperability by linking varied archaeological publications through standardized metadata and intelligent connections. Designed as a cornerstone for Swiss archaeology, Chronicles Online supports extensive data harvesting using the OAI-PMH protocol and employs structured ontologies to achieve semantic consistency. Specifically, in the context of Chronicles Online, the platform aligns with the Getty Art & Architecture Thesaurus (AAT) for standardized terminology and the AO-Cat (a simplified CIDOC-CRM subset) for core data relationships. ArcheoBase is engineered to adapt to any ontology, ensuring flexibility for integration in future national or international projects requiring different data standards. Together, these efforts build a connected knowledge framework, ensuring that archaeological records are intelligibly linked for both researchers and the public.

Introduction:
Chronique Online consolidates Swiss archaeological heritage records into a unified digital infrastructure, addressing the challenges posed by Switzerland's decentralized data practices. With ArcheoBase as its backbone, the platform employs ontological standards and persistent identifiers to create a findable and accessible repository.
By mapping to AAT for vocabulary standardization and aligning with AO-Cat—a CIDOC-CRM subset designed for high-level archaeological data elements—Chronicles Online enhances interoperability with global research networks, aligning with standards seen in projects like ARIADNE RI.

Methods and Materials:
Through APIs and SPARQL endpoints, the platform enables data exchange and integration with global repositories, creating a machine-actionable and interoperable framework. Planned innovations include a retro-digitization project to archive materials from as early as 1907, thus building a comprehensive digital repository that spans over a century of archaeological insights.

Results:
By streamlining access to Swiss archaeological records, Chronicles Online supports both specialized and public research. Its compliance with FAIR standards ensures that data is accessible, interoperable, and reusable across disciplines. The platform allows cantonal services to contribute new records in real-time, minimizing publication delays and enriching the repository with up-to-date findings, creating a model of sustainability for digital heritage management.

Discussion:
Switzerland’s Chronique Online, powered by ArcheoBase, showcases the potential for adopting flexible, open-source infrastructures in commercial archaeology. Its development demonstrates how integrating FAIR-compliant data models can transform heritage data management. By interlinking diverse archaeological publications, Chronicles Online underscores the importance of inclusive, FAIR-compliant data structures, supporting both scientific research and public engagement.

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96. FAIRifying Swedish archaeological geodata through flexible standards?

Daniel Lowenborg (Uppsala University)*; Sakarias Lindgren (Uppsala University); Kristina Martinelle (Uppsala University); Yunyun Yang (Uppsala University); Vasiliki Tsoumari (Uppsala University)

There is a long tradition of producing geodata as part of contract archaeology excavations in Sweden. Until recently, the output of the excavation has only been the report, but since the past few years that is changed, and now, it is required to upload geodata (as shapefiles) of excavated trenches, the shape of the archaeological site, and a list of finds (as CSV) (Löwenborg al., 2021). However, the main volume of data with documentation of the excavation is still not made available. With the new Swedish National Infrastructure for Digital Archaeology, Swedigarch, this is also starting to change. So far, geodata produced in the system Intrasis are converted to open formats (GPKG and CSV) and the full digital documentation of geodata is made available as individual databases, one per project. There are several thousands of databases in this format, from about 20 different organisations in Sweden, and as part of Swedigach, this data is collected, converted, transformed, and made available, with the long-term aim to also be able to link to finds and results of analysis etc. Data produced with Intrasis is suitable for reuse since it has a defined format and there is some level of structure to how data is organised, albeit not with structured vocabularies. Intrasis is, however, not used in all excavations in Sweden, and different organisations use different systems, but it is common to produce some kind of GIS-based data.

With the ambition to make more of the data FAIR, we are currently exploring ways to convert geodata of any origin and form to a general format, using custom-made plugins for QGIS. This could be used to rework existing data to match a predefined template and add identifiers as part of that, to facilitate linking to other resources. Ideally, this should be done as part of reporting an excavation, by the organisation who performed the excavation. This would require substantial changes to the system of heritage management in Sweden, and there are both technical and administrative challenges to achieve this. Most importantly, it is necessary to build a consensus around how this should be done, with all parties involved in Swedish archaeology. As data management also would take time for each project, the cost for that would need to go to the budget and be confirmed by financial instances. There also needs to be a plan for how data would be curated and archived.

A first step towards addressing the challenges could be to outline a suggestion for a standard to geodata for Swedish contract archaeology. This can act as an example of the usefulness and relevance of introducing standards in geodata management, technical limitations in creating data, quality control and how a workflow for geodata works in all parts of the system. A core aspect of the methods would be to rely on open formats and free and open software for all steps, but also compatibility with existing systems in use. Another important fundamental principle is that data should not limit the interpretative process during fieldwork, and it is key that archaeologists can document and describe the excavations using any tools and practises they prefer. It is only at the reporting stage that information needs to be standardised to some degree, with common formats and vocabularies. The original version of the information should still be maintained, so there would be a certain level of flexibility in the standards, accommodating for different traditions and practices during excavation.

At the conference, we will present the concept QGIS tool for migrating geodata and the preliminary standard we are designing, with reference to considerations of how this can be a feasible system for contract archaeology in Sweden, and the ongoing work to build a national consensus around this approach.

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438. What is a feature - today?

Anna Anzenberger (Illisystems)*; Stephan Winkler (Illisystems)

This question has occupied generations of archaeologists for a long time and still does today, as this definition is more important than ever. This is because features and finds are documented, examined and analysed in different ways. While the recovered objects in the archives and collections are also available to future generations and developed methods of research, the excavation requires the destruction of the features, which are sometimes only recognisable by the different colouring of the soil. The informative value of features stagnates at the level of the quality of the excavation documentation. This makes the extraction of information from the features on site the most important task of the excavators.

The idea of what a feature is, especially the type and amount of information, varies greatly in different countries and regions. For the interoperability and reusability of data, however, a clear and unambiguous understanding of the information contained in a feature is essential and more important than ever.

By comparing different understandings of features from different countries and different doctrines, it is shown how different the components and descriptions of features are. The aim is not to work out the one - true - definition of features, but to present a model-like structure with which as much information of features as possible can be mapped so that the data can be further processed by machine without loss of information.

430. Experimental interpretation of ancient games through playtesting

Aggelos Tsilogiannis (Aegean University); Markos Konstantakis (Aegean University)*; Spyros Vosinakis (University of the Aegean)

Introduction

Board games have always been an intriguing archaeological discovery, as they often tell us plenty about the culture of the past [1,2]. Regarding understanding how those games were played however, reconstructing the rules and mechanics of these ancient games poses a significant challenge for researchers, as they must infer the gameplay based on incomplete artifacts, vague contextual clues, and brief literary references. By understanding the gameplay, archaeologists can gain a deeper comprehension of the cultural context that shaped it. Thus, there exists a rising interest in accurately reconstructing the experience of play in ancient times. This paper aims to assist that field by collecting more interpretable data about these games through a gamified experiment [3].

Ludus Latrunculorum ("The Game of Little Soldiers") serves as a compelling case study for examining ancient games. While researchers have access to material that hints towards elements of the game, no definitive ruleset has survived. This gap in documentation makes it an ideal subject for experimental methodologies aimed at reconstructing gameplay and understanding its societal significance [4].

Methods and materials

This paper proposes an experiment centered on the ancient Roman game Ludus Latrunculorum, employing a novel methodology grounded in the principles of gamification and meaningful play. Participants will engage with replicas and a digital twin of the game within a thematically designed environment, improvising rules as they play, given specific context as prompts. Players will be split into groups each having different context for the game (theme, goal, interactions between pieces) and being placed in different scenarios (players might role-play as Roman soldiers, mercenaries, gamblers etc.).

The study embraces the concept of 'play in archaeology,' using the experimental process to reconstruct potential rulesets and explore the cultural significance of gameplay. The outcomes will be assessed through expert evaluation and their ability to validate or challenge existing knowledge about the game.

Results

Our experiment will generate a range of valuable insights into Ludus Latrunculorum. Specifically, it will produce a diverse array of potential rulesets derived directly from observed gameplay. Additionally, the experiment will shed light on the cultural significance of the game within its historical context, offering a deeper understanding of its role in ancient Roman society. These findings will provide a foundation for experts to refine or reassess existing theories about the game, supporting a more informed interpretation of its mechanics and social role.

Discussion

This study proposes a new direction in the reconstruction of ancient games, positioning them as interactive microcosms of historical cultural practices. By using experimental and gamified approaches, researchers may gain more nuanced insights into the social contexts these games represented, ultimately enhancing our understanding of ancient leisure, competition, and community interactions.

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421. Playing Conservatively with a Radical Legacy: Digital Heritage and Institutional Tension at Prospect Cottage

Alan Meades (Canterbury Christ Church University); Catriona Cooper (Canterbury Christ Church University)*; Katie McGown (Canterbury Christ Church University)

How do we navigate institutional conservatism and contrasting stakeholder views when creating digital heritage work with a radical cultural context? Our project to create a digital version of Derek Jarman's Prospect Cottage reveals how the adoption of game technologies, and indeed the language of videogames and play, generates discourses that simultaneously complement and challenge heritage interpretation.

Prospect Cottage in Dungeness, Kent, UK, was the home and studio of Derek Jarman (1942-1994), filmmaker, artist, author, queer icon, and British radical from 1986 until his death from AIDS-related illness. Prospect Cottage became a powerful locus of creative production for Jarman, and the work and garden he created in this remote, fragile, and inhospitable location are resonant explorations of mortality, nature, and sexuality that continue to inspire new generations.

Jarman left a multiplicity of legacies through his garden, artwork, films, and writing. The variety and depth of his work has attracted accolades from many different audiences and groups, giving rise to overlapping interpretations, emphases, and priorities. His time at Prospect Cottage only represents the final years of his career, the site has become a synecdoche for his entire life and creative output, fostering intense interest in the location, as evidenced by the 2020 crowdfunding campaign to buy the property.

There are two dynamics underpinning the urgency in creating a digital work of the site: visits are only permitted via a charged small group tour, restricting access of audiences locally and globally, and affecting the ability of new generations to learn about Jarman's legacy. Secondly, we are still within a period of living memory of Jarman's time at the cottage.

This creates fertile grounds for the development of a digital experience of the site, but as we shall explore, it is complicated by stakeholder groups with often competing, sometimes contradictory, and always strongly held views of how hagiography, legacy, and reputation, can be reconciled with digital heritage and play in the work. Drawing on Trammell's (2023) framework of "repairing play," we examine how institutional caution, stakeholder tensions, and misconceptions about games technology have shaped our attempts to represent and reimagine this significant site of artistic practice, AIDS activism, and queer history. We will discuss the challenges that we have faced, the ways in which these have been navigated (so far), and how a digital approach to the site may be able to uniquely convey aspects of Jarman's legacy.

Our initial approach exemplified what Trammell (2023, p. 26) identifies as a privileged, institutionally-safe reading of cultural space - a technically accomplished but culturally sterile recreation built using laser scanning and Unreal Engine 5 (UE5). We produced a largely literal version of the Prospect Cottage site without any additional content for fear of objection from key stakeholders, and to demonstrate the aesthetic potential of the project to decision-makers who are unfamiliar with games engines. Through this approach we were inadvertently participating in what Trammell critiques as the separation of pleasurable aspects from difficult cultural truths (2023, p. 87-88). This cautious prototype, while demonstrating technical possibilities, revealed deeper tensions about authenticity and representation. In later discussions with another stakeholder group, Jarman's estate specifically criticised the broader “sentimentalisation of Derek” in contemporary culture, pushing us to confront how digital heritage might resist the transformation of radical legacy into comfortable consumption - a particular concern given Jarman's own resistance to institutional constraint.

Even in its prototypical form the Prospect Cottage project illuminates and navigates multiple competing visions of Jarman's legacy: institutional custodians seeking to protect a building and environment; cultural organisations pursuing preservation and a coherent aesthetic vision; garden enthusiasts celebrating horticultural achievement of the site but not always its equally significant queer or HIV legacy; LGBTQ+ communities claiming vital heritage and the need to reconcile unheard stories and authorial dynamics; and game designers advocating for the medium's creative potential to commissioning gatekeepers who are unfamiliar with games or their contemporary vocabularies. These tensions exemplify what Trammell identifies as the institutional tendency to “read play as mere leisure… a privilege afforded to White people” (2023, p. 26), where different groups inadvertently participate in sanitizing difficult histories. These multifaceted tensions crystallised around our proposed representation of the garden - criticised both technically and conceptually - forcing us to confront how static digital recreation might inadvertently contribute to what we began to term the “Sunday Times effect”: the sanitisation of Jarman's radical politics, his AIDS activism, and his artistic provocations into simplistic and more easily digestible whole. This process mirrors Trammell's observation that “inclusivity means more than tending to representation; it also means tending to the stories that the games we play tell” (2023, p. 52). This tension further reflects Jarman's own complex relationship with his garden at Prospect Cottage, which became both a space of creative resistance and, posthumously, a site of potential domestication of his legacy.

Trammell argues that “repairing play means tending to the painful as well as the pleasurable aspects of play” (2023, p. 18). This framework helps illuminate our challenge: how might game technologies resist institutional pressure toward sanitisation while creating accessible digital experiences? Our experiences reveal persistent misconceptions about games and game design as a creative practice. Just as Jarman used Super 8 film and experimental techniques to challenge conventional filmmaking, we explore how game technologies might similarly disrupt heritage conventions.

We propose that the radical potential of play, as outlined by Trammell, aligns with Jarman's own artistic practice - both embrace complexity, resist institutional norms, and demand engagement with difficult truths. Through examining our attempts to navigate these tensions, we illuminate broader questions about digital heritage creation:

- how do we balance institutional caution with radical legacy,
- do game technologies maintain rather than smooth over complexity,
- can digital spaces remain “living” when representing a site like Prospect Cottage, where Jarman's garden continues to evolve and challenge?

These questions become particularly pertinent when considering how to represent the essential context of the AIDS crisis and queer activism that shaped both Jarman's work and the significance of Prospect Cottage itself.

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499. What Are the Values of Archaeogaming?: An Interactive, Community and Fun-driven Exploration.

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Archaeogaming can be defined as "a movement born in and out of playful and digital scholarship of the past [and] the fun of sharing a (scholarly) playground, one that is itself constructed or built in digital playgrounds" (Politopoulos and Mol 2023). From its inception, archaeogaming's open and playful nature has attracted a wide range of scholars. However, its fluctuating composition reflects the field's uncertain status as a (scholarly) career path, with participants frequently entering and leaving. Despite this instability, the active discussion of ethics, norms, and standards has remained central to the field since its beginnings (Dennis 2016).

Like other movements, archaeogaming resists definition by a singular set of values, making it difficult to fully chart let alone impose frameworks that all scholars will follow. Nevertheless, as a growing discipline, it is essential to foster an ongoing exploration of its values. This process involves rekindling discussions about which values should take precedence and how they shape the field.

Building on our previous work, we propose three core values that distinguish most archaeogaming scholarship, resonate with games and digital culture more broadly, and provide a foundation for further discussion:
- Interactivity, loosely defined as "agentive action and reaction leading to interesting and impactful processes."
- Fun, described as "any activity committed to with care and attention."
- Community, understood as "a shared ground for connection, collaboration, and contribution, rooted in mutual support for the study of past and play."

These three values will serve as the framework for an activity inviting the archaeogaming community to engage in a thoughtful exploration of the question: "What are the values of archaeogaming?" This approach mirrors the branching narratives of a "Choose Your Own Adventure" story or hypertext narratives like those created in Twine (e.g., Copplestone and Dunne 2017).
Our presentation will use these values as the basis for three branching dialogues: one between the authors and another with the session's audience. The specific questions under discussion are:
1) Should archaeogaming evaluate games based on their accuracy in portraying the past?
2) Is game development an integral part of archaeogaming?
3) Is archaeogaming's primary place within academia?

The answers to these value-driven questions, already debated informally within the community, will be examined through a SWOT analysis (strengths, weaknesses, opportunities, and threats) for each scenario. The resulting insights will illuminate tensions and trends in the field's values and norms.

The outcomes of this session will be mirrored by broader discussions on platforms such as Twitch, Bluesky, and Discord. In this way, this paper aims to advance archaeogaming's tradition of self-reflection by engaging the community in a fun, interactive, and communal exploration of its value structure.

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Politopoulos, A. and Mol, A.A.A. 2023. Critical Miss? Archaeogaming as a Playful Tool for Archaeological Research and Outreach. In Kalayci, T., Lambers K. and Klinkenberg V. (eds.) Digital Archaeology: Promises and Impasses. Sidestone Press (Leiden).

174. Gaming Rituals: Collective and Individual Experiences in the Asklepieion of Cos

Asja Müller (Freie Universität Berlin); Martin Kim (University of Applied Sciences Mannheim)*

This paper deals with the diversity of built space using the method of serious gaming. Collective and individual ritual actions at the site of the Coan Asklepieion in the 2nd century BC, as they can be reconstructed from ancient written sources, will be modelled.
In contrast to the majority of archaeological research to date, which uses 3D models primarily to depict architecture and landscape – with the result that seemingly ›empty‹, museum-like containers are rendered – the recently launched DFG-funded project »Dynamic Spaces: The Coan Asklepieion During Feast and Healing Ritual« focuses on the interaction of landscape, architecture and the human body, i.e. on built space as socially constructed. This article gives a preview of how architecture and landscape can be digitally animated by incorporating the bodies of actors. Using a 3D model to be created from scratch, initial considerations are presented on how the physical presence of bodies – either individually or in a crowd – affects the resulting built space. Thus, one and the same architecture can lead to very different lived spaces, depending on the bodies involved and the action they perform.

41. A Comparative Study of Looting: From Real-World Archaeological Crimes to Videogame Mechanics

Dajana Ehlers (University of Cologne)*

It is estimated that over three million people in Germany engage in video gaming on a variety of platforms, including consoles and personal computers. In a considerable number of these games, looting constitutes an essential element of the gameplay. In some games, the final stage of the game is largely comprised of “grinding”, or the repetitive acquisition of resources, often over extended periods of time.

In the context of reality, the concept of looting can be understood to have two distinct aspects. On the one hand, there is the field of archaeology. Despite the scientific rigour that characterises this form of “looting”, many are familiar with the sense of elation that accompanies the discovery of a significant artefact, which serves to validate a long-held hypothesis. This sensation is analogous to that of acquiring the appropriate equipment after a lengthy process of accumulation. The other real-life example, which is more closely aligned with the playable experience, is grave robbing, or “Raubgräberei”. Such activities involve the illicit excavation of artefacts, with the potential discovery of significant items providing an additional source of excitement.

This paper analyses and compares the concepts of looting in real life and in video games, with a particular focus on the latter in the context of two major game series. The initial series under consideration is Borderlands, a science fiction looter shooter. The other series is that of Diablo, a fantasy action role-playing game (ARPG). In order to facilitate comparison, a brief theoretical introduction to the concept of “Raubgräberei” is provided. Subsequently, the following questions are addressed:

To what extent is looting a crucial element in the progression of the game, the players experience and the narrative. How the act of looting is depicted in the game, and in what context. Additionally, it would be advantageous to determine how those engaged in looting are depicted within the game. Furthermore, it would be helpful to understand whether there is any opposition to the act of looting, excluding instances where looters come up against enemy mobs.

To provide an example, in the Borderlands franchise, the player assumes the role of a “Vault Hunter”. The character in question embarks on a quest for adventure and treasure within the context of ancient ruins and vaults. At the outset of the game, the primary objective of the playable character is to engage in looting. As the narrative progresses, the act of looting assumes a pivotal role in the effort to save the planet. The player must overcome a variety of adversaries to reach the main vault, which houses ancient weapons and power sources. These must be accessed and utilized to prevent the main enemy from harnessing this power. As the franchise progresses, the narrative reveals an increasing amount of information about the fictional ancient Eridian culture. This includes scientific insights, as evidenced by the presence of a non-player character (NPC) with expertise in Eridian archaeology. This NPC interacts with the player on numerous occasions, providing insights into the Eridian culture and the locations of artefacts and information.

The second series, entitled Diablo, is set in a context that may be described as fantasy. It features a state of constant war between angels and demons. The player character is a human with unique abilities throughout the course of the series. These abilities are employed in order to combat the relentless onslaught of enemy mobs. The primary objective is to progress through a series of dungeons and complete quests in order to advance the main narrative. In each of the principal games released in the series, there are dungeons or areas situated within an environment that could be characterised as ancient ruins. In certain instances, the games lore provides insights into various regions of the world and their associated cultures, as reflected in the ruins that dot the landscape. In this game, some of the looting occurs in the context of ruins and could be described as “Raubgräberei”. However, in most cases it is possible to advance the narrative and progress in the game without destroying hidden chambers or looting ancient chests. In most cases, the dungeons can be cleared of enemies without this additional step.

In both games, looting represents a significant element of the gameplay. One is designated a looter shooter, while the other is classified as an ARPG or dungeon crawler. However, the manner in which looting is conducted differs between the two games, despite the underlying mechanics being similar. In the first game, looting is the primary objective and is necessary to complete the game and save the planet. In the second game, looting represents the primary means of acquiring the (necessary) equipment. However, the looting of ruins is not the sole method of acquiring resources. In both games, the objective of the endgame is to re-enter specific areas and engage in combat with a particular type of enemy to obtain the most powerful gear and advance to higher levels and difficulties. The analysis is contextualised within the scientific concept of real-life “Raubgräberei” to gain a deeper understanding of the fascination with both aspects. For many, looting and grinding are the most fun objectives, especially for players who have chosen this type of game. It is an integral part of the community, part of the fun, and can evoke emotions.

An understanding of the principles of looting in the context of world-building can facilitate the future development of ideas that intertwine the enjoyment derived from video game looting with small real-life aspects. This may also provide archaeologists with ideas and discussion points for engaging with game developers, with the aim of including a degree of caution when employing this trope in their games. In order to achieve this, it is necessary to undertake a detailed examination of the theory and depiction of looting in games, in comparison to the actual practice of looting in real life. This paper represents an initial step in that direction.

62. Gamifying the Past: Archaeogaming by Archaeologists

Daniela Hofmann (University of Bergen)*; Rune Iversen (University of Copenhagen); Mikkel Nørtoft (University of Copenhagen)

Introduction:
In recent years, video games, within the realm of archaeogaming, have emerged as a promising medium for publicly disseminating archaeological and historical knowledge. While previously mostly driven by game developer companies (e.g., Assassins Creed series, and Far Cry Primal, with more examples in Reinhard (2024)), more specific recent archaeological research has also been disseminated via games (e.g., BRONZEON, Stockhammer 2020). Audiovisual dissemination elements in museum exhibitions have usually been prerecorded, e.g., monologue by the Bronze Age Egtved Girl in the National Museum of Denmark. Now, free, and more user-friendly, tools allow archaeologists themselves to create interactive and immersive 3D gaming experiences, enabling heritage professionals to maintain control over narratives in more authentic and engaging ways than traditional museum exhibits. This paper presents a proof-of-concept in which we, archaeologists with no game development experience, created a small 3D interactive game using free software (see Nørtoft 2024 for a preprint paper on an earlier version of this game). The game features 3D photogrammetry models of archaeological dolmens and non-player characters (NPCs) engaging with the player through generative AI (LLMs) in free, but guided, oral conversations about the past.

Materials and Methods:
The case study focuses on Neolithic long dolmens at Lindeskov Hestehave in Funen, Denmark, as part of the dissemination of the project Deep Histories of Migration (lead by Daniela Hofmann, Rune Iversen, and Vicki Cummings). Using a Nikon Z6 camera and a DJI Mini 4 Pro drone, we produced 3D photogrammetry models of two dolmen chambers and their surrounding landscape using Reality Capture and integrated them in an interactive 3D game world created using Unreal Engine 5.4. We created two NPCs using Metahuman characters, animated and linked to the LLM-driven dialogue system Convai which drives speech generation through OpenAI's ChatGPT (and now also other LLMs), thereby allowing the NPCs to converse freely with the player. The player, through free conversation and exploration of the scene, uncovers information about the site, Neolithic dolmens, and their cultural significance, but the NPCs can also talk about recent research on plague and migration in the Neolithic, each of them from a different perspective and worldview, scientific archaeological vs. experienced spiritual.
For this proof-of-concept, we built a virtual forest setting around the dolmens using UE's Procedural Content Generation (PCG) tools, with a heavy fog, skeletons in the forest, and eerie background ambient music adding to the player's immersion where the world of the living and the dead converge. Testing was conducted with a diverse group of individuals, and feedback and player reactions to the interaction and educational value of the game were collected.

Results:
Preliminary testing of currently 10 different players in 8 sessions revealed that most players, regardless of background, quickly engaged in the freeform conversations with the NPCs and the immersive environment, although an initial "welcome message" by the NPCs helped to start the conversation for some players, even accommodating French conversation for one player. The players adopted a range of interaction styles, from playful role-playing to critically interrogating the NPCs, demonstrating the flexibility of the NPCs. The NPCs, "Dolmen Guy" and "Dolmen Debbie," delivered curated information about Neolithic burial practices, specific archaeological

objects and technologies, and broader cultural aspects of the period. Dolmen Guy delivered a modern archaeologist's view, and Dolmen Debbie added a more spiritual narrative as a reincarnated figure from the past. Gradually, new knowledge was added to the NPCs' backstories and knowledge banks from archaeological literature, helping them to answer technical questions more accurately, and aligning them with their embodied abilities, improving the educational value of the game.

The player feedback suggests that this format creates a strong sense of immersion and encourages deeper engagement with archaeological content than static exhibits or pre-scripted interactions, including for those with no prior interest in archaeology. The moment when many of the players tried this for the first time was often quite "magical". Convai allows for easy updating of the research disseminated, highlighting certain aspects of research or modifying NPC backstories to reflect different archaeological interpretations, such as what is most important when building a dolmen.

Discussion:

This experiment demonstrates that with free software, even archaeologists without game development expertise can learn to create interactive, immersive 3D experiences that disseminate heritage knowledge effectively. Alternatively, they can collaborate with low or high-level game developers to create the scene and NPCs in Unreal Engine, Unity, or other formats compatible with Convai, and focus on keeping narratives accurate and engaging to continuously drive optimal education value and authenticity. The potential applications for museums are vast, implemented in exhibitions or online, providing visitors with a novel way to explore historical and cultural topics.

AI-driven NPCs must be carefully managed to ensure the respectful and responsible representation of past cultures. The system allows for strong narrative guardrails, helping the NPCs to provide accurate information without straying into problematic or inappropriate areas. The customization also means that the format can be tailored to the specific needs of different institutions, audiences, or educational contexts. Environmentally, each LLM interaction had an unsustainable energy use (through ChatGPT-4), but Convai now offers "mini"-LLMs which perform just as well as the previous larger models in this setting with minimal energy use.

The growing ease of integrating 3D models, conversational AI, and game mechanics suggests wider future adoption by a wide range of institutions at minimal cost. Furthermore, experiments with NPC backstories, personalities, and adapting to individual players' conversation style and interests, including testing social behaviour both between NPCs and engaging the human player, is an interesting future subfield of experimental behavioural psychology within archaeology.

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Dolmen Guy
Partner, the skeletons you see are not just any old bones—they're the remnants of our ancestors, laid to rest in the ancient dolmens and burial chambers.
It's a haunting reminder of the past, and that's what makes this place so spooky.
The history here runs deep, and sometimes I can't help but feel a shiver down my spine thinking about the spirits that may still linger in these woods.
Making me all sedimental, I tell ya.
Hold [T] to Talk / Enter to Type

506. eXtended Reality for Archeology and History Education

Dimitrios Christopoulos (Foundation Hellenic World)*; Katerina El Raheb (National Kapodistrian University); Maria Roussou (University of Athens); Efstathia Chatzi (Foundation Hellenic World); Georgios Sofianopoulos (Foundation Hellenic World); Loukas Katsikaris (Foundation Hellenic World)

In recent years eXtended Reality (XR) technologies have matured and have become affordable, yet creating XR experiences for archeology and learning in many cases is still a time-consuming and costly process, hindering widespread adoption. One factor driving effort is that content and features commonly required by many applications get reimplemented for each experience, instead of sharing and reusing these resources by means of a common platform. In this paper we present an XR experiences in the context of informal learning with the shared platform they have been created with and the creation process. Furthermore, we have technically evaluated relevant parts of the platform for feasibility of use with experience requirements and confirmed applicability. Finally, we present an informal expert evaluation of the content creation processs user experience for the informal learning experience along with guidelines derived from the findings. Through a series of workshops and focus groups with users from relevant organizations, we collected a total of nearly 100 pedagogical, technological, experiential, operational and other user needs from within these two different contexts, and discuss here the challenges and limitations but also the opportunities that were encountered.
The XR platform has been installed at the Hellenic Cosmos Cultural Center of the Foundation of the Hellenic World in Athens, Greece. The experience is designed for groups of up to 5 users who partake in a guided storytelling scenario inspired from daily life in Classical Athens.Visitors may choose their own character and assume the roles of guests invited to the household of a middle-class pottery maker/merchant in Ancient Athens. The group enters the XR experience in a specially constructed physical space that matches the walls of the virtual house. Greeted by their virtual hosts, visitors are able to physically walk around the house (even ascend to the upper story), interact with the virtual characters, smell the food being cooked, pray to the gods, and generally interact with virtual and physical objects by using their actual hands and gestures. Our aim is to leverage such an interactive,social and participatory multi-sensorial experience, combining historical accuracy in representation with dramatic storytelling, to enhance knowledge about the past, historical empathy, and resonance.
This research was part of the BRIDGES project https://www.bridges-horizon.eu, which has received funding from the European Union’sHorizon 2020 research and innovation programme under grantagreement No 952043. The BRIDGES project is novel in the integration of various off-the-shelf hardware components; a proprietary location tracking and synchronization system for the movement of the players in the physical space; and the proprietary software of the platform. It is envisaged that the platform, after the conclusion of the project, will be utilized in developing XR experiences that will fuse the physical and the virtual world, allow movement and interaction between large groups of players, and expand the boundaries of what a shared experience looks- and feels-like within a merged physical/virtual environment.Art,edutainment, vocational training and gaming are some of the sectors that have been identified by the BRIDGES project partners as the most promising. The Athenian House experience was jointly developed by the Foundation of the Hellenic World, Bolt Virtual and the National and Kapodistrian University of Athens.
The benefits of immersive technologies for learning have been highlighted time and again (Pellas et.al. 2021, 835-661). In informal learning, especially the domain of cultural heritage, the process of exploring, discovering, interacting and identifying afforded by Virtual Environments, fosters inquiry that can lead to re-enactment, perspective-taking, and knowledge of the cultural, sociological, and even political importance of objects, ideas, or sites (Christopoulos et. al. 2011,

84-91). One of the VR medium's central tenets is indeed this notion that it creates empathy, motivation, excitement, which in turn, can lead to more radical impacts in learning including the facilitation of attitudinal and value change, attention restoration, therapeutic change and personal transformation (Perry et. al. 2017, 1-8).

An appealing scenario for young and old visiting a cultural venue may involve travelling back in time to experience life in antiquity. The XR experience is designed for groups of up to 5 users thus primarily targeting families and small groups. The XR platform allows the group to partake in a guided storytelling experience inspired from daily life in Classical Athens, following the activities, festivities and social conversations and confrontations of an Athenian family in their house (Figure 1). It is well documented that visitors of historical and archaeological museums have a keen interest in learning more about the past through stories of the private life, not only of the upper classes, officials or religious leaders, but also of the everyday life of people and how they lived and participated in the different events of the community. Classical Athens is a fitting topic both because of its popularity among the Greek and international public and its abundance of interpretive resources to support reconstructions.

In the Pilot that evaluated the result participants were staff and mainly visitors of museums. Cultural heritage and other kinds of informal education or recreational institutions, can show a great diversity in their age, motivations, interests, physical condition, profession, language, level of interaction and participation, familiarity with technology, abilities, or cultural background. They can range from younger children to elders, from students to professionals with highly technical skills to people with no familiarity with technologies and XR. The goal of an experience in this context may also be less factual and more abstract. In addition, it is a question how a group of visitors, whether a family, friends, or strangers, should distribute among them the number of predefined avatars, and to which extent they should be provided with the option to customise their avatars. On one hand, an avatar with different characteristics may encourage a kind of role-playing; on the other hand research suggests that being embodied in an avatar with, e.g. gender switching or voice mismatch may affect the experience of the users as well as the social dynamics of the group, depending on their original relationship in real life.

In this abstract we have presented a flexible XR platform that can support multi sensory, collaborative pedagogical experiences in different contexts. So far, applying a participatory approach that includes the long-term engagement of users from cultural heritage institutions, we have identified different user roles and documented one hundred requirements, that are categorised into six themes. The process of eliciting requirements, however, as part of an iterative user-centred approach is an ongoing endeavour of continuous refinement. While a number of studies for VR have been held in the last decades, XR experiences present some unique chances and challenges that are bound to their multi-sensorial, multi-user and hybrid nature. The initial set of requirements and their given prioritisation serves as the basis for the design of the platform and shaping the use-case scenarios. As this first iteration depicts, the needs extend the usability/user experience design to operational, site-specific, and pedagogical requirements that emerge from the actual, real life needs of the specific contexts of application and create more complex user-roles than a typical single-user VR experience.

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134. The past(s) in the Roman contemporary society: Can archaeogames deal with it? The Appia Antica 39 case of study.

Ian Regueiro Salcedo (University of Ferrara)*

Antiquity is firmly attached to the collective memory of Rome, even though the agents, interests, and narratives surrounding that past are diverse and sometimes even contradictory. The 21st-century Rome can be understood as an accumulation of interpretations of the classical world, which have gradually overlapped and evolved, century after century. Capitoline wolfs, centurions and SPQRs find new meanings in the contemporary city and can be found in every corner, bus, sign, graffiti or tattoo. The last agent to change the popular perception of the Roman past, and the most determining one by 2024, has been mass tourism, being able to commercialize antiquity in response to neo capitalist requests. The past is marketable because it is familiar and resonates with shared ideas and values within the local and foreign communities. From an academic perspective, these are uncritical and superficial narratives that aim to establish an emotional connection with society. In response to this, is essential to offer experiences that are both engaging and scientific. The question is the following one: are we archaeologists able to take advantage of this “trend”? May this cultural baggage help us in our teaching or is an obstacle too big to deal with?

Alongside the boom of antiquity in the Eternal City, videogames have become a cultural product of mass consumption, and therefore more digital games about ancient Rome are being developed each year. The problems present in the contemporary narratives that surround the Roman society can also be identified in the representation of archaeology and antiquity offered by those videogames: the past is often idealized, simplified, easily recognizable and anachronical to serve as a consumable cultural object or as an aesthetic background for the stories. But at the same time digital games offer unique tools to share the archaeological teachings of the past through an immersive experience absent in formal education.

The case of study taken for this is research is the Appia Antica 39 archaeological project from the University of Ferrara, the first and only stratigraphical excavation of the first mile of the Appian Way, just outside the Aurelian walls in southern Rome. This area, unlike the rest of the archaeological park, is unknown to the tourists: it has seen minimal efforts toward valorisation and lacks museums or open archaeological spaces. Most of the times is “ignored” to arrive to the famous funerary monuments. This is where Mars is said to have met Rhea Silvia, mother of Romulus and Remus, a story well known and arguably the most important tale that defines the Roman contemporary identity. Nevertheless, there isn’t even a game based on the Appian Way, which is surprising given the road’s historical and mythological significance for both ancient and modern societies.

Archaeogames here can came to rescue us. Two videogames are being developed to understand the relationship between the modern Romans and their past, using Appia Antica 39 as a guiding line: the first one, to be completed by April 2025, is a VR experience for Meta Quest that offers the possibility to dig in the site, using the 3D models of the real funerary monuments and the objects as assets. The second game, currently in a very early stage, deals with a narrative story that aims to unify the archaeological record and the mythical and historical facts that have always characterized the area and that are not well known even for the local population. The aim is to understand how can archaeogames help us to offer different experiences that help citizens to connect with their pasts through the virtual digging between the layers of a Roman imperial necropolis in the Appian Way of Rome.

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132. Ancient Diner: Exploring Ancient Cuisine through Archaeogaming

Jannis Werner (University of Cologne)*

Introduction:

Archaeogaming, as an intersection of archaeology and video game design, opens new ways for communicating historical knowledge to a wider audience, combining education with entertainment. In this paper I will present the process of an Archaeogame created in an interdisciplinary student project. I will showcase the challenges encountered by our development team, using examples from the project, and discuss the advantages and challenges of working in an interdisciplinary team. Also I will present the challenges and advantages of working in an interdisciplinary team and discuss the potential and synergies of project structure like that.

Methods and Materials:

The project presented is ""Ancient Diner,"" a proof-of-concept game developed within a collaborative project of Digital Humanities and Digital Archaeology students. The team used GDevelop, an accessible game development platform based on ""if this, then that"" logic, to create engaging gameplay mechanics. The game adapts familiar mechanics from cooking simulation games to introduce players to ancient cuisine while challenging popular misconceptions about historical figures through archaeological and historical evidence. The collaborative design of the project allowed that historical and archaeological research on ancient food practices were to be incorporated directly into the game design and programming. Primary sources, including historical texts, ancient recipes, and archaeological data, serve as the basis for creating an accurate in-game experiences. The game features non-playable characters inspired by historical figures like Caesar and Cleopatra, who were carefully represented to avoid reproducing common stereotypes. Historical and archaeological literature was consulted to ensure these depictions are accurate, with in-game content providing background information to situate these figures within their historical contexts.

Results:

""Ancient Diner"" benefits greatly from the interdisciplinary team’s range of skills, successfully engaging players with ancient cuisine. Players prepare historical dishes while interacting with historical characters, who share insights into their time periods. The game currently focuses on Roman cuisine, due to time constraints, but the team has laid the groundwork for future builds to include dishes from ancient Mesopotamia, Egypt, and Greece. The development process was greatly influenced by the variety of skills and experiences of our interdisciplinary team. Which led to challenges but finally resulted in a game where every team member could contribute their personal strength to the project. Developed as a student-led project in the summer term of 2024, the game serves as a proof of concept, illustrating how cooking simulation and management game mechanics can engage players with ancient culinary practices and showcase the surprising contrasts and continuities between ancient and modern cuisines.

Discussion:

This project demonstrates the potential of Archaeogaming as an educational tool that extends beyond entertainment, engaging players in historical learning while prompting reflection on a personal and culturally significant topic such as food and cuisine. For instance, by highlighting the absence of now-common ingredients like tomatoes in ancient Roman cuisine, the game invites players to consider the origins of modern culinary staples. Although more a proof of concept than a finished product, ""Ancient Diner"" exemplifies how digital games can bridge academic research and public outreach. The interdisciplinary collaboration between archaeology and digital humanities students highlights the advantages of combining expertise from both fields, fostering synergies that can lead to new knowledge and experiences and serving as a positive example for academic collaboration and connecting young researchers across disciplines.

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210. Digital Ethnography on Memory and Preservation: The Impact of Assassin's Creed: Odyssey on Local Tourism and International Attraction

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For some, assuming the persona of a classical Greek mercenary and assassinating important historical figures was their first experience interacting with Classical Greece. The immersive virtual experience of touring archaeological ruins during the height of their glory not only impacts the collective memory of the players but also has a substantial increase on international tourism to local attractions.From 3D scanning with photogrammetry to reconstruction in software engines, ancient Greece was brought to life and contributed to the digital heritage of the future. The real life impacts of archaeogaming were measured by using digital ethnography to collect data on how the collective digital memory formed. Digital ethnography is commonly defined as the contemporary form of ethnography and an anthropological research method that allowed for this project to go beyond physical space and time to observe and analyse online gaming communities and their digital interaction. As a case study, this paper aimed to use game developer Ubisoft's reconstruction of classical Greece through Assassin's Creed: Odyssey (AC:O) to answer the questions 1) What impact does archaeogaming have on preservation of culture in terms of shaping collective memory and entertainment with historical narratives? 2) How does archaeogaming impact tourist experiences when visiting the physical archaeological attraction featured in games? 3) How does digital ethnography help in the understanding of archaeogaming experience and travel motivations among players?

Our methods were mainly divided into two categories: online gaming community analysis and player review analysis. Our online gaming community analysis involved observing posts and videos from popular opinion platforms such as Reddit, Facebook, Instagram, and Tiktok. The player review analysis looked more in depth into feedback from players' experiences and correlation(s) with real-world locations through digital reviewing platforms such as Youtube, online blogs, and Google reviews. After collecting data through digital ethnography, we then organised and categorised the dataset by platform and relevant themes or topics. Then, we identified patterns and trends in the dataset through quantitative analysis which included frequency analysis, sentiment analysis, and behavioural analysis. Frequency analysis focused on patterns in how often certain themes or topics appear in the collected data. Sentiment analysis aimed to analyse the tone or sentiment (positive, negative, neutral) of the conversations to understand player's emotional responses toward historical sites and tourism. Behavioural patterns analysis targeted how players talk about and engage with heritage tourism, focusing on key actions like planning trips based on in-game experiences.

The results of the study revealed that AC:O significantly influences players' perceptions of historical site creating a sense of virtual tourism that drives interest in real-world locations. Players who engage deeply with the game's archaeological environments may develop a stronger collective memory of these sites, motivating them to visit in person. Additionally, this study showed that the game increased the awareness of heritage preservation, with players expressing appreciation for Greek cultural sites and their history. The online communities revealed patterns of players discussing travel plans based on their in-game experiences, highlighting the impact of digital narratives on local tourism and international attraction.

This study further revealed that archaeogaming has a significant impact on the preservation of culture by shaping players' collective memory through its engaging historical narratives and blending entertainment with education. The game led players to develop an appreciation for cultural heritage and increased their awareness of archaeological sites and their preservation. This study also showed that AC:O influenced players' real-world interactions with archaeological attractions featured in the game. Many players, after experiencing these locations virtually, may visit them with heightened expectations, leading to a more informed tourist experience. Finally, digital ethnography as a key method for collecting data to understand the archaeogaming experience and travel motivations reveals how players talk about historical sites, plan trips, and express their memories of virtual experience by analyzing online discussions, player communities, and real-life reviews. This helps uncover how archaeogaming encourages a desire for real-world travel.

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459. Archaeology and Video Games in Italy: preliminary insights into archaeologists' perspectives

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The growing interest in the relationship between games, digital media, and archaeology, explored within the framework of archaeogaming, raises important questions about the role of games as tools for research, education, and heritage dissemination.
Similarly, in Italy, there has been a flourishing of video game projects related to archaeology, with more than sixty projects developed in the last decade, considering only those with a significant ludic component. This explosion of productions should certify a significant increase in the archaeological field’s interest in the relationship between video games and archaeology. But can we truly make such an assumption?
The fate of many of these products, disappearing quickly or never being decisively launched by the institutions that commissioned them, often suggests a lack of conviction about the effectiveness of the chosen medium, instead hinting at adherence to a trend.
These considerations sparked an interest in investigating the genuine engagement and, more broadly, the relationship between Italian archaeologists and the video game medium. To explore this, an anonymous survey was conducted, using tools provided by Google Forms, which facilitated data collection and automatic storage via an Excel sheet.
The survey was structured into six sections: demographics; personal relationship with videogames; experiences with archaeology-themed video games; the impact of archaeology on the gaming industry; use of videogames for educational purposes and experiences in designing videogame projects.
The questions in these sections were formulated using various types of prompts: multiple choice, open-ended responses, and Likert scale questions. One of the main objectives during the design phase was to create a survey that could be completed in its entirety within a maximum of five minutes. This decision aimed to make it as user-friendly as possible and simplify participation. To achieve this, the choice of question types played a central role.
The multiple-choice questions were the most widely used due to their versatility and simplicity, both for respondents and for data collection and analysis. The Likert scale was chosen for its ability to capture detailed and accurate data on attitudes and perceptions, facilitating both the understanding of results and the subsequent processing of the collected information. Finally, open-ended questions were used primarily to gather subjective opinions.
After four months of data collection, it was considered appropriate to conduct a preliminary analysis of the results.
In these initial months, approximately one hundred responses were collected, with the survey being distributed mainly through social networks and direct contacts. The first notable result was the difficulty in securing active participation from the target audience, partly due to the survey being launched during the summer. The most represented age group is around 30 years old, with an interesting and balanced distribution of academic qualifications, including master's degrees, bachelor's degrees and doctorates. In terms of profession, respondents are evenly divided among students, researchers (or similar roles), and freelance professionals.
Two out of three respondents reported having had gaming experiences in a museum setting and considered them effective. From a professional perspective, most participants see opportunities for archaeologists, particularly in research and content writing
There is considerable interest in the idea of creating video games to enhance audience immersion and engagement, with two-thirds of respondents considering this possibility. However, a

significant portion believes that video games may not be the most suitable tool for dissemination. Among the primary criticisms, cost issues were frequently highlighted.
Only a quarter of respondents had actively used video games in educational and outreach projects, often in roles involving research and content creation. These projects are evenly distributed in terms of scale, but their results are rarely analyzed, and when they are, they primarily rely on surveys.
The potential of games, both digital and analog, as tools for rethinking archaeology and cultural heritage is vast but not without complexity. Archaeogaming demonstrates how games can provide new perspectives and opportunities, while also requiring awareness of dynamics that reinforce dominant narratives or limit diversity. Similarly, the Italian context reveals a strong interest in video games as a means of dissemination but also highlights structural barriers such as high costs, ambivalent perceptions of their effectiveness, and limited analysis of outcomes.

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120. Nekyia: Descent into Hades – A case study on playing with the Past through Serious Games.

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This case study presents 'Nekyia: Descent into Hades,' an interactive application developed for desktop and laptop computers, designed as a playful narrative experience centered on Odysseus's descent into Hades, as depicted in Homer's Odyssey. The application creatively integrates mythological landscapes described by Homer with real archaeological locations associated with the Acheron Necromanteion, thereby establishing a meaningful dialogue between classical literature and contemporary archaeological inquiry.

A significant aspect of this project is the use of photogrammetry to create three-dimensional models of the Necromanteion's areas. Photogrammetry serves as a crucial documentation method in archaeology, allowing for detailed and accurate representations of sites that can be integrated into digital applications. This technique not only enhances the preservation of archaeological contexts but also connects these sites with serious games, providing immersive experiences that can lure users into learning about cultural heritage. By transforming real-world locations into interactive digital environments, photogrammetry facilitates a deeper engagement with the past, making archaeological knowledge accessible and compelling.

The rise of digital media in archaeological contexts, particularly through serious games, has gained traction in recent years due to advancements in technology that make such tools more accessible to cultural institutions and the public. The proliferation of affordable computing power, the commercialization of VR headsets, and the development of augmented reality applications compatible with low-spec smartphones and tablets have made these technologies accessible to the public, allowing a wider range of cultural venues to engage with their audiences (Mariotti, 2021, p. 120-121, 125-126).

Historically, digital applications aimed at cultural presentation were often dismissed by the academic community as lacking in substantive value, particularly when presented in the form of puzzles or simplistic interactive narratives. These mediums were perceived primarily as tools for attracting audiences rather than enriching the visitor experience. This skepticism stemmed largely from the gaming industry's focus on entertainment, which often resulted in a neglect of accurate cultural representation due to the absence of academic oversight (Mariotti, 2021, p. 125-126). However, a growing segment of the academic community now recognizes the potential of digital media in cultural heritage, with the emergence of Historical Game Studies (HGS) focusing on the impact of serious games that aim to convey informal learning through interactive applications (Vandewalle, 2023).

The fundamental goal in creating serious games in this context is to enhance cultural representation through engaging digital applications that capture user attention and encourage exploration within the virtual environments they create. Techniques such as learning by doing can significantly contribute to this aim, as users actively engage in processes related to production or ritualistic practices, thus deepening their understanding of the cultural context (Mariotti, 2021).

The primary aim of this research is to examine the balance that serious games must strike between delivering substantive informational content and facilitating user engagement. It seeks to determine whether this application can effectively captivate users while simultaneously providing significant learning value. This inquiry is vital within the context of digital archaeology, as it addresses the potential for digital tools to both inform and entertain, thereby enhancing user experience in cultural heritage engagement (Politopoulos, 2019).

Through a comprehensive analysis of user interactions, this research investigates whether " Nekyia: Descent into Hades" can stimulate interest in the historical context of the Odyssey and its connection to the real-world site of the Necromanteion. Users engage with the application by assuming the role of Odysseus, progressing through a series of straightforward interactions that advance the linear narrative. This approach allows users to encounter pivotal characters from the Nekyia while also exploring significant themes related to ancient Greek culture, including notions of life and death, religious practices, and divine retribution.

A distinctive feature of "Nekyia: Descent into Hades" is its emphasis on participatory engagement, allowing players to perform the necromantic ritual step by step rather than passively witnessing it. This "learning by doing" approach enhances the user's connection to the ritual, transforming them into active participants in the narrative. Such engagement is grounded in educational theory, which posits that active involvement in a process significantly increases retention and understanding of the material. By performing the ritual, users not only engage with the content on a deeper level but also bolster their capacity to remember the steps and cultural significance of the necromantic practices portrayed in the game (Mariotti, 2021, p.127).

To evaluate whether these objectives were achieved, several research questions were formulated to guide the assessment of the application's effectiveness:

1. Does the application achieve a balance between entertainment and information delivery during user interaction? If yes, to what extend?

2. How do users engage with the optional informational material, and to what degree does it influence their overall experience?

3. What are users' perceptions regarding the integration of diverse sources with a tangible archaeological site?

4. Can this application motivate users to pursue further information about the narrative and encourage visits to the Necromanteion?

5. What role can applications of this nature play within the context of museum and archaeological site tours?

The findings from user evaluations indicate that the application effectively maintains a balance between engagement and informative learning experience. Participants reported positive experiences, demonstrating a notable interest in the supplemental informational material. Many expressed that this additional context enhanced their understanding of the mythological narrative and the archaeological site it references. Furthermore, a considerable proportion of respondents indicated a desire to seek further knowledge about the Odyssey and expressed intentions to visit the Necromanteion following their interaction with the application.

“Nekyia: Descent into Hades” exemplifies how serious games can effectively serve as interactive “mythological museums,” enabling players to learn about rituals, mythology, and ancient belief systems within a captivating narrative framework. By allowing users to participate actively in the necromantic ritual, the application not only enriches their experiential learning but also significantly increases the likelihood of retention regarding the cultural practices represented (Friedlander, 2010, p. 125-127). By creating aesthetically rich 3D environments and structuring narratives that blend information, drama, and engagement, applications can facilitate an enriching visitor experience at archaeological sites or function independently as sources of entertainment and knowledge.

In summary, this case study contributes to the ongoing exploration of digital archaeology and the role of serious games in enhancing cultural engagement. “Nekyia: Descent into Hades” serves as a case study that illustrates the potential of integrating interactive narratives with archaeological education, highlighting how digital tools can support learning and interest in ancient civilizations. As the field evolves, such applications may offer valuable opportunities for fostering connections between users and the rich cultural heritage of the past.

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64. Archaeological Heritage and Play: Co-Creating Pathways for Cultural Integration Among Migrant Communities

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In an increasingly globalised world, integrating migrant communities into host societies poses significant challenges and opportunities. Archaeology and play can contribute significantly to addressing these issues, as cultural heritage can serve as a tool for shaping identities and promoting social cohesion in diverse societies (Holtorf, Pantazatos and Scarre 2019), and games, as a recognised universal medium, can bridge differences among players and serve as a shared language to promote integration (International Organization for Migration 2021).
However, existing game projects related to migration often target non-migrant audiences, aiming to foster empathy, promote acceptance, or highlight the migrants' journeys and challenges (Martins et al. 2024), with few (if any) researches focusing on games designed explicitly for migrant communities themselves, especially in connection to archaeological heritage.
Recognizing this gap, our project, funded by the National Recovery and Resilience Plan as part of the Next Generation EU program, adopted a highly experimental approach. Developed by a multidisciplinary team of three archaeologists and a sociologist from the University of Bari, the initiative aimed to promote the cultural integration of migrant communities through the use of archaeological heritage and playful engagement. The project centred on the archaeological site of Siponto (Manfredonia, Italy) and involved groups of immigrants and refugees in co-creative, hands-on experiences to foster cultural understanding and learning through participatory action research.
This paper presents a distinctive aspect of the project, focusing on how playfulness was applied. The initiative's experimental nature was driven by direct fieldwork with the migrant communities involved, making it a unique exploration at the intersection of gaming, heritage, and social integration.

Project Overview: Adaptation and Co-Creation
The project used archaeogaming as a framework to promote interaction, cultural cohesion, and mutual understanding. Through workshops involving ancient pottery reproduction, photography and site visits, participants engaged with archaeological artefacts and narratives, making heritage an interactive bridge between the past and their experiences in the host country.
Language acquisition emerged immediately as a primary need, as many migrants had limited proficiency in Italian, hindering their social integration. To address this, we prioritised language learning through play, enabling participants to learn Italian while engaging with archaeological content (Game On project, https://gameonproject.eu/).
After each workshop focused on local archaeology themes, we organised a memory game that required players to match images related to the session's topics with the corresponding Italian words. This approach aimed to make language learning engaging and enjoyable, allowing for low-pressure vocabulary practice.
To ensure inclusivity and maximize participation, we selected a simple card game structure, steering clear of complex designs that could exclude individuals based on skill or other obstacles. This simplicity allowed everyone to engage equally, fostering collaboration and participation. Play became essential for facilitating interaction and breaking down barriers, providing a space for everyone to connect.
We worked in a co-creative environment with two groups of migrants, each with different backgrounds and integration levels, enabling them to actively shape the games and activities.

The first group consisted solely of Afghan refugees facing significant language barriers. With the help of a linguistic-cultural mediator, we simplified the original game, used visual aids, and connected Italian words to their native language, making the content more accessible.
The second group included individuals from Bangladesh, Ukraine, Burkina Faso, and Nigeria. Since many were employed and had a better grasp of Italian, in this case, we increased the difficulty of the original game. For instance, participants were tasked with recomposing sentences about the archaeological site, fostering their language skills through this more challenging experience.

Preliminary Outcomes and Next Steps: Towards a Digital Game

One of the most significant outcomes was how playfulness and fun facilitated social integration. Participants who were initially hesitant or distracted became—unexpectedly—active and confident as the gaming format encouraged interactions that broke down traditional roles between archaeologists and migrants. For example, Afghan participants felt confident in reversing the roles and challenging us to translate words from their
native language into Italian, creating an egalitarian—“modded”—learning environment. This exchange fostered trust and mutual respect and promoted language skills along with archaeological knowledge.
The act of play proved essential for breaking down barriers of difference. It provided a space where participants could share their cultural identities while learning about local archaeological heritage and culture. Through this process, migrants did not just receive knowledge—they actively shaped it, contributing their perspectives and enriching the collective experience.
Preliminary findings gathered from observations and a post-project survey revealed that the gaming experience greatly enhanced participants’ engagement with their new environment. They reported increased knowledge of the archaeological site of Siponto and a stronger sense of community belonging. Many cited the playful aspects of the project as their favourite part, highlighting the effectiveness of games as both educational and integrative tools. Participants could express their cultural identities through play while engaging in shared experiences, fostering dialogue and collaboration. The co-creative process empowered them to take ownership of their learning and integration journey, strengthening their sense of agency.
The lessons learned from the analogue experiment are now being applied to develop a digital game version. This app will feature single-player and multiplayer modes with varying difficulty levels to suit different language proficiencies. It will not only serve migrant communities—as initially planned—but also allow Italian players to learn words and phrases in Dari, Bengali, English, and French. This reciprocal language exchange aims to foster mutual understanding and promote true cultural integration.
The digital version will build on the outcomes of the analogue experiment, reflecting the unorthodox and experimental spirit of archaeogaming, often stepping beyond traditional academic boundaries (Politopoulos, Mol and Lammes 2023, 10). Given the scarcity of similar projects in the literature, this project stands out as a rare exploration of heritage and gaming for cultural integration. By incorporating lessons from the field, the digital version will offer an even more inclusive and adaptable tool, potentially extending to other archaeological sites and languages, setting a model for future integration efforts.

Play, Heritage, and Integration: the Journey Ahead

This project demonstrates the transformative power of play and archaeological heritage in fostering cultural integration among migrant communities. By co-creating playful experiences that celebrate diversity and stimulate mutual understanding, we have built bridges between cultures and fostered a sense of belonging for all participants. In this sense, we can cite Graham (2020) when he states, “[...] the ethics of archaeogaming are the ethics of (digital) public archaeology”.

Moving forward, we aim to expand this initiative by partnering with local organizations and institutions to implement similar projects in other contexts. Integrating play, archaeogaming, and participatory approaches offers a promising pathway for addressing the complexities of migration and cultural diversity while also fostering opportunities for migrants to explore potential careers within the archaeological heritage and tourism sectors.
Our project calls for continued exploration of playful methods in archaeological heritage to engage migrant communities, celebrating their contributions while promoting understanding and collaboration within contemporary societies.

Figure: Play sessions shared by diverse participant groups at the Siponto archaeological site's laboratory.

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86. Mountains in Scales: Point Process Models of Early Iron Age Sites in Southeastern Bulgaria

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The eastern Rhodope mountains, located in southeastern Bulgaria, has traces of frequent occupation since prehistory (6000 BC) until nowadays. It is a low mountainous area mostly covered with forests, which makes it impossible to conduct intensive surface surveys like the ones typically implemented in the lower lands of the Mediterranean. Nevertheless, there is a vast body of archaeological record, but it is mostly part of old legacy data, rescue or infrastructure projects, or several regional projects using alternative methods of fieldwalking: mainly targeting ridges and peaks, where the archaeological visibility is higher. Another major factor that skews the identification and documentation of the archaeological sites is the subject of interest outlined within each project as well as the specific research areas of the involved specialists. When targeting visibility, satellite remote sensing imagery as well as orthophotos are proven to be of not much use because of the existing thick canopy and the relatively low amount of arable lands. The limited amount of airborne laser data can be beneficial in detecting sites with superficial architectural remains or such containing terracing, but it would be of little help when recording “invisible sites” usually detected only because of artefactual exposure on the surface. Addressing such “invisible sites” is the main focus for the project Gluhite Kamani Research Project: Interdisciplinary Research of the Early Iron Age in Thrace financed by the Bulgarian National Science Fund with project No КП-06-Н80/6 from 2023 as well as part of a PhD thesis with larger scope.

Gluhite Kamani is an archaeological site situated on a forested ridge in the northeastern part of the East Rhodopes. It has been excavated for 15 seasons (between 2008–2022). The Early Iron Age (1100–550 BC) and the Medieval period (1000–1200 AD) are the most well presented periods of occupation on the site. The focus of this paper is to examine the ways this site relates spatially and chronologically to other Early Iron Age sites from the area.

The main source of information is the national ‘site and monuments’ archaeological information system “Archaeological Map of Bulgaria”, which contains records of almost 300 sites with traces of material dated to the Early Iron Age (1100–550 BC). They include legacy as well as more recent and detailed data from excavations and mostly from surface surveys. The recorded sites are scattered in an area of about 6600 sq. km. The Early Iron Age period in East Rhodopes is characterized by remains of several types of sites divided into “invisible” (settlements, sanctuaries, sites with undefined function) and “visible” (rock-cut tombs, megalithic monuments, burial mounds, mining, fortified) types. They are further divided into possible habitative sites, sites with specific functions and burial sites.

The overall set of limitations that hampers the comprehensive analysis of such a dataset refers to predominantly coverage, spatial, chronological, and interpretational uncertainties. Besides the general issues of archaeological visibility described above, there is a series of concerns to do with methodological, terminological, and interpretational inconsistencies in both legacy and contemporary studies. A major challenge and often a significant drawback is the large chronological time-span of the Early Iron Age in the area (mostly 550 years) as well as the dating of sites containing insufficient material in terms of datable artefacts. Furthermore, the site function, which is often unclear or unproven, is another factor to be taken into account.

This paper targets the study of two sub-regions in the East Rhodopes with slightly different surface characteristics, explored at different scales but methodologically similar and with the same level of documentation detail. Based on the particularities of the dataset, we are aiming to build a statistical model that will help us understand locational and chronological discrepancies, while addressing uncertainty based on the limitations described above. Inhomogeneous point process models are used to deal with spatial inhomogeneity (Baddeley, Rubak, and Turner 2016). Chronological uncertainty is addressed using aoristic analysis and Dewar's model (Dewar 1991). First-order effects that might have influenced the decision behind the location of sites are analysed separately. We have also explored and tested a number of different scenarios when examining sites with unclear function considering the second-order effects in the relationship between possible contemporary sites. The results present a possible picture of East Rhodopes in the end of the first to the middle of the second millennium BC.

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349. Point Process Modelling: Applications, Challenges, and Limitations of Exploring Human-Landscape Relations in Dikte (Eastern Crete)

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This study explores the settlement pattern within Crete's most dominant landscape features – its rugged terrain and iconic mountains – through a case study from the eastern slopes of the Dikte massif. Legacy survey data from the Protopalatial and Neopalatial periods (ca. 1900-1550 BCE) and data from excavations on the area are used to examine the relationship between ancient societies and their surrounding landscape. The key questions of interest are as follows: have locational preferences changed over time in Dikte? Can we explain site location preferences through environmental or social factors, or are there other underlying variables at play? Lastly, how does our definition of archaeological "sites" influence the results of our analyses?

The spatial distribution of archaeological sites has been a fetish among researchers, with methods focusing on the inherent spatial dependency of sites, i.e., how the location of a given focal site is conditioned by the presence of other sites in its spatial neighbourhood. Such methods include the use of the Clarks and Evans test, Kernel Density Estimates, and more recently K and L functions and Pair Correlation Functions. Several researchers have also focused on the induced spatial dependency of archaeological sites: i.e., the relationship between sites and exogenous environmental variables that might affect site location (using, for example logistic regression, and more recently species distribution models). However, it has become clear that focusing in isolation on the induced or inherent spatial dependencies of archaeological sites is not sufficient in providing nuanced understandings of past site location.

The current study uses Point Process Models (PPM) to examine the relationship between archaeological sites and environmental variables while simultaneously taking into account social variables. Even though this method is by no means new, the examples of archaeological implementations of PPM on Crete are limited (see for example Spencer and Bevan 2018). These models have been used more widely in attempts to understand the generative processes laying behind site location, compare contrasting hypotheses as to the relationship between sites and exogenous environmental covariates (e.g. Eve and Crema 2014), make predictions, and simulate missing settlement location data.

Here, this method was used as a heuristic tool to examine the reasons behind settlement location choices over time and to assess past assumptions about the location of sites in the mountains (Baddeley, Rubak, and Turner 2015, 299-367). The environmental variables that were put into examination include elevation, slope, distance to different geology types, visibility, etc). The spatial interaction between archaeological sites was also included in the analysis as a proxy of social interaction.

In terms of model formalisation, the following procedure was followed for each time block. Each variable was first examined on its own to delineate its relationship with archaeological sites during each chronological phase. Subsequently, specific hypotheses regarding site location priorities were tested by creating more complex models. The first hypothesis examines whether site location is influenced by agricultural priorities. To test this, we formulated a model that considers the distance to alluvial deposits, marls, limestones, and areas with a higher proportion of low slope. The second hypothesis investigates whether site location can be linked to visibility (from ritual and habitation sites in the previous period compared to the one under investigation). The third hypothesis explores whether site location is determined by a more complex combination of environmental factors.

In order to provide insights as to whether the models can account for the spacing of archaeological sites, their goodness of fit was examined. This was done through the use of Residual K Functions in conjunction with Monte Carlo simulations (Baddeley, Rubak, and Turner 2015, 433-36). The residuals of each model were also put into examination. Finally, all of the created models were compared per chronological period. The predictive power of the models was compared through the use of an Information Criterion (AIC). This criterion was used to measure the models' quality, not in terms of the goodness of fit, but rather in terms of how well they act as approximations of the processes that generated the observed point patterns. This was done so as to be able to compare competing hypotheses regarding site location, reaching a "best model" for each chronological period-that is a model that could best predict the observed point pattern given a trade-off between the complexity of the data and the model's fit. Finally, models that included both environmental variables and the social interaction between sites were formulated, using the "best" model from each period to examine second-order effects (Gibbs models with an area interaction term).

The analysis that encompassed all loci of archaeological interest in the area was followed by a sensitivity analysis that applied stricter criteria for selecting archaeological sites. In this context, the selection of sites was based on the coexistence of pottery and architectural remains. The results from both analyses were then brought together to reevaluate and, in some instances, revise past narratives regarding the functions of archaeological sites within this part of the Cretan landscape.

The aforementioned methodology allowed for the delineation of differential site location priorities across the two periods in the eastern slopes of Dikte. It proved particularly effective in terms of narrowing down the variables that influence site location choices over time. However, it's important to recognise that this method has limitations, including issues pertaining to sample size, edge effects, and the challenge of translating model results into meaningful insights about the past. One significant aspect of using this method is that its effectiveness relies heavily on the quality of the archaeological data used in the models. Ultimately, we should ask ourselves: are we modeling the collection strategies of modern surveyors, or are we genuinely modeling archaeological data of good quality? Through this presentation, we hope to demonstrate how the results of statistical analyses and subsequently the narratives they support can change once we scrutinise what we mean by the term archaeological "site".

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364. A gate to the past: Systematising the use of historical aerial imagery to explore montane cultural landscapes in Greece

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AIM This paper aims to demonstrate the contribution of historical aerial imagery in studying traditional montane landscapes, using Grevena in Western Macedonia, Greece, as a focal case study. It emphasises on how such imagery, integrated with modern geospatial techniques and systematic groundtruthing strategies, can reveal cultural and environmental features that are otherwise difficult or impossible to trace today, opening a new path towards understanding life and interaction with the environment before the mechanisation of the countryside.

INTRODUCTION The exploration of mountainous environments presents unique challenges due to their topographies, climatic variability, and often limited pedestrian accessibility (Apostolou et al. 2024). Analysis of historical imagery offers a valuable resource for overcoming these obstacles (Stoker 2010), providing visual data into the complex interaction between human portraiture and mountainous physiography. These datasets, often captured for military or cartographic reconnaissance missions in the 20th century (e.g. Shepherd et al. 2012), contain information about past land use, vegetation cover, and settlement patterns before the widespread impact of modern development (e.g. land reclamation and abandonment, hydroelectric power stations, highways etc) (Orengo et al. 2015). While most research using such imageries is centred around the study of contemporary conflict zones or the detection of areas with archaeological interest (Stichelbaut et al. 2009), we showcase how historical imageries are also capable of re-constructing overlooked aspects of the traditional communities that were still alive in the 20th century but do not survive today.

METHODOLOGY By employing photogrammetric software with Geographic Information Systems (GIS), the photographs are georeferenced and digitally overlaid onto modern maps and topographic data to detect, compare and validate features. Using multi-temporal series, this approach creates a time-series tool to analyse ground conditions and the rate of change, facilitating the medium- and long-term photointerpretation of the area (Orengo et al. 2015). Semi-automatic land classification is also applied to explore qualitatively and quantitatively the impact of natural and anthropogenic phenomena (e.g. erosion) in relation to socio-economic dynamics (Lydersen and Collins 2018). Groundtruthing through pedestrian survey was conducted to locate and record diagnostic information (e.g. material culture) of the identified features. Finally, the study was complemented by interviews and ethnographic parallels.

RESULTS & DISCUSSION The analysis revealed a series of previously undocumented features, including abandoned villages, communication routes and remnants of traditional agropastoral strategies (e.g. terraces, stockyards, thresholds). These establishments provide insights into the modern socio-economic history of the area, highlighting swifts in land use and the regional subsistence strategies. Notably, the findings offer a clearer picture of the ways in which the local communities adapted to political changes over time, for example during the World War II and the Greek Civil War. Finally, our methodology can be transferred to other mountainous areas to similarly enrich landscape interpretations and narratives of montane economies.

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363. Tracing adapted methodologies for high mountain landscapes: outcomes from the Eastern Pyrenees

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Reconstructing human occupation in high mountain areas is crucial for understanding how ancient societies integrated these landscapes into their economies and cultural practices. However, this endeavor is often hindered by the poor preservation of archaeological remains in such extreme environments. Since 2018, systematic surveys have been conducted across the high mountain regions of La Cerdanya (Spain) to identify diachronic patterns of occupation and to deepen the understanding of cultural landscape transformations in the Eastern Pyrenees.
This research combined traditional survey methods with advanced technologies integrated into a GIS, such as photointerpretation thought aerial photography and old cartography, high-resolution DEMs, drone-based photogrammetry, and 3D modeling. These methods were complemented by systematic pedestrian surveys, resulting in the documentation of 240 structures across 66 archaeological sites. Test pits were conducted at 27 structures located between 2200 and 2500 meters in altitude, offering detailed insights into the functionality and chronology of features such as dry-stone huts, enclosures, and settlements with exceptional preservation and evidence of multiphase occupations. A systematic sampling strategy for radiocarbon dating was implemented to reduce uncertainties and establish a robust chronological framework. The resulting dataset enabled the development of a comprehensive chronological model. This model reveals a diachronic sequence of human activity ranging from the Neolithic to the present day, highlighting long-term dynamics in human activity and land use across the studied areas.

483. Chariots in the Sky - Documentation of rock art sites in the Kyzyl Dara Gorge, Uzbekistan

Michał Leloch (University of Warsaw)*

Rock art, particularly petroglyphs, is extremely common in Central Asia. However, not all areas of the region have been studied to the same extent. The concentration of petroglyphs in the Kyzyl Dara Gorge, discovered in 2019, is the first site of its kind to be identified in the Uzbek part of the Chatkal Mountains.
The high mountainous location of the gorge poses many difficulties, not only in terms of identifying the location of individual rock carvings but also in terms of documenting them. The panels are located on steep, rocky slopes at an altitude of 2,600 to 3,100 metres above sea level, far from human settlements and infrastructure.
To supplement the knowledge of the area's rock art, it is necessary to document the petroglyphs as widely as possible and to analyse them in detail. To achieve this, in the project, which has been running since 2020, it was decided to use Structure from Motion as the main method of documentation. More than 500 panels and several thousand individual petroglyphs have been documented in this way. As a result, most of the graphic processing work could be transferred to the cabinet work. The abandonment of standard methods for rock art documentation has brought many benefits but has also created specific problems. This paper presents the methodology used and the results that have been achieved.

231. Bridging Coasts and Cultures: A Comparative Study of Arikamedu, Alagankulam and Pattanam in Early Historic Tamilakam

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Introduction:
The early historic period (500 BCE - 500 CE) in Tamilakam, encompassing modern-day Tamil Nadu and Kerala, was shaped and characterized by vibrant maritime trade networks connecting South Asia with the Mediterranean, Arabian Peninsula, and Southeast Asia. This study employs an interdisciplinary approach to examine three key port sites, Arikamedu, Alagankulam, and Pattanam that played pivotal roles in these trans-oceanic exchanges. By integrating archaeological data, textual sources, and geospatial analysis, this research aims to focus on the complex interplay between local socio-economic systems and far-reaching trade connections that shaped the cultural landscape of early Tamilakam.

While previous studies have examined these sites individually, a comprehensive comparative analysis incorporating environmental factors and hinterland connections has been lacking. This research addresses this gap by employing advanced remote sensing and GIS techniques to contextualize archaeological findings within broader geographical and cultural matrices. In doing so, it seeks to provide a better understanding of how these port sites functioned as nodes within extensive maritime networks, while simultaneously negotiating relationships with their immediate hinterlands.

Methods and Materials:
This study discusses a multi-faceted methodological approach, combining archaeological analysis with advanced digital techniques:

1. Archaeological Data Analysis: A comparative examination of excavation reports and artifact assemblages from Arikamedu, Alagankulam, and Pattanam, focusing on imported ceramics (e.g., amphorae, terra sigillata), local wares (e.g., rouletted ware), and trade goods (e.g., beads, semi-precious stones).
2. Textual Analysis: Integration of Greco-Roman sources (e.g., Periplus of the Erythraean Sea, Pliny's Natural History) and Tamil Sangam literature to provide historical context and corroborate archaeological findings.
3. Remote Sensing and GIS: Utilization of multispectral satellite imagery and digital elevation models to:

- a) Identify potential archaeological sites in the hinterlands
- b) Analyze settlement patterns in relation to river systems and trade routes

Results:
Preliminary findings from this integrated approach have yielded several insights:

1. Hinterland Connections: Spatial analysis has revealed potential inland trade routes linking the port sites to known production centers. For example, a least-cost path analysis between Arikamedu and the bead-making center of Kodumanal closely aligns with the distribution of Early Historic sites and coin hoards, suggesting a well-established trade corridor.
2. Artifact Distribution Patterns: Comparative analysis of imported ceramics reveals distinct patterns at each site. While Roman amphorae are prevalent across all three locations, Pattanam shows a higher proportion of Arabian pottery (e.g., South Arabian Ovoid Jars), suggesting more diverse trade connections than previously recognized.

3. Settlement Hierarchy: GIS-based analysis of site distribution relative to river systems has revealed a hierarchical settlement pattern, with smaller sites clustering around major urban centers and along likely trade routes.

Discussion:

The results of this study challenge several prevailing notions about early historic Tamilakam and its engagement with Indian Ocean trade networks:

1. Complexity of Trade Networks: The presence of diverse imported goods at all three sites, along with the evidence of extensive hinterland connections, indicates a sophisticated and multi-faceted trade system. This finding challenges existing simplistic models of direct Indo-Roman trade, instead suggesting a complex web of intermediaries and regional exchanges.
2. Cultural Interactions: The spread of imported goods from coastal sites into the hinterland suggests a deeper penetration of foreign cultural influences than previously recognized. This calls for a reassessment of models depicting early historic Tamil society as predominantly rural and isolated.
3. Regional Variations: While sharing many commonalities, each port site displays distinct characteristics in artifact assemblages and hinterland connections. This variation suggests a degree of specialization or competition between ports, rather than a uniform engagement with Indian Ocean trade.
4. Methodological Implications: The integration of remote sensing and GIS techniques with traditional archaeological approaches has proven highly effective in contextualizing site-specific data within broader regional patterns. This highlights the potential of digital methods to deepen our understanding of complex historical phenomena.

Thus, this study emphasizes the value of employing advanced computational methods in conjunction with archaeological and textual approaches to gain a more comprehensive understanding of early historic trade networks. By situating Arikamedu, Alagankulam, and Pattanam within their environmental and cultural contexts, we can better appreciate the complex interplay between local agency and global connections that characterized this dynamic period in South Asian history.

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350. Digital archaeology as a tool of engaging the public with local heritage: a case study of the Hero-stones in Maharshtra,India.

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Introduction

Digital archaeology in today's age has advanced to the point where digitization is crucial in every step of archaeological research. Tools like photogrammetry and RTI allow the digital documentation of objects, field sites and even monuments. The results produced by these techniques are of high-quality and extremely beneficial for both archaeologists and the common public alike. The successful application of these technologies in the field of cultural heritage management, makes one wonder about its application in the local heritage sector which otherwise does not attract much formal attention. Involving the common public, who perhaps know more about the local heritage around them, is the best medium to apply these skills. Internationally, studies such as the ACCORD project (Jeffrey et al 2015, 289-95), INNOVA CUBA project (Tucci et al. 2018, 20-23) and the Karakorum Rescue Project (Van Aerde and Khan 2021, 77-90) have successfully integrated digital archaeology techniques and community archaeology to preserve local heritage sites. In India, archaeology is still heavily dominated by government agencies such as the Archaeological Survey of India followed by educational and heritage institutions leaving the common public out of its discourse. With archaeology being largely limited to academics and field professionals, digital archaeology tools can be applied to bridge this gap between the public and archaeology. The ease of learning cost effective digital techniques such as Photogrammetry, and their non-invasive nature in relation to archaeological sites and artefacts should be leveraged to engage public in archaeology and heritage.

Local heritage on the other hand, plays a big part in creating a sense of identity for the community around it. It also helps in understanding the broader history and culture of the region. However, local heritage sites are often neglected as they do not catch as much attention compared to mainstream heritage and historical places. This leads to the declining value and significance and often such sites undergo environmental damage or vandalism due to the lack of awareness about the site. The hero-stones (commemorative stones dating back to 2nd century CE) in India are one such example of local heritage being neglected from mainstream study.

This study investigates the potential of digital archaeology, combined with public participation, to engage local communities with their heritage. Focusing on hero-stones in Maharashtra, it explores whether involving residents in photogrammetric documentation can deepen their connection to these monuments, foster awareness, and promote preservation.

Methods and Materials

To achieve its goals, the study employed a community-based approach, selecting six participants from diverse educational and professional backgrounds. These participants were trained in multi-image-based photogrammetry, using accessible tools like smartphones and commercial software (Agisoft Metashape). The study's focus was three hero-stones: two from Atgaon village and one from Sudhagad Fort in Maharashtra, chosen for their accessibility and relatively intact condition.

The process was divided into four phases: participant selection, data collection, 3D model creation, and participant feedback. Training sessions emphasized the simplicity and cost-effectiveness of photogrammetry to empower participants with practical skills. Participants photographed the hero-stones over two days, ensuring comprehensive coverage with overlapping images to optimize 3D modelling. Data from these images was processed using photogrammetry software, resulting in detailed 3D models that were uploaded to Sketchfab, an online repository for public access. Finally, participants completed online questionnaires and engaged in discussions to evaluate their learning experience, awareness of hero-stones, and attitudes toward heritage preservation.

Results

The study demonstrated the feasibility and effectiveness of engaging local communities in digital archaeology. Participants successfully captured images of the hero-stones which were processed into 3D models, showcasing the practicality of using everyday devices like smartphones. The 3D models preserved intricate details of the hero-stones, including carvings of battles, worship rituals, and celestial imagery, emphasizing their historical and artistic value (fig. 1). These models are now accessible on Sketchfab, enabling researchers and the public to explore them virtually.

The training provided to the participants on photogrammetry (how to click pictures and create 3D models on Agisoft Metashape) aided the participants in feeling involved in the field of archaeology. Survey responses revealed an increased curiosity to learn about and explore other heritage sites in their vicinity. Participants recognized the potential of 3D documentation as a cost-effective and impactful tool for preserving neglected monuments. Several participants reported that the project inspired them to educate others in their community about the importance of heritage preservation, suggesting a ripple effect of awareness and engagement.

Additionally, the findings highlight the hero-stones' value as historical sources, providing insights into past societal conditions, religious practices, and ecological dynamics. For example, the Atgaon hero-stones depicted diverse battle scenes and religious rituals, while the Sudhagad stone featured simpler, cruder carvings, potentially representing an earlier stage in the tradition of hero-stone creation.

Discussion

The study underscores the transformative potential of digital and public archaeology in preserving and promoting local heritage. The involvement of participants demonstrated that digital tools like photogrammetry are not only accessible but also effective in fostering public engagement. The success of this small-scale study suggests a broader application: crowdsourcing photographs and involving communities across India could result in a centralized repository of 3D models, aiding both academic research and public appreciation of hero-stones.

Hero-stones, as rich repositories of cultural, historical, and ecological information, remain underexplored in Indian archaeology. This study emphasizes the urgency of documenting and virtually preserving these monuments, particularly given the challenges posed by environmental degradation, climate change, and urbanization. Virtual preservation offers a sustainable alternative to physical conservation while allowing global accessibility and scholarly collaboration.

However, the study also recognizes the limitations of digital methods. While 3D models provide realistic visualizations, they cannot replicate the tactile and emotional experience of encountering heritage artifacts in their physical context. Furthermore, virtual preservation must complement, not replace, physical conservation efforts. The study's small sample size and localized scope limit its generalizability, but it provides a compelling foundation for future research and larger-scale initiatives.

In conclusion, this study illustrates how digital archaeology can bridge the gap between communities and their heritage, fostering a sense of shared responsibility for preservation. The successful engagement of participants points to the potential of integrating public archaeology with digital tools to address the challenges facing India's vast and diverse heritage. Expanding such efforts nationwide could ensure the documentation, accessibility, and appreciation of countless local monuments, contributing to a more inclusive and participatory approach to cultural heritage management.

Final 3D Model of one of the hero-stones from Atgaon (fig.1)

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424. The Marea Numismatic Project and the HEURIST

Szymon Jellonek (University of Warsaw)*; Barbara Zając (National Museum in Krakow); Wojciech Ostrowski (Warsaw University of Technology; Jagiellonian University in Kraków)

Marea / Philoxenite is located along Lake Mareotis, about 50 km from Alexandria. It was one of the most important centres in the Byzantine period on the road leading from Alexandria to the sanctuary of Saint Menas at Abu Mina. The remains of a large pottery kiln have been identified under the apse of one of the largest basilicas in Egypt located in the northern part in this city. It was also a transhipment port. Previous research has identified particular structures in the centre, such as xenodochia, baths, latrines, tombs and churches. The city presumably functioned until the mid-8th to 9th century. Archaeological research in Marea / Philoxenite has been conducted since 2000 by the Polish Centre for Mediterranean Archaeology, University of Warsaw in cooperation with the Archaeological Museum in Krakow. For now, more than 9,000 coins have been recorded at the site. Among the finds are a late Roman minimi, coins from Ptolemaic and Roman periods, cast blanks and Byzantine coins, a small group of Arab-Byzantine coins struck after the Arab conquest of Egypt in 640, as well as Umayyad coins. A transparent and easy-to-use database was required to manage this amount of data.

After presenting our database plans at the 2023 CAA in Amsterdam, we were able to establish a functional database based on the Heurist network with an application of the Numismatic Description Schema (NUDS). Geodetic measurements and context information are also included in the database made for the Marea Numismatic Project so that they can be mapped. There are already over 9,000 records in the database, and another 1,000 are awaiting entry. The coin photos will then be linked to the database and uploaded to the University of Warsaw repository. Additionally, monograms and symbols like crosses, stars, or ligatures will be added to the typefaces, and RTI studies of individual coins will be included to the records. It is among the first numismatic databases created on-site during an excavation, giving numismatists the ability to influence the information they obtain from archaeologists. Comprehensive numismatic databases such as the Marea Numismatic Project, which can be integrated with excavation databases, will allow multifaceted analyses of the archaeological material recovered.

199. From Classroom into the Field: Training the Next Generation in Non-Destructive Archaeological Methods at the Colonia Ulpia Traiana (Xanten)

Nikola Babucic (University of Hamburg)*; Martina Seifert (Universtity of Hamburg)

This paper presents an educational model developed through annual field schools at the Archaeological Park of Xanten (Colonia Ulpia Traiana) organized by the Institute of Classical Archaeology at the University of Hamburg since 2013. The field school is limited to one week each year and divides into two parts: one theoretical in the seminar to learn about the archaeological site and the methods used, one practical in the field focused on application. The main goal is to equip young scholars with the skills needed to generate and interpret subsurface images using non-destructive methods in archaeology. Students engage with an array of widely used geophysical and survey methods—magnetic survey, ground-penetrating radar (GPR), electrical resistivity tomography (ERT), and geodesy (Total Station/DGPS). This hands-on training is complemented by thorough data documentation bridging ancient history and modern science in a dynamic and multidisciplinary learning environment.

Our presentation highlights how we integrate teaching and fieldwork, emphasizing the importance of a holistic approach that combines classroom preparation with practical application. This model not only enhances student understanding of geophysics and Roman archaeology but also fosters valuable skills for the preservation of archaeological heritage. We will discuss the standards developed in our field schools and explore the broader international and interdisciplinary context they contribute to. By sharing our experiences, we aim to encourage dialogue on field-based teaching methods and knowledge transfer, aligning with our belief that sustainable knowledge transfer is essential for establishing new global standards in archaeology and geophysics education.

467. Teaching Photogrammetry in the field: Insights from Jagiellonian University Excavations at Nea Paphos

Wojciech Ostrowski (Warsaw University of Technology)*; Łukasz Miszk (Jagiellonian University in Kraków)

Integrating digital documentation and analytical methods into archaeology curricula poses significant challenges in Poland, especially within field training contexts. In excavation fieldwork, teaching photogrammetry has become essential, demanding tailored approaches for documenting diverse artefacts and organizing on-site instruction. This paper discusses the implementation of photogrammetry training for Jagiellonian University students as part of the fieldwork program at Nea Paphos, Cyprus. Since 2016, these practical classes have supplemented on-site workshops for researchers, supporting the adoption of 3D models as a standard in excavation documentation.

Drawing on eight years of experience, this study presents an overview of the workshop program, modifications made over time, and student feedback, with particular attention to the logistical and pedagogical challenges of teaching abroad. Additionally, a critical evaluation of the field curriculum contrasts its strengths and limitations with classroom-based instruction at both Jagiellonian University and Warsaw University of Technology.

The basis of the paper will be a presentation of the programme of the workshop itself, the changes made to it and the students' perceptions from the perspective of the eight years of experience of conducting it, with a special focus on the specific conditions on site and also related to teaching abroad.

202. Interdisciplinary Summer School as Tool for Teaching Digital Archaeology

Pawel Lech (Polish Centre of Mediterranean Archaeology)*; Łukasz Miszk (Jagiellonian University in Kraków)

There is a growing agreement that how students are trained in digital archaeology must adapt to keep pace with modern demands. This paper focuses specifically on digital archaeology, a field where skills in data processing are as vital as those in handling field tools and instruments. We aim to demonstrate how we teach essential scientific foundations that underpin digital projects, particularly on Classical Archaeology. Teaching young scholars to reconstruct the past through digital methods—selecting optimal tools, gathering and analysing data, and preparing results for publication—is a dynamic, interdisciplinary task that connects ancient history with contemporary science education.

The ability to apply knowledge of digital archaeology in practice is particularly important. A particular challenge is learning how to conduct surveys and pre-process the results directly in the field. While teaching digital competencies in university buildings is relatively straightforward and takes place in most research centres, applying them in practice, in the field, is often more challenging. A good way to provide the right conditions for learning digital archaeology solutions in the field are summer schools where field research can be combined with the practical learning of new competencies.

This paper presents a structured approach to teaching geophysics, GIS, WebGIS, and photogrammetry, beginning with introductory concepts and culminating in a summer school program. Our insights come from experience gained through fieldwork education in Nea Paphos, the Hellenistic and Roman capital of Cyprus. We will not only showcase how we integrate individual teaching practices in field research but also highlight the significant educational impact of our methodology in both classroom and fieldwork settings.

By blending theoretical instruction with immersive field experiences, our comprehensive approach ensures that students master foundational digital techniques while developing practical experience. This fosters a deep appreciation for both Classical and Digital Archaeology. Finally, our model supports a multidisciplinary understanding of the past and equips students with skills essential for preserving archaeological heritage.

We will present our standards developed during the Summer Field School, along with the broader attributes of the international and interdisciplinary projects that contribute to these standards. As part of our integrated methodology, we will also introduce our GIS platforms and web-based geo-information systems, such as Arches. Through this paper, we hope to inspire a dialogue among scholars about field teaching methods and to encourage sharing of experiences. As suggested by the organizers of this panel, the sustainable transfer of knowledge is critical in establishing "new global standards.

88. Let's Understand Each Other: The Role of Visual Representation in Interdisciplinary Archaeological Research - the Case of Musti Terraces

Jakub Franczuk (Faculty of Architecture, Warsaw University of Technology)*; Julia Chyla (Faculty of Archaeology, University of Warsaw)

The project focuses on the potential of visual and graphic representations in enhancing the understanding of archaeological findings and reconstructing past landscapes and cityscapes. Specifically, it explores the Roman city of Mustis in Tunisia. Visual reconstructions are not only instrumental in presenting different interpretations of archaeological evidence, but they also serve as a tool to make these interpretations accessible to a broader audience beyond archaeology. By combining various methods, from excavation and surface survey to drone photography, GIS mapping, LiDAR scanning, and photogrammetry, we aim to present a coherent image of Mustis' ancient landscape informed by collaborative interdisciplinary research.

Our work at Mustis combines several advanced archaeological techniques to reconstruct the Roman cityscape. Excavations have provided a solid foundation of material evidence, while surface surveys and drone-based aerial imagery offer additional insights into the urban layout and surrounding landscape. GIS mapping and LiDAR scanning were employed to create a detailed spatial framework of the site, allowing us to understand its landscape in multiple dimensions. Photogrammetry has also been utilized to capture and model individual architectural elements and broader site features. Each of these methodologies contributes to a Virtual Tour, which allows viewers to explore the complexity of Mustis across different scales - from the city level down to individual buildings while understanding the reasoning behind each reconstructed element. The ability to visualize archaeological results plays a significant role in reducing misunderstandings and misinterpretations, both within the academic community and for the general public. Such transparency is crucial for engaging diverse audiences, from specialists to the general public, and allowing them to understand what is being presented and why specific choices were made in reconstructing the past.

Our research results in an immersive Virtual Tour that showcases Musti's multi-layered nature. This visualization emphasizes the terraced landscape and the intricate urban layout, highlighting how different methods and data sources come together to form a comprehensive view of the past. The Virtual Tour also includes an explanatory layer, revealing the thought process and arguments behind the presented reconstruction. This approach illustrates the outcomes of our research and engages the audience in the interpretative process that led to these results. This method of visualizing the interdisciplinary research process exemplifies a collaborative approach to reconstructing and understanding ancient cityscapes.

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409. A Co-Design Approach To The Visualization(S) Of Uncertainty In 3d Hypothetical Reconstructions: An Example From The Field Of Prehistoric Archaeology

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The notion of uncertainty is inherited to scientific research, from the initial phase of data acquisition to the processing, transformation and use of the research outcomes. In the field of hypothetical reconstruction there have been numerous proposals related to the visualisation of uncertainty -through gradient scales-, with the vast majority coming from the field of architecture. During the last years the number of uncertainty scale proposals coming from and applied to archaeological hypothetical reconstructions has been increased significantly, but some aspects remain vague. Especially in prehistoric case studies, the absence of written sources or even of preserved structures -since sometimes only their negative imprint is recovered- complicates the use or adaption of scales proposed for other, more recent periods.

In this presentation we will introduce a new proposal to approach conceptually the visualisation of uncertainty in hypothetical reconstructions in the field of prehistoric archaeology. In terms of theoretical perspective, our approach focuses on the visualisation of uncertainty in accordance with the different theoretical approaches currently present in the field of prehistoric archaeology. Our case study is the hypothetical reconstruction of a wooden hut from the Neolithic waterlogged settlement of la Draga (Banyoles, Spain), and a preliminary 3D reconstruction of the hut has already been modelled.

The visualisation of uncertainty in such cases can be used as a dynamic tool to see the unseen and to represent elements for which the type and/or amount of data and information in our disposal is limited. Moreover, it provides new opportunities to widen the focus from the reconstruction of independent structures aiming towards the reconstruction of the prehistoric milieus, including agents, objects, actions and interaction among them. This approach demonstrates a different perception of the archaeological record and entails a broader way to experience and present prehistoric hypothetical reconstructions.

Our proposal is based on a still ongoing co-design process consisting of different groups of specialists in the field of hypothetical reconstruction, visualisation and uncertainty. The objective is to obtain a first-hand approach and to understand how they define and, consequentially, how they would represent and visualise uncertainty, letting them elaborate their proposals using our case study as a starting point and formulating new ideas and suggestions working directly on our 3D model.

We will present, as described above, the idea behind the co-design approach for the visualisation of uncertainty, as well as the process followed during the co-design sessions. The different stages of the process can be briefly described as:

- Literature review. At first, a literature review was conducted to distinguish and systematise the different approaches that we would like to examine: from quantitative and measuring-oriented scales of uncertainty (e.g. applying fuzzy logic), to qualitative/descriptive ones, and from positivist to more phenomenological and reflexive approaches, including also experts from fields such as feminist archaeology and gender studies.

- Co-design & semi-structured interviews. When completed the literature review, semi-structured interviews followed with the corresponding experts in every case as we endeavoured to understand which elements would each group prioritise and how they could actually take the leap towards the visualisation of the prehistoric past depicting at the same time the reliability of the data and the uncertainty of the final proposed hypothetical reconstruction.
- Visitor's evaluation. Once the ongoing co-design process will be completed, the forthcoming step will focus on visualising the proposals and conducting evaluation sessions, in collaboration with the corresponding museum, to observe and analyse which option triggers and captions more the audience's interest and hence which is the most adequate and efficient way to visualise uncertainty in order to explain and disseminate information about the prehistoric past.

To sum up, our proposal turns towards a pluralistic, collective construction of meaning, reframing uncertainty as a transparent way to waive narratives. Our goal is to understand, test and evaluate how the different specialists would apply different approaches to visualise uncertainty, expanding their application to the reconstruction of the prehistoric milieus and its components -people, objects, and their actions and interaction-.

191. Rediscovering Landscapes: Digital Recontextualization of a Kootenai Brown Homestead

Madisen Hvidberg (University of Calgary)*; Peter Dawson (University of Calgary)

This paper discusses how through a combination of traditional historic research methods and innovative digital technologies, a historically significant cabin in an open-air museum in Western Canada was recontextualized into its “lost” original landscape. In this presentation, we will show how terrestrial laser scanning informed by archival research practices allowed for us to digitally recombine a heritage site and landscape, a novel application of digital archaeology in Canada that allows for better education and public understanding of the European settlement history in the Southwestern Canadian Rocky Mountains.

The historic cabin belonged to famous Canadian John George “Kootenai” Brown, known for being the first European to see and experience what is now Waterton Lakes National Park and for his subsequent work with environmental conservation in the area (Macdonald 1992; Rodney 2023). In his years at Waterton Lakes, Kootenai Brown lived in at least four homestead cabins (Macdonald 1992; Rodney 2023). All of these locations have been known historically, until 1977 when his second homestead was relocated off private land to the Kootenai Brown Pioneer Village museum in the nearby town of Pincher Creek (Kootenai Brown Pioneer Village 2023).

While the relocation of this heritage site ultimately led to better preservation of the cabin itself, the original landscape it was situated on became lost to memory. Even though relocation of heritage structures is a common method used for preservation, heritage guidelines recommend it should only be done when it is the last feasible option for a site (Heritage Victoria 2007; Gregory 2008:11). This has to do with affects that relocation has on the heritage integrity of the site as its physical location is part of its cultural significance (Heritage Victoria 2007; Gregory 2008:11). This is especially true for Kootenai Brown’s cabins as they were very intentionally situated on the beautiful mountain landscapes within Waterton Lakes that influenced Brown’s life so much and because the history of Waterton Lakes Park is inevitably tied to Brown’s work while he lived in the park.

The unfortunate disconnect between cabin and landscape lasted until 2016 when the original location was rediscovered by Parks Canada employee Edwin Knox through archival research and ground truth survey. In rediscovering this location, Knox found a small depression where the foundations of the cabin would have once been and identified seven culturally modified trees (CMTs) adjacent to the meadow (Knox, personal communications 2022). Each of these inscribed poplar trees has at least one set of initials and a date relating to Kootenai Brown’s occupation of the site (Getty and Ludlow 1972).

As these trees are reaching the end of their natural lifespan and because Waterton Lakes Canadian Rocky Mountain Parks have begun experiencing devastating seasonal wildfires (Clark-Wolf et al. 2023), the digital heritage research lab at the University of Calgary was contacted to digitally preserve the meadow and CMTs before they are inevitably lost to natural forces. In spring 2022, our research group documented the meadow and the CMTs with a GeoSLAM ZEB Horizon, the first documentation project we conducted with a mobile terrestrial laser scanner (TLS). This laser scanner allows for large areas to be documented very quickly and allowed for the entire landscape including cabin foundations and the CMTs to be digitally captured in only two 20-minute scan cycles.

After documenting the meadow site, our research group reached out to the Kootenai Brown Pioneering Museum where Kootenai Brown's cabin has been kept since its relocation. We did this with the intent of digitally capturing the cabin to create a point cloud dataset that could be combined with the point cloud dataset of the meadow landscape. Working with the museum, in summer of 2023 we digitally captured Kootenai Brown's cabin using a Z+F 5010X IMAGER, a high precision stationary TLS. The cabin was captured in 16 scans, taking about three hours in the field. The resulting point clouds for each documentation project were processed in the weeks following their documentation and hosted on our online heritage archive (https://alberta.preserve.ucalgary.ca/) as open access datasets along with background information and photo galleries for each site. Even at this stage, hosting the point clouds and historic information of each of these sites in the same online repository contributes to the recontextualization of this heritage site and better public education of Kootenai Brown's story associated with European settlement in this area of Canada. Yet the unique thing about digital data is that it allows for this recontextualization to go a step further. The ability to manipulate point cloud datasets informed a by combination of archival research and landscape study enabled us to digitally place the cabin back into its original landscape using the open-source program CloudCompare.

Our increasing ability to edit, manipulate, and represent data by different means opens the door for heritage engagement in new and exciting ways, such as this example of being able to virtually see Kootenai Brown's cabin on its original landscape for the first time since 1977. This novel application of reality capture technologies in Canada helps to mediate culturally significant impacts to cabin due to its relocation, provide better preservation of a historic landscape important to the settlement of Western that will inevitably be lost, and offer innovative solutions to tell a more complete story of Kootenai Brown and the history of Western Canada.

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15. All roads lead to... Deultum! Case study of the ancient road network in the area of the Roman colony of Deultum

Ivo Cholakov (National Archaeological Institute with Museum - Bulgarian Academy of Sciences); Angel Grigorov (Independent researcher)*; Plamena Dakasheva (National Archaeological Institute with Museum - Bulgarian Academy of Sciences)

The present study examines the road network in the immediate vicinity of Colonia Flavia Pacis Deultenisium – one of the two Roman colonies built in the province of Thrace in the 1st c. AD. Deultum was founded by emperor Vespasian for veterans of the Legio VIII Augusta and the ancient city has been studied since the 1980s, but until recently little was known about its surroundings. The research area is located in present-day Southeastern Bulgaria and has been studied for seven years (Cholakov in print). Field surveys were further supplemented by computer-generated models and this paper aims to present the results of the combined application of Cumulative Focal Mobility Network (Pažout 2017) and Central Point Network (Herzog 2013, 246–48) analysis on already registered archaeological sites. The analysis is also considered at a supra-regional level in an attempt to understand how the local population reached other major settlement centers. The aim of this method is to reveal new possible connections that could not otherwise be noticed with the conventional approach, as well as to gain insight into the communication potential of the region and the place of the sites in it. Hypothetical routes are further compared with available field data, thereby testing the reliability of computer-generated models in archaeology, which within the present study appear to successfully guide the focus of field surveys.

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10. Spatial Archaeometry Approaches to the Study of Roman Pottery from the Southern Levant

Marcio Teixeira-Bastos (University of São Paulo (USP))*

The advent of integrated visualization methods, including GIS systems, rendered videos, graphics, and fully interactive computer game engines, has significantly transformed the field of archaeology. Within this innovative framework, we seek to promote discussions surrounding Spatial Archaeometry—an interdisciplinary approach that applies scientific techniques to assess the properties of archaeological materials across various scales, from individual objects to sites and landscapes (Casana, 2014; Opitz, 2021). In this context, the spatial characteristics of these measurements play a crucial role in their analysis and interpretation. Spatial Archaeometry merges diverse theories and methodologies for data collection, analysis, and conservation, facilitating the investigation of thematic case studies (Dell'Unto.; Landeschi 2022; Klen et al., 2015). This research employs qualitative and quantitative thin-section petrographic analysis to explore clay lamps' raw material sources, production techniques, and distribution networks from 17 southern Levantine archaeological sites. A comprehensive analysis of 90 lamps has uncovered regional variations in clay procurement and manufacturing processes. Our findings aim to illustrate how Spatial Archaeometry can yield genuine new insights into past societies, thereby significantly enhancing our understanding of historical contexts. This case exemplifies our commitment to developing a robust interdisciplinary methodology for studying ancient pottery and archaeological sites. By integrating geoarchaeology, complex spatial datasets, and social anthropology, we not only account for data at the micro-level but also adopt a landscape-oriented anthropological perspective. This perspective emphasizes human adaptation to dynamic social, economic, religious, and environmental conditions, remarkably increasing settlement density, mobility, and the intricate interrelationships between social, religious, and ecological factors.

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31. Coins and Urbanization: Analyzing Roman Coins from Tel Dor using the Reflectance Transformation Imaging (RTI) technique

Vagner Porto (University of São Paulo)*

In general, coins are considered evidence of broader economic activities, zones of influence, and the political history of a region. They are rarely used to understand the urban growth of a specific location, but their find spots can provide valuable information about fiduciary activities at the individual context level, thus creating a richer understanding of urban development. The project Cultural Contacts in Judaea-Palaestina During the Roman Period aims to investigate how these numismatic evidences can contribute to a more detailed understanding of urbanization and spatial development of a site. This presentation focuses on the case study of Tel Dor during the Roman period, employing the technique of Reflectance Transformation Imaging (RTI) to analyze the coins from that era, along with mapping the find locations. The theme of the presentation is the initial phase of this endeavor: compiling a photographic catalog of Roman coins and applying RTI to identify them.

211. Research on Public Bathes in the Pyrenees Mountains Based on Space Syntax

Mei Yang (CAA)*; Zhiwei Ji (Hainan University)

The architectural spatial layout of Ancient Roman public baths is affected by many factors, previous architectural archaeology research always focused on the archaeology excavation results and history data analysis, which lacked rational and quantity architectural space analysis. Space syntax can afford a visualized data model and a more intuitive quantitative analysis study approach for the ancient Roman public bath space. Based on the architectural design theory and the space syntax research way, this paper compares the 4 ancient Roman bath architectural archaeology site spaces, which are converted into the data model. The JPC graph, space-integrated degree of statistical analysis, spatial connection value, and other indicators are derived. Through the demonstration of these models, the ancient Roman bathing space can be intuitively restored and visual field analysis can be carried out. This research provides a new perspective and idea for us to study the architectural space of the ancient Roman public more objectively.

393. The Hills are Alive: Combining 3D modelling with GIS to study watchtowers in Northern Jordan

Tia Sager (University of Helsinki)*; Marta Lorenzon (FI); Benjamín Cutillas Victoria (Universidad Complutense de Madrid)

Photogrammetry, 3D scanning, and 3D reconstructions have become important tools not only for the preservation of cultural heritage, but especially for the study of ancient architecture. Critical reconstructions, when combined with digital methodologies such as Geographic Information Systems (GIS), offer significant potential for uncovering spatial and functional relationships within historical landscapes. While prior studies have leveraged GIS to investigate defensive structures like watchtowers in ancient Jordan, these analyses predominantly focus on later historical periods (Kennedy 2013). This paper advances the field by exploring the combined application of 3D modelling and GIS to investigate the interaction between architectural remains and the landscape in northern Jordan during the Iron Age.

In Northern Jordan, the Late Bronze Age to Iron Age transition brought about significant changes to the material culture and architecture in the region. The proliferation of fortifications and fortified sites included so-called "watchtowers," solitary structures that dotted the landscape often found on hilltops usually along possible ancient roadways. While their function is still debated, these ancient structures have been extensively documented through surveys of the area (Glueck 1933; Mittmann 1970), but very few have been excavated. Their role in the landscape therefore remains poorly understood.

Using a multi-scalar methodology that combines photogrammetry, 3D modelling, and GIS, this paper will assess a possible watchtower (TYRAS 89) identified in northern Jordan during the Tell Ya'moun Regional Archaeological Survey (TYRAS) (Lorenzon et al. 2023) in 2022. Positioned on top of a hilltop at some distance from other settlements, TYRAS 89 raises critical questions about the function and role of such structures in northern Jordan, especially in relation to fortified settlements in the area such as Tell Ya'moun and Tell Al Assara. Utilizing high-resolution photogrammetric data captured in 2022, this paper evaluates the potential of 3D reconstructions in conjunction with GIS-based viewshed analyses to model sightlines and assess the strategic positioning of the watchtower within its surrounding terrain.

Relying on the MEGA-Jordan database, the study conducts an intervisibility analysis to explore visual connectivity between TYRAS 89, other surveyed watchtower sites, and the nearby tell sites such as Tell Ya'moun and Tell Al Assara (Paliou 2011; Rothenberg et al. 2024; Tang et al 2024; Zeng et al. 2020). By attempting to reconstruct the structure's estimated height and calculating its hypothetical viewsheds, the analysis investigates whether these structures could have maintained visual communication across the landscape, potentially forming a network of surveillance.

The goal of this paper is to reconsider the function of these enigmatic structures, challenging the way in which they have previously been assessed through survey and secondary sources. The findings contribute to a deeper understanding of the interplay between settlements and their surrounding environment in northern Jordan, addressing long-standing gaps in the study of ancient landscape organization and its implications for regional socio-political dynamics.

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338. Exploring the Cultural Landscapes of Xeros River Valley in Cyprus through a Manifold Approach

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Introduction

A manifold approach (Sarris 2013, 761-770) combining pedestrian archaeological surveying, geophysical techniques, and satellite/airborne remote sensing was conducted in the Xeros River valley (Kophinou region), located in the western part of the Larnaca district. The Xeros valley covers an area of approximately 2,400 hectares, and the archaeological survey by the Settled and Sacred Landscapes of Cyprus project (SeSaLaC) employed both field-by-field and sampling landscape methods (150-meter-wide strips at 150-meter intervals, surveyed intensively) to identify loci of concentrated sherds (Papantoniou and Vionis 2018).

The project focuses on examining the evolution of settled landscapes and sacred spaces from prehistory to early modern times. Geophysical prospection surveys aimed to investigate concealed architectural remains in targeted areas identified through surface material diagnostics. Meanwhile, satellite and aerial imagery were used to detect archaeological indicators, such as crop marks, that may be linked to past human activity.

Methods and materials

Ground-based prospection of the sites was conducted using ground-penetrating radar (GPR) and magnetometry in a systematic and complementary manner. The GPR utilized a Sensors & Software NOGGIN PLUS unit equipped with a 250 MHz antenna, achieving high-resolution scanning (5 cm intervals along parallel transects spaced 50 cm apart) of the areas of interest. Magnetic measurements were taken using a Bartington G601 fluxgate gradiometer with a 0.5/1.0 x 0.125 m sampling strategy. The geophysical data underwent a systematic processing pipeline, with specific steps tailored to the type of measurements (Sarris 2020, 376-407).

Four multispectral satellite images from WorldView-2 (WV-2), acquired on June 11, 2009, were utilized to create a mosaic of the broader region. These multispectral images, with a spatial resolution of 1.6 m, were rectified and pansharpened to 0.4 m using the Intensity–Hue–Saturation (IHS) algorithm. The resulting images were correlated with available Google Earth imagery and aerial photographs (dated 1963, 1993, and 2014) provided by the Department of Land and Surveyors (DLS) via their WMS service.

Geophysical, Aerial and Satellite Remote Sensing Results

The processing and photointerpretation of aerial and satellite imagery revealed several linear and circular cropmarks or soil marks. Some of these features were linked to looting activities, which were confirmed by aerial imagery from 1963. Other linear features were interpreted as remnants of earlier cultivation practices or construction activities. Additionally, the analysis successfully identified piles of stones, likely representing the remains of collapsed structures.

Geophysical data were integrated within a GIS environment, revealing several candidate anomalies based on the interpretation of maps generated through various processing procedures. The combined GPR and magnetic data effectively pinpointed specific subsurface targets and provided an approximate extent of the features.

At Kophinou – Agios Herakleios, the outline of a large building (16 x 4 m) running N-S, adjacent to the southwest corner of a basilica-style church, with at least 1–2 internal divisions, was identified. The structure appears to extend further north, though no substantial architecture surrounds it. The absence of intense magnetic signatures suggests that the structure is likely a stone construction without evidence of burning. In the same area, GPR measurements revealed a dense architectural complex extending across approximately 25 x 18 m (Fig. 1-Left).

At Alaminos Kambos, a series of anomalies was detected in an area showing soil traces on aerial imagery from the Cyprus Cadastral Department, likely indicating poorly preserved architectural remains, potentially destroyed by intensive agricultural activity. In another part of the region, a quadrupole anomaly (~14 x 21 m) with high magnetic gradient values suggests a "hot spot", probably associated with workshop activities or a large kiln (Fig. 1-Middle).

At Menogeia Limnes, the surface distribution of late antique overfired pottery and wasters indicated intensive workshop activity. This was further confirmed by both magnetic and GPR surveys. The magnetic survey revealed several intense "hot spots" (-113 to 122 nT/m), while the GPR survey identified numerous linear reflectors extending beyond the initial designated survey area. The magnetic values are consistent with those typically found in ceramic or metallurgical kilns. While the kiln itself is likely smaller, its thermal activity is propagated extensively in the magnetic data. Additionally, a large compound with multiple rooms, covering an area of approximately 30 x 30 m, was identified near the kiln, suggesting the presence of processing and storage structures at the site (Fig.1-Right).

Other areas, such as Astathkiotissa, were also surveyed using geophysical methods, confirming evidence of diachronic anthropogenic activity in the region.

Discussion

The manifold research approach in the Xeros River valley employed a bottom-up methodology. Ground Penetrating Radar (GPR) and magnetic prospection surveys revealed numerous potential archaeological targets in the areas identified during the Xeros valley archaeological survey. Some features distinctly indicate architectural remains, ranging from well-preserved to poorly preserved structures, while others point to anthropogenic activities that may not be directly linked to habitation.

Airborne and spaceborne sensors effectively identified traces of collapsed buildings, evidence of past illicit excavations, cultivation patterns, and other human activities, some of which appear to have occurred across various historical periods. All the above have illuminated the previously unknown cultural landscape of the region.

In 2024, the SeSaLaC team started a trial excavation at Kophinou – Agios Herakleios, to investigate the large structure (southwest of the Early Byzantine basilica-remains), as revealed through geophysical prospection. The team unearthed part of a narrow room adjacent to the west wall of the basilica, serving as its narthex, while a second structure in a N-S direction further south seems to have had a 'domestic' function (perhaps a small late medieval monastery?). A 3rd trench revealed a multi-period cemetery, in use continuously from the 5th-6th to the 16th century AD, testifying to the long period of human presence in the area, and the domestic, ritual and mortuary character of the site.

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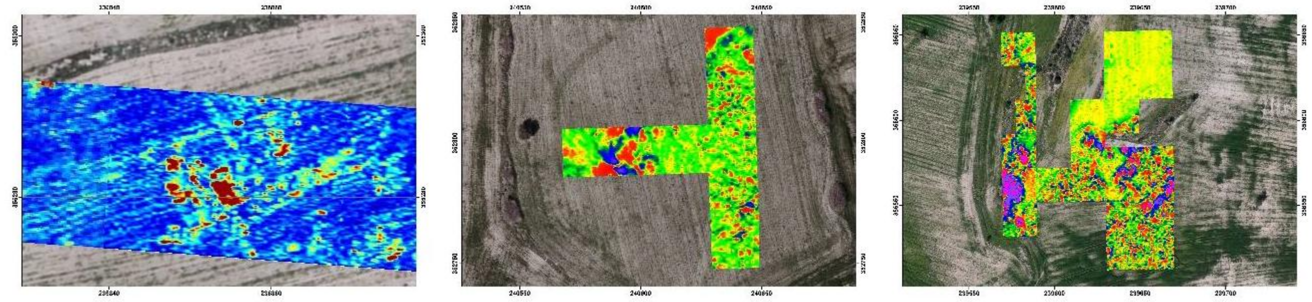

Figure 1. LEFT: GPR Depth slice of 70cm at Kophinou – Agios Herakleios, revealing a dense architectural complex. MIDDLE: Magnetic data at Alaminos Kambos highlighting several hot spots likely associated with kilns. RIGHT: Magnetic results at Menogeia Limnes indicating a large compound associated with workshop facilities and a kiln, closely correlated with the high density of metal slags found in the area.

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354. Towards the development of a quantitative spatial method for the study of the social organisation of the Igiliz archaeological site (Morocco, 11th-13th c.) : a case study on faunal remains.

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The mountain of Igiliz in the Moroccan Anti-Atlas is home to an archaeological site of major historical importance for the Almohad empire, which came to rule the medieval Islamic West (1147-1269). Located at an altitude of 1,300 metres in a remote, rural and semi-arid landscape, Igiliz has been under research since 2009 by the Moroccan-French archaeological programme, “La Montagne d'Igiliz et le pays des Arghen”. The combined study of the archaeological record and historical texts has progressively shed light on the fast-evolving functions taken on by the site during its major occupation period between the 11th and 13th centuries. Following a first poorly documented phase, in the years 1121-1124 Igiliz became a refuge for the religious revolutionary Ibn Tūmart and his Almohad followers (Van Staëvel et al. 2020, 123, 140). The site was then both a fortress and a military base, hosting devotional and eremitical practices as well as tribal gatherings. After the departure of the Almohad community, the site subsequently welcomed pilgrimage activities in the memory of Ibn Tūmart (Van Staëvel et al. 2020, 140). Igiliz was thus attached both to a tribal community with its organisation and practices, but also to the history of the Almohad movement associated with a rigorist Islam. The variety of the functions taken on by the site, which is telling of the dynamism of the occupation, raises questions about the social structure of its inhabitants (Van Staëvel et al. 2020, 140). While the texts, together with the architectural and artefact studies demonstrate the complexity of its organisation, analysis still needs to be taken further, in particular on the basis of archaeological data and a quantitative approach.

The research that is presented here therefore sets out to explore the means of archaeological knowledge and analysis of the social organisation of Igiliz. Positioned in the historiographic continuity of the spatial turn, geographical space is considered the material manifestation and the direct reflection of the social organisation of a society (Soja 1971, 13). Thus, the study of objects, their associations and their distribution in space could make it possible to distinguish functional and social divisions within archaeological sites, consequences of a division of society into social groups involved in distinct activities. In particular, foodstuffs and especially faunal remains (Clavel et al. 2021) are an interesting proxy for addressing functional and social organisations, as differentiation through diet is found more widely in the medieval Islamic world. Thus, food consumption practices are approached quantitatively, using a Geographic Information System (GIS) to carry out a spatial and statistical study on bioarchaeological remains and the associated ceramics. The aim is to contribute to a better understanding of the occupational, functional and social dynamic of the site through its successive phases, hence also questioning the way of representing time on a still medium.

If inter-site approaches generally tend to be favoured over intra-site studies, the general scarcity of spatial studies conducted for the Islamic West has to be noted. Although spatial (and quantitative) studies have become increasingly popular within the last few decades, they have not yet – aside from a few exceptions – made an entrance in the field of Islamic archaeology in Portugal, Spain, or Morocco. This is all the more relevant given that – unlike in historical archaeology – intra-site approaches are well established in the landscape of prehistoric archaeology, where they are used to detect patterns in the spatial distribution of artefacts, revealing functional organisations. However, excavation techniques and methodologies used for prehistoric and historical archaeology are distinct, apprehending space in a different way. From the outset, recording methods impose a change in the scale at which the data can be viewed. In historical archaeology, the choice is usually made not to record the exact geographic coordinates of the position of each artefact. The smallest spatial entity to which it is associated is the stratigraphic unit, therefore changing the geometry to a polygon instead of a point.

Through the subsequent manipulation of visualisation and treatment methods in QGIS, as well as complementary Correspondence Analysis, spatial patterns are analysed and interpreted. Concerning faunal remains, their distribution and association, i.e. of species and body parts is studied to identify specificities or similarities between the assemblages of excavation units or structures. In turn, these may be indicative of the function fulfilled by the space or room, and/or of dietary choices which could enable the grouping together of structures with common characteristics that could form part of the same functional and social whole. This approach is exemplified in the attached figure, which visualises the proportions of both Caprinae and Bos taurus taxa within the total assemblage of each excavation unit in the Igiliz archaeological site. The faunal remains represented on this map are not sorted by phase or context, yet already show a differential spatialisation of both taxa, the reason of which (dynamic time processes, functional differences or social differentiation) is investigated through the production of subsequent queries. The data processing and analysis therefore combines socio-topography and functional analysis of spaces while exploring existing GIS and statistical tools for developing a quantitative spatial method adapted to a new problem for the chrono-cultural area under study.

The paper will expose the theoretical process and issues encountered to build a quantitative and spatial approach for the study of an immaterial concept such as the social organisation of past societies; and present the first results stemming from the method, focusing in particular on faunal remains which are at the core of the study.

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30. Mediterranean research laboratories in Brazil: Labeca -MAE-USP

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Labeca, The Laboratory of Studies on the Ancient City, a thematic laboratory at the Museum of Archaeology and Ethnology at the University of São Paulo, has the primary objective of studying Greek social organization through the way the Greeks established their cities on the ground. Labeca gathers teachers, students, technicians and researchers who develop works on the ancient Greek cities as well as Punic and Indigenous ones, following several lines of complementary research, guided by the laboratory's major projects. One of our aims is to spread the knowledge produced in Labeca to a broad public, from academic experts to schoolteachers. For this purpose, we use a wide range of approaches, from video documentaries to scientific articles, made by the lab's staff. We have a diverse collection of materials on the ancient city, created by our researchers, including images, videos, maps, city plans, literary sources and bibliographical material. In 2024, eighteen years after its inception, we can say that Labeca has consolidated itself as a place for academic promotion, discussion and dissemination, but also as a channel

for the extroversion of the knowledge produced. This presentation aims to present results and ongoing research, focused on new technological application techniques, both for the dissemination of knowledge and for access to research by researchers from other parts of Brazil. One of LABECA's main tools is the application of new technologies (digital humanities) that work through images, whether two- or three-dimensional, passive or interactive. Research with collections proposes the application of non-invasive techniques for research with objects from the MAE-USP, as well as RTI, 3D technologies used to analyze data in three-dimensional environments as well as interactive examples that help the cognitive process of researchers, teachers and/or students.

67. Unveiling Urbanization in Ancient Udyana (Swat, Pakistan): A GIS-Based Archaeological Investigation

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The application of GIS techniques in archaeological research offers valuable insights into the dynamics of settlement and urbanization. This study explores the urbanization process in ancient Udyana (modern-day Swat, Khyber Pakhtunkhwa, Pakistan), a region with limited previous research.

Through field-intensive investigations, this research identifies major and minor habitations from the ancient period, analyzing factors influencing urbanization. The study area encompasses two distinct landscapes: valleys and hilly regions.

Key findings indicate:

1. Valley regions urbanized earlier than hilly regions.
2. Valley plains were preferred over hilly areas for settlement.

GIS analysis revealed spatial patterns and relationships between:

1. Environmental factors (topography, water resources)
2. Infrastructure (roads, trade routes)
3. Settlement distribution

This research contributes to understanding the urbanization process in ancient Udyana, shedding light on the historical and archaeological context of the region.

224. Showing true colours with LOIS. Towards an intuitive and standardised Level Of Interpretation System for 3D-visualisations in Dutch archaeology

Floris Jan Bruggink (University of Amsterdam)*; Loes Opgenhaffen (University of York)

These days, with ever-increasing graphical fidelity, astonishing visualisations can be produced of archaeological sites and heritage objects. As amazing as this technological advancement is, it does not come without risk. The public, viewing a photorealistic render of the past, may perceive it as a compelling truth: the photorealism giving the false impression of absolute certainty (Schäfer, 2018). Therefore, it is more paramount than ever to ensure proper documentation and visualisation of the underlying reconstruction process, especially in the Dutch archaeological field where no national standards are available. A well-known way to visualise this documentation is with the use of colour coded certainty indexes. This paper will introduce the Level Of Interpretation Systems (LOIS), based on such colour-indexes and developed for use in the Dutch digital archaeological field (Bruggink, 2024) and discusses its applicability through two case studies.

There are no requirements or guidelines available for (3D-) visualisations in Dutch archaeology. The Kwaliteitsnorm Nederlandse Archeologie (KNA), the national archaeological standard, is practically silent on this matter. Its latest version, 4.2 (2024), contains no more than a handful of outdated references to digital practice, even fewer of which related to (3D-) visualisations. This lack of a standardised workflow or method of documentation risks the black box-effect. Academic workflows, such as the ‘degrees of certainty’ developed by the 4D Research Lab (University of Amsterdam), are effective within their own sectors but were not adopted by development-led archaeology.

On an international level, the London Charter (2009) and the Principles of Seville (2011) are available. These non-compulsory, generic and by now largely outdated set of guidelines, have been adopted by few Dutch organisations and companies but were never integrated on a national level wholesale. These various and often disparate existing workflows and related certainty indexes are impeding interoperability on a national scale and implementation by other parties. The indexes differ greatly in their colour usage as well. A number of these indexes use counterintuitive colour schemes, often based on heat-map gradients, which require in-depth knowledge of the underlying system and principles before the colour coded visualisations can be fully understood. This complicates knowledge transfer to a non-specialist audience, as these may not understand the choice of colour.

The Level Of Interpretation System (LOIS) has been designed to overcome these shortcomings and multitude of systems. LOIS is a colour-coded certainty index with a total of five scales. The first four scales have sources available directly related to the modelled object. Scale five is applied when no direct evidence for an element is available, meaning that parallels must be used to establish its shape. The LOIS colour gradient is based on the traffic light-model (i.e. “red is bad, green is good”), except for scale five (Informed Estimation). This facilitates the separation of the last class from the rest of the gradient, which would be difficult to achieve with the aforementioned heatmap-based indexes. This provides an intuitive, perceptive model for the Dutch archaeological sector. Inspired by principle 4.4 (Documentation of Knowledge Claims) of the London Charter (LC), this last class has been given a glaring pink. The first four levels adhere to the “evidence based restoration“ section of LC principle 4.4, while the fifth level is based on “hypothetical reconstruction“. This is in contrast to other certainty indexes: generally, the lowest level of certainty is kept within the colour gradient or given a discrete colour, as if to draw away

the attention from the uncertainties. LOIS strives to uncover the lowest level of certainty, giving it a prominent position in the index. The most uncertain parts do not need to be disguised, as generally a great deal of research goes into these elements. With this use of an obtrusive colour, the ‘known’ is clearly separated from the ‘unknown’, safeguarding scientific transparency. The comprehensibility of the system allows not only exclusive use by specialists, but can be deployed to communicate the uncertainty of archaeological visualisations to the public as well. The use of a traffic-light based index in communication to the public was proven effective by the Virtual Interiors Project (Huurdeman & Piccoli, 2021). This use of intuitive colour systems allows the public to peek behind the academic curtain. In this manner, an initial sense of the overall (un)certainty is given, which is further supported by extensive underlying documentation which can be implemented into the model with the use of annotations. A prototype application, showcasing the basic required functionalities, was developed using Unreal Engine 5. Initial presentations to stakeholders, among which Dutch archaeologists and policymakers, were positively received (Bruggink 2024). The true effectiveness of the comprehension of LOIS by a non-specialist audience is subject to future research.
The practical implementation of LOIS will be demonstrated through two case studies: the first being an academic, non-photorealistic reconstruction of the late medieval and early 20th century phases of a townhouse in Deventer (NL), reconstructed as a test-case for the development of LOIS. The second case study is a (near-) photorealistic visualisation of the benedictine abbey at Rijnsburg (NL) in the 16th century, meant for public display in a museum. Both case studies employed the usage of image based modelling to obtain elements with a very low level of interpretation, which were used as a basis for the reconstructions. These cases, with very different objectives, show the versatility of LOIS.
To summarise, the Level Of Interpretation System provides an intuitive framework to tackle (un)certainties in archaeological 3D-visualisations. It presents a straightforward and transparent method to communicate the underlying reconstruction process, a pressing necessity given the fragmented state of workflows in the Dutch field. This communication is not limited to the academic sector: the choice of colour allows for comprehension by non-specialists as well. Could LOIS pave the way to a standardisation of documentation in the Dutch archaeological field?

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Level Of Interpretation System (LOIS)		
Colour	**Hex Code**	**Class**
	#009900	Very Low Level of Interpretation
	#00FF00	Low Level of Interpretation
	#FFF000	Moderate Level of Interpretation
	#FF0000	High Level of Interpretation
	#FF00FF	Very High Level of Interpretation (*Informed Estimation*)

Figure 1: The Level Of Interpretation System. Image credits: author.

110. The Minoan Central Asterousia as a Case of DEM-Aided GIS Study of Network Connectivity

Nasser Ayash (University of Heidelberg)*

Introduction

The region under investigation centres on the central Messara and central Asterousia in southern Crete, located around the slopes surrounding the Kophinas peak. Due to the historical trajectory of research and the sporadic nature of excavations regarding the Minoan period, this area has traditionally been studied as part of the periphery of Phaistos (Driessen 2022, 5–8). Thus, surveys in the region tend to focus on the western part of the Valley, with the notion that cultural elements emanated to central Messara from there. Similarly, on the mountain, until recently, only the coast of the western and western central Asterousia up to Trypiti was considered relevant. Recently, however, the central Asterousia harbours have become more known via the existence of new tholoi and harbour regions that extend the active Minoan coastline to this region.

GIS based approach

Therefore, a holistic approach was implemented, concentrating on the framework of heritage landscape, where topography itself forms a palimpsest of the ever-changing historical development and elucidates the local social trajectories of which the region is part. For this purpose, geological and paleoclimatic data were studied, as well as the implementation of DEM/GIS tools combined with walking.

Implementing GIS techniques provided an innovative means to shed light on this hitherto less explored region. These were analysed, not just as an annex or manual of the work but as embedding the methodological analysis into the archaeological question at hand.

Modelling movement in GIS: Implementation and Calibration

Movement was modelled on the levels of least cost paths, network connectivity and focal mobilitiy network, building on similar studies in the region (Déderix 2017). These analyses were subsequently evaluated by physically walking the paths proposed by the GIS, noting their usability as a tool as well as their limitations.

In the literature, these methods are not always employed to their full potential. There is, however, considerable scope for broader and more precise applications in archaeology, which require an intrinsic understanding of the functions themselves. Such an approach would enable a synthesis of results of various functions rather than a sole reliance on individual inputs. More than four functions were analysed, and methods of their critical approach and utilisation were proposed, also hoping to act as a model or example for similar investigations. The intrinsic characteristics of each function that can be understood from their graphs, cause variations in the results when applying a multitude of them. But this is exactly the most enriching element allowing the extraction of a useful understanding of the terrain under study, not despite their discrepancies but because of them. For example, the Ox-cart function will show more branching than the exponential, while some functions, such as the Tobler, are seen as more fit for slightly hilly valley areas, whereas Ox-cart and Bell-Lock yield more realistic paths in mountainous areas.

This analysis is particularly vital in regions such as Koumasa, Apesokari, and Rotasi, situated at the intersection of mountain and valley. A balanced approach to the dynamics suggested by the various functions is essential in these regions.

Enhancement of the models

One of the criticisms against GIS methods is the danger of strict reliance on quantitative results. So, a qualitative evaluation of them was pursued by physically traversing the paths, so to empirically test the algorithm results, before applying them to prehistoric scenarios. This showed the reliability of them but also indicated limitations, some of them linked to the DEM resolution or to intrinsic characteristics of the algorithm.

Furthermore, other GIS tools such as the viewshed and watershed can be seen in aiding the understanding the whole region, when seen as an enhancement of the in situ investigation. The combination of these methods, contribute for a holistic approach to certain archaeological datasets, such as the low intervisibility and statistical correlation with water sources for Early Minoan tholoi. Furthering this systematic approach can contribute to our understanding of the distribution of tholoi in the Messara in a holistic manner.

Discussion

The GIS analysis, especially the paths produced and walked, prove the existence of a certain network that illustrates the strategic roles of sites linking the Asterousia and the Messara - like Apesokari and Koumasa - in palatial periods, shedding light into their role as nodes and explaining the deviation of this region from their topographically peripheral role, albeit for only the minoan period, after which the regression to their role to which they is predestined to by topography were inescapable, adjusting to the developing social trajectories and explaining its subsequent decline. Simultaneously, a disentanglement from the traditional monosemantic correlation with Phaistos is strengthened, while aiding in a new partitioning of Asterousia.

Methodologically, this research acts as a case study that showcases the potential of GIS methods in archaeology, including an inquiry into their reliability, and proposing a methodology for usage, while defining their shortcomings and applicability, which can help gain acceptance in the archaeological community. Finally the usage of both QGIS and ArcGIS allows for discussions of usability and accessibility.

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536. Historical anthropic traces from abandoned and marginal contexts in Northern Apulia: detection and research for an integrated approach to the landscape.

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The proposal aims to examine the documentation of historical anthropic activities identified in currently abandoned or marginal landscapes; some examples in northern Puglia (southeastern Italy) are examined. This research is part of a project carried out on the historical landscapes of the Capitanata.

Non-systematic surveys were carried out in areas not currently affected by anthropization, above all in the Gargano promontory; mainly, these are forested sectors or slopes with widespread rocky outcrops. The surveys have documented a rather intense historical use of these areas, compared to the current abandonment, which can be generally classified between prehistory and the beginning of the last century. The traces are mainly referable to rural stone structures (locally defined as 'pagliai'), rupestrian spaces, structures for the collection and conservation of water, mills, infrastructures supporting agriculture (barnyards for the processing of agricultural products, presses for the production of oil and wine), and sheep farming (fences), activities relating to the stone production cycle (quarries and limekilns). Furthermore, disused terraces (even if they relate to small crops) and paths (the traces mainly concern artificial arrangements of the rock) must be added.

In part, the remote sensing analysis preceded the surveys; anomalies identified from aerial photos and lidar data were checked in the field. In other cases, preventive work was not very useful, both due to the intrinsic limitations of the tools (for example, aerial photos for wooded areas) and the absence or poor quality of the available LiDAR cartography (this sector is covered by surveys with 1 m of detail, unfortunately with large empty spaces).

Starting from some examples identified in these contexts, the proposal evaluate the effectiveness of the remote sensing tools. Generally, the punctual nature of this type of historical evidence sometimes limits the contribution of remote sensing; on the other hand, it allows for a very effective selection of areas to be investigated quantitatively.

For example, rock structures almost completely escape the available covers, but the presence of external elements helps to identify these sites. Problematic aspects also concern small structures such as limestone and small quarries; the available detail, the presence of vegetation, and the partial obliteration make recognition difficult. Furthermore, the most recent supports do not allow effective reasoning on the ancient phases of use of some evidence, such as for quarries; they document situations that have greatly expanded in recent decades, which is why it is useful to integrate the work with historical aerial photographs, where although the detail is less for the areas examined, the documented situation is much less compromised.

However, remote sensing data often allows for better recognition of evidence related to 'marginal' activities than even fieldwork. For example, the aerial photos capture open spaces or delimited sectors near the limestone, hypothetically attributable to fuel storage areas and exploited in the preparatory phase. Reading this type of data is sometimes more complicated in the field when cleaning or excavation is not possible. Furthermore, it is valuable for evidence extended over long stretches, such as rock canalizations connected to cisterns.

Finally, a comparison of the specific findings with existing coverage is interesting. Reference is made to documentation with UAVs and the creation of photogrammetric models. Furthermore, where possible, this type of documentation allows for a rapid survey of structures, also in this case useful for completing the data collection later. It is a non-negligible factor considering the difficult accessibility of many of these sites.

492. Origin and evolution of the "tratturi". Diachronic reconstruction of the archaeological landscape between Molise and Apulia

Angelo Cardone (Università degli Studi di Bari A. Moro)*; Alessia Brucato (UNIBA - CNR ISPC); Andrea Di Meo (University of Molise (UniMol)); Francesca Di Palma (Italian National Research Council, Institute of Heritage Science (CNR-ISPC))

Tratturi constitutes the most evident trace of the ancient and recent past of the transhumance system; we are referring not only to the economic and legislative sphere but also to the social one, to the invisible people, the shepherds who have traveled there. The term tratturo (from the verb trahĕre -to pull, drag-) indicates a wide track with a natural surface for the periodic movement of flocks, usually with long straight stretches; our work concerns the South Italy, where tratturi connected the Abruzzo Apennines to the Apulian Tavoliere. Here the phenomenon of transhumance and the related infrastructures have been officially regulated by the kingdom since the 15th century (establishment of the “Customs of Mena delle Pecore”: Russo 2015, Violante 2009), but the historical roots are much older. These paths have been active since at least Roman times, but they probably constituted routes used, at least on a local scale, in even older periods. Therefore, these tratturi represent an important union between ancient and modern viability, emerging as long-lasting road axes that have polarized the territory crossed; this is well exemplified by the Tratturo Castel di Sangro-Lucera, one of the main tratturi in central-southern Italy.

In this contribution, therefore, the objective is to start from the origin of the tratturi and follow their historical evolution to analyze their material structures and the landscape connected to them; the cut is diachronic and focuses on the stretches between Puglia and Molise. Studies on the tratturi network in this sector have a long tradition and are numerous, but often focus on historical aspects starting from cartographic and written documentation produced in the modern age. Although the reconstruction of the routes is already known, we have tried to document the emergencies and archaeological traces found along these pats. The first step was to consider data from historical cartography, studies, and databases of the cultural heritage of the area. Above all, remote sensing analysis has been applied to historical satellite images, aerial photos from the middle of the last century, and Lidar data. These tools allow for non-destructive study and two reasons make them very useful; many pieces of evidence have disappeared in recent decades, or often are found in areas that are now marginal and neglected between Puglia and Molise. This work thus allows us to begin reconstructing the material landscape connected to these tracks, in addition to the main structures already known. These roads 'attracted' productive activities linked to the resources of the territory and small settlements; furthermore, various detected potential sites or areas of exploitation are near the road routes. Their chronology and relationship with transhumance remain often undefined, but it is clear that the proximity to a major communication route supported the concentration of anthropic activities.

Furthermore, a balance sheet to evaluate the conservation of this landscape over the past decades is possible. Historical and cartographic data can be compared with the traces still visible from remote sensing around the middle/second half of the last century, to reason about the material state of the infrastructures. Recent transformations have had a strong impact on these traces, even if are quite different in the examined regions; except mountainous areas, in Puglia building and land reorganization activity has erased many traces, in Molise many parts of the tratturi remain in uncontaminated areas.

Finally, this study addresses a future perspective of fieldwork, to frame the relationship between tratturi and nearby evidence.

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235. Revealing the (un-) Known in Marginal landscapes. LiDAR applications in the Mountainous area of Monti Aurunci (Latium – Italy)

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The Monti Aurunci Regional Park, located in southern Lazio, Italy, is renowned for its geological and naturalistic features as well as its archaeological significance. This area hosts a wealth of archaeological sites covering from pre-Roman and Roman periods to the modern era, many of which remain largely unexplored. These sites are currently being investigated as part of the Monti Aurunci Project (MAP, https://www.archeologiadiffusa.org/2022/09/17/map/), an initiative led by the University for Foreigners of Siena (UNISTRASI). Among the notable sites in this region is the multi-layered and abandoned hillfort known as "Le Mura di Campello." However, dense forest cover significantly hinders the identification, interpretation, and mapping of archaeological remains in the area. Furthermore, the lack or low quality of existing datasets limits their usability for archaeological purposes. To address these challenges, a drone-based LiDAR survey was conducted in the winter of 2023, yielding high-resolution data that have proven invaluable for archaeological analysis. With an average point density of 142 points per square meter, the LiDAR data facilitated the identification of numerous archaeological features, enriching the understanding of the Monti Aurunci's cultural heritage. Over 100 previously undocumented features were mapped, including terracing systems, hillforts, dwellings, walls, and road system. The creation of high-resolution Digital Terrain Model (DTM) not only enhanced the comprehension of this complex archaeological context but also provided a solid foundation for meticulously planning future field campaigns. This study underscores the transformative potential of LiDAR technology in archaeological research, particularly in heavily forested environments. The results obtained have refined our understanding of the historical settlement dynamics in the Monti Aurunci area and opened the door to new methodological approaches. These findings are replicable across other Regional Park case studies, offering promising future research directions.

529. Desertic Landscape. Umm ar-Rasas (Amman, Jordan): Remote Sensing Analysis and geophysics surveys in the Byzantine-Umayyad village

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Umm ar-Rasas, the current governorate of Amman, is located approximately 30 km southeast of Madaba. It is an archaeological site renowned for its Byzantine mosaics characterising its churches that were excavated between the second half of the 1980s and the early 2000s (ie. Piccirillo and Alliata 1994).
Three settlement units are present in the site: the castrum dating back to the end of the third and beginning of the fourth centuries AD, the northern Byzantine-Umayyad village and the Stylite tower complex situated approximately 2 km to the north.
Since 2013, the site has functioned as an authentic interdisciplinary and inter-institutional open-air laboratory in the frame of the project "Innovative methods, research and training activities for the conser-vation and valorisation of Umm ar-Rasas" funded by the Italian Ministry of Foreign Affairs and International Cooperation (MAECI). Archaeologists, engineers, architects, physicists, geophysicists and restorers from diverse institutions and universities collaborate on research projects aimed at preserving and enhancing a World Heritage site.
Following the initial phase of research, which focused mostly on the churches of St. Stephen's complex (Gabrielli, Portarena, and Franceschinis 2017), a new investigative cycle commenced in 2021. In this frame, a top-down multi-methodological and multi-scale approach was implemented by gradually reaching more detailed levels of knowledge regarding the castrum, the ancient topography of the Byzantine-Umayyad settlement, and the reconstruction of the surrounding historical landscape. In 2021 and 2022, a small-scale analysis through remote sensing, including both historical and recent satellite image datasets, led to the identification of traces of the potential northern boundaries of the the Byzantine-Umayyad settlement. In order to validating or refuting this hypothesis, in 2023 precise ground surveys, further augmented by photogrammetric, laser scanning surveys and geophysical prospections, were carried out (Di Palma et al., 2023-2024, in press). In this work, the comparison of all results from the application of different methods is presented, obtaining an accurate and precise interpretation of the models developed from the acquired data. The global evaluation led to the convergence of several physical parameters that described the same situation demonstrating the validity of the adopted methodological approach in the study of archaeological sites and understudied contexts, such as those found in desert environments, particularly desert steppes, where vestiges of historical sites and landscapes are occasionally fossilised and barely discernible in the present day.

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280. Restoring Context: Aerial Imagery from Occupied Greece in the Archive of the German Archaeological Institute at Athens

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Apart from all devastating political and humanitarian consequences, the German occupation of Greece between 1941 and 1944 brought about unique circumstances which allowed a number of German organisations to conduct archaeological research in the occupied territory. One of the projects led by the German Archaeological Institute at Athens (Deutsches Archäologisches Institut (DAI), Abteilung Athen) in close cooperation with the Wehrmacht's "Kunstschutz" was to test the use of aerial photography in archaeological reconnaissance, especially for topographical and landscape studies. These images of sites and landscapes throughout central and southern Greece serve as a valuable source for what might today be called historical topography and survey archaeology [1]. In spite of the ongoing war, the German Airforce deployed a team equipped with modern cameras for reconnaissance flights which collected several thousand photographs. The cameras were operated by archaeologists on board to spot the targets.

A large number of the photographs have been preserved in the Archive of the German Archaeological Institute up to the present day as full-size prints of the 30 × 30 cm films, which may in fact be considered the native contemporary format for analysis and interpretation. This discussion will cover the most particular image group: series of orthophotographs and oblique views covering areas and individual sites selected specifically because of their archaeological relevance. Until major parts of the repository were digitised in 2007, visual scrutiny of the originals was the only research option, and it was obviously limited to recognizable tiles. During the last years, extensive conservation and restoration work has followed, and new scans give digital access to the complete, yet unpublished collection. A new application of a well-established computer-based approach aims to simplify modern research on this collection and will in future enable the international research community to benefit from the achievements in an open access format.

The digital imagery may now be thoroughly examined without any risk for the physical media, but beyond that it also offers opportunities for new methods of study and contextualisation. The extant documentation varies in detail, and often the areas depicted are only roughly indicated by present standards. Especially individual frames of the continuous strips of orthophotographs lack distinct objects that would allow for easy identification. Therefore it seemed desirable to stitch and geolocate the connected material in order to make the imagery available for general research purposes, e.g., field studies and comparison with other geographical datasets.

The images have varying characteristics, as some are single photographs and others are part of connected orthophoto series. Camera model and flight altitude also differ, leading to different ground sample distances that sometimes even change within a single flyover. No ground control targets were used, and surviving in-flight notes are typically limited to starting point, direction, altitude and airspeed information. The frame rate in connected sets was regulated by the operator, usually achieving sufficient, but not necessarily constant overlap for visual stereo comparison between adjacent frames.

In trials with photogrammetric software, a large amount of preprocessing proved necessary already for camera reconstruction and basic alignment, although stereo models could be derived from suitable image sets. These would, however, still lack geoinformation as the images do not contain known reference targets, and the method cannot be used on single shots at all.

In the end, a less complex approach based on the photographs as plain images was chosen. For photograph series, mosaics were composed using PanoTools with the Hugin frontend [2]. With the given source material, it was clearly advantageous that the primary focus of the software is on well-balanced visual rendering rather than on geometric reconstruction. While different target layout projections are available, it also provides several methods for exposure balancing and blending. In a second step, both image mosaics and single orthophotographs were georeferenced with GDAL tools through the relevant QGIS interface [3], using recognizable features on basemaps available for modern Greece as references.

Processing of the whole dataset brought to light some characteristic issues. Automatic generation of control points for image stitching sometimes required manual review and correction. A simple mask needed to be applied to exclude the instruments and registration marks superimposed on each photo. In contrast to the tests with photogrammetric software, film grain did not cause trouble, thus, the original photos could be processed without any preprocessing. For the final blending and exposure fusion of each mosaic, a careful selection of tool parameters needed to be found. Although challenging, it was possible to reconstruct the geolocation of all images. Apart from hints in the contemporary documentation this step required archaeological and topographic knowledge as well as some understanding of the massive changes that have taken place since the war with respect to single structures, the traffic network, built-up areas and even the configuration of agricultural areas.

A substantial part of this historic aerial photo archive has been successfully processed relying on a free and open source toolchain. The output images are currently being supplemented with metadata and uploaded to the institute's geoserver, where they shall be made publicly available. Preliminary examination suggests that the historical conditions preserved in the dataset will prove a valuable source for both specific archaeological sites and the study of larger areas throughout central and southern Greece.

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[2] Hugin and PanoTools: https://hugin.sourceforge.io; https://panotools.sourceforge.net

[3] QGIS and GDAL: https://qgis.org; https://gdal.org"

449. A Diachronic (Final Neolithic – Venetian) GIS Analysis of Settlement Patterns in the Agios Nicolaos Area of East Crete

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In this contribution we investigate the settlement patterns in the area of Agios Nicolaos, in east Crete, from the Neolithic (ca. 4,000 BCE) through to the end of the Venetian period (1669 CE).
The investigated area is situated between the western shores of the Mirabello Bay and foothills of the Dikti Mountain range. It stretches over many diverse ecozones spanning from costal plains to mountain slopes. This pronounced and diverse topography played a crucial role in shaping the regional settlement pattern over time, impacting local socio-economic, political, and ideological systems, as well as historical events. Additionally, the mountainous character of the region determined the communication routes. The region has been occupied continuously, from Final Neolithic until the present, with prominent local centers such as Priniatikos Pyrgos, Lato, Elous, and more recently the modern town of Agios Nicolaos.
The Mirabello area has been the subject of several extensive surveys that have corroborated settlement pattern changes related to major political events as well as long-lasting traditions of settlements in the hinterland of the island (Hayden 2003, Haggis 2005; 2012). Despite being an important region situated between Central and East Crete, the Agios Nicolaos area, on the western shores of the Mirabello, has not benefited from intensive surveys, as the southern and eastern areas have. This study aims to partially change this situation. Though high-resolution data, usually produced by intensive surveys, is not currently available, there are several publications of small-scale archaeological investigations for this area. These publications form the bulk of the data used for the presented study.
Operating with the view that there is a recursive relationship between landscape, socio-historical factors, and settlement situation, we seek to identify underlying patterns in the settlement structure of this area over a broad time-period. Relying on available environmental, archaeological, and historical data, the main goals of this presentation are to document changes in settlement patterns using GIS data systems and to provide an explanation for them.
GIS is long-proven to be a valuable tool in archaeological investigations, especially in terms of presenting and analysing spatial data. The use of GIS tools allows for a goal-oriented, spatio-temporal analysis, which can, in turn, aid in both the detection and understanding of these underlying settlement patterns. Through the use of GIS-based analyses we seek to investigate some of the characteristic features of prehistoric and historic settlement in the region, such as intervisibility, relation of the settlement to communication routes, access to arable land, and, for many sites, a defensible or prominent position in the landscape. Our analyses allow us to not only to track the local diachronic changes in settlement patterns, but also to compare them to the known patterns elsewhere.

443. Surveying the Under-world: Digital Applications for Recording the Archaeological Landscapes of Mediterranean Island Caves

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Introduction

Mediterranean islands, from the large massifs of Cyprus, Crete, Sardinia, Corsica, and Sicily to island Archipelagi, as the Cyclades in Greece, and small isolated islets, such as the islands and islets of the Adriatic Sea, are host to numerus natural caves. Even if a complete catalogue of caves is not available, from speleological datasets, there are almost 45,000 recorded caves in the islands to date. A significant majority of them have been entangled with human activities from prehistory to the present day and have played – and still playing – an active role for the islands' communities.

Archaeological research in these under-explored and underground landscapes, have flourished since the noughties, following an advancement in led lighting systems and speleological techniques who helped researchers to stay and work longer underground (see Trimmis 2018 for a review). Equally theoretical approaches of cave archaeology in Europe have further developed and now caves are understood as enclosed subterranean landscapes that offer certain affordances to people that they are interact with them.

This paper aims to be a follow up to earlier publications that explore paperless mapping methodologies and photogrammetric recordings in subterranean archaeological sites and how these could be incorporated in cave-oriented GIS applications. The scope is to present a multi-scalar surveying methodology for these marginal and underexplored aspects that dominate the Mediterranean landscapes, but there are also enclosed micro-landscapes themselves. Digital non-invasive methodologies have therefore been developed to recorded and conceptualised this diachronic relationship and to assist interpretations about the role of these subterranean landscapes play for the island socieities.

Methods and materials

The paper explores applications of paperless mapping methods specifically designed for cave surveying. These include both software and hardware applications, such as Topo Droid and Therion software, and BRIC, SPA, and DistoX devices for cave survey. Equally, the paper employs Mobile Device Based Lidar applications to enhance the 3D recording of the cave space and to also minimise time and error during survey. These software and hardware application have been tested in various cave archaeology projects, such as the excavations in Rača cave at the Adriatic Island of Lastovo, the Amorgos Cave Expeditions and the Kataphygadi Cave Excavations in Greece, and during the Balkan Cave Archaeology project. In all these projects, further to recording the cave landscapes, applications of detecting caves from satellite imagery and Lidar survey have also been explore.

Discussion

The applications presented in the paper and the final workflow for integrated archaeological survey in caves is ultimately a low-cost methodology that can be easily adapted and applied in cave sites beyond the Mediterranean. Equally the software applications presented here are easily adaptable and since they are open-source application they can easily be implemented in smaller projects, from small teams, that are running in tight budgets.

Ethical considerations are also addressed in the paper, especially regarding data ownership, access, and the potential misuse of digital replicas. The aper discuss how digital documentation serves the preservation and interpretation of cultural heritage without compromising the integrity of the sites.

Looking ahead, advancements in artificial intelligence (AI) and machine learning offer exciting possibilities for automating data analysis. AI can assist in identifying patterns, classifying artifacts, and predicting site locations, accelerating research while maintaining accuracy. Additionally, the development of lightweight and portable digital tools will make these technologies more accessible to field archaeologists.

Digital applications have revolutionized the way we survey, record, and understand, that study of Mediterranean caves, offering precise and non-invasive methods for documenting and analysing the subterranean archaeological landscapes. Advances in paperless mapping, GIS plugins that work in underground spaces, mobile device-based Lidar applications, and more versatile Remote Piloted Vehicles enable researchers to capture the complexity of caves and their interactions with human history and the environment.

524. Archaeological research in andisols area. Machine Learning for the Remote Sensing Data Analysis

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This study examines and analyses lesser-known environments in central and southern Italy that are characterised by the presence of andisols. This is achieved through the utilisation of multispectral satellite data, which has been processed with image intelligence software.
The term ‘Andisols' (or Andosols) is derived from the Japanese 'an do', which translates to 'black soil'. The formation of these soils is a consequence of volcanic eruptions, which produce a range of materials including volcanic ash, pumice, lapilli and lava. They exhibit a high capacity for retaining nutrients and water, which is conducive to soil fertility. These soils are most prevalent in areas with average rainfall and relatively cool temperatures. Andisols constitute approximately 1% of the Earth's surface and are most prevalent in Europe, the United States, Central and South America, New Zealand, the Pacific region, East Africa, and Italy (Shoji, Nanzyo and Dahlgren 1994). In Italy, the andisols are present in the regions of Tuscany, Lazio, Campania, Basilicata, Sicily, and Sardinia.
The objective of this contribution is to examine the most significant archaeological traces discovered in volcanic soils. In order to achieve this objective, a series of case studies are presented which analyse situations in Lazio, Campania and Sicily using multispectral data from current high-resolution satellite images.
The images were subjected to rigorous examination within the Envi and eCognition software environments. The objective of the present study is twofold: firstly, to provide a comparative analysis of the two software programs; and secondly, to illustrate the potential of eCognition software (Nussbaum and Menz 2008), which automates geographic data processing, for further investigation in the archaeological domain. The application of eCognition in the field of archaeology remains relatively unexplored (Kramer 2015).
The initial experiments will be elucidated in comprehensive detail and will encompass the computation of Vegetation, Water, and Soil Indices, in addition to the segmentation and classification (supervised and unsupervised) tecniques of eight-band satellite images.

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408. Exploring the Application of Deep Learning in Mapping Ancient Flint Mining Landscapes in Egypt

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The archaeological study of flint mining is a significant research topic in prehistoric archaeology. Various prospection methods have been employed to map the mining structures, such as GPR or geophysics. Most of the research, however, focused on the study of terrain characteristic to mining areas. Typically it can be analyzed only with high-resolution digital elevation models generated by LiDAR or rarely UAV photogrammetry, as many mining sites are usually covered with vegetation or trees. Egypt represents a very unique opportunity to study a well-preserved mining landscape. Current research suggests that typically flint mines were located on terraces within dry river valleys (wadis). Flint outcrops were exploited as early as the Palaeolithic (MSA), until at least the Pharaonic Late Period (Köhler, Hart, and Klauzner 2017). Even though a number of flint mines are known in Egypt, the topic is still understudied.

One of the largest and best studied flint mines in Egypt is in Wadi el-Sheikh, which functioned from the Palaeolithic times to the late Pharaonic times. In the mine area, it is noticeable that ancient workers used various techniques for extracting flint raw material. The following were distinguished by the researchers: shallow pits, trenches, deeper shafts or horizontal galleries (Köhler, Hart, and Klauzner 2017). Given that the mining area of Wadi el-Sheikh is located in marginal landscape and is not covered by vegetation, most of the mining features are well visible on the satellite imagery and can be used to develop a deep learning model to detect the individual shafts (Altaweel et al. 2024; Buławka et al. 2024).

This approach is based on the application of the YOLOv11 using HEXAGON spy satellite imagery. Several sets of HEXAGON images have been acquired and georeferenced. The mines were labeled using a VIA annotator. The dataset has been created using the ArchaeolDA package for creating augmented data, making sure of good practices in data curation and split.

The paper discusses the problematics of mining landscape studies using satellite imagery with deep learning, data augmentation and good practice. Methods applied in the project allow us to properly document and distinguish many features related to past mining activities, and analyze their distribution, types, and mining methods practiced in the past, which then allow us to detect similar ones used in other parts of the country.

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454. Semi-supervised Deep Learning Point Cloud Classification for UAV Lidar and Photogrammetry

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Introduction
The use of UAV platforms with lidar sensors for low-altitude, high-resolution topographic survey is becoming more common in archaeological prospection and feature recording. Advances in these tools and the release of more cost-effective sensors and drones is democratizing access to lidar data collection in archaeology. While traditional airborne laser scanning (ALS) required archaeologists to collaborate with specialists, these tools are now empowering archaeologists to collect and process these data themselves, offering new levels of control and the need to develop specialized skills.

When processing UAV lidar datasets to produce industry-standard raster datasets for analysis – including digital surface models (DSMs) and digital feature models (DFMs) – most users employ existing classification algorithms offered by standard software packages. However, these classification models were developed for higher altitude, lower resolution ALS and are not optimized for the higher resolution datasets offered by UAV lidar and photogrammetry. Existing algorithms are also unsuitable for Mediterranean vegetation profiles, which differ widely from the forested and jungled landscapes where ALS has been demonstrated to be most effective. Finally, these classification models were not designed to specifically target archaeological remains, which differ widely in scale and exposed architecture from traditional point cloud classification methods.

In the context of growing adoption of machine learning applications in archaeological research (Bickler 2021), this paper explores new advances in the use of deep learning for the development of semi-supervised classification models specifically targeted for Mediterranean landscapes and the documentation of archaeological features. We compare the results of classification models produced from semi-supervised deep learning models to a range of industry standard classification algorithms, exploring the strengths, weaknesses, and potential for advances in point cloud classification for archaeological enquiry. In so doing, we argue for the need to develop analytical tools designed specifically for the high resolution datasets produced by low-altitude UAV data collection in the context of archaeological feature documentation.

Methods and materials
Our primary case study leverages data collected from the Naxos Quarry Project (Levine et al., forthcoming), a diachronic survey of the landscapes within which Naxian marble was quarried in antiquity. Now largely agricultural land, these landscapes present a range of archaeological features and evidence for human activity from prehistory to the present. Within our study area, we selected a typical landscape that presents a range of early modern agricultural features like walls and terraces, diverse vegetation that ranges from olive groves to dense maquis, and a range of archaeological features including abandoned architectural blocks, sculpture, and quarry debitage.

We documented this study area with UAV lidar and photogrammetry at a range of altitudes, return settings, and resolutions, aiming to develop a robust dataset for methodological comparison. From these data, UAV lidar and drone point clouds were processed using a wide range of pre-trained classification models, highlighting the strengths and weaknesses of the most common methods for the processing and analysis of UAV point cloud datasets. Due to the scarcity of clearly labeled archaeological features in our study area, we explore the use of unsupervised and semi-supervised deep learning approaches. There is a rapid development of machine learning analysis and segmentation of close and medium range lidar-based point clouds, not least due to the advent of technologies for self-driving cars (Guo et al. 2020).

In the first iteration, unsupervised learning algorithms are used to identify potential features and anomalies on a high resolution dataset. This preliminary segmentation is manually evaluated through validation and repeated self-training, expanding the labeled dataset. The hybrid training data is finally employed in the training of a classifier.

Results

Based on the comparison of the results of the various classification models, we highlight the effectiveness of semi-supervised deep learning classification models for the detection of a range of anthropic features in the marble quarries and agricultural landscapes of Naxos. We then discuss the effectiveness of UAV lidar and photogrammetry in penetrating a range of Mediterranean vegetation types and the performance of deep learning classification models in particular. We conclude by discussing a range of archaeological features at different levels of visibility, preservation, and type. In doing so, we explore best practices at the intersection of drone data collection, analysis, and in-person archaeological survey for the systematic diachronic documentation of Mediterranean landscapes.

Discussion

This paper highlights the potential for point cloud classification models developed specifically for low altitude, high resolution UAV data in archaeological fieldwork. However, the benefits of these models are not limited to lidar data collection. We critically analyze the effectiveness of low-altitude UAV lidar in Mediterranean archaeological landscape documentation, comparing these results to the more established method of UAV photogrammetry in terms of price, time investment, and overall data quality. This highlights that the development of more advanced point cloud classification models will substantially increase the effectiveness of not only UAV lidar, but also low-cost more established tools like UAV photogrammetry in archaeological study. We conclude by extending the potential use cases of deep learning classification models for other uses in archaeological datasets like terrestrial laser scanning, traditional high-altitude ALS, and more.

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70. Making AI accessible to archaeologists: Developing a tool for automatic feature recognition from ALS

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Introduction

The need to use machine learning (ML) in archaeology is constantly increasing with the rapid development of image analysis techniques and the increasing availability of high-quality airborne laser scanning data (ALS, lidar). Improving the detection of archaeological sites by applying AI to remote sensing data is the most advanced and effective approach to uncovering potential new archaeological sites (Kadhim and Abed 2023). To address these challenges, we have developed the Automatic Detection of Archaeological Features (ADAF) tool, which uses convolutional neural networks (CNN) to detect archaeological features from ALS data. The tool is a product of international collaboration between the ZRC SAZU, the Discovery Programme, the Bias Variance Labs and Transport and Infrastructure Ireland (TII). Particular attention has been paid to the design of the user interface to create a user-friendly tool that we hope will lower the barrier to entry for AI in landscape archaeology. The software requires minimal interaction and no prior knowledge of deep learning techniques, which greatly improves accessibility for the archaeological community.

Methods and materials

The underlying ML models were trained using an extensive archive of ALS datasets in Ireland. The ML-ready data was created from the ALS datasets provided by TII, which were processed into various archaeological visualisations and sliced into ML-ready tiles. Together with the labelled mask of the known archaeology, each tile represents a so-called patch that can be fed directly into the ML model.

The data for the labelled masks is based on recorded monuments (according to the Sites and Monuments Record). The visible footprint of each monument was digitised by an archaeologist and assigned a confidence level. Three types of archaeological features were considered during the survey, namely enclosures, ringforts and barrows. The patches were divided geographically into a training, a validation and a test groups so that the distribution of samples was identical in all datasets. To find the optimal configurations for the software, we conducted a series of experiments with the prepared datasets on different ML architectures for both object detection and semantic segmentation.

After an extensive analysis with different visualisations on a number of state-of-the-art DNNs, we came up with two ML architectures that provided the trained ML models for the ADAF tool. The HRNet architecture was used for semantic segmentation and the FasterRCNN architecture was used for object recognition, both of which are available in the AiTLAS toolbox. The difference in accuracy when using different visualisations was less than 6%. However, we opted for the simple local relief model, which was not optimal in all tests, but was favoured due to the significantly lower computational cost.

The ADAF workflow can be divided into three main steps: Pre-processing, which involves calculating visualisations using the Relief Visualisation Toolbox (RVT) and creating ML-ready data; Inference, which uses the developed ML models to detect archaeological features; and Post-processing, which involves methods to improve detection rates and remove obvious false-positive detections. User interaction with ADAF is reduced to the essentials: The user must select the input raster file, the desired ML method and the post-processing parameters. The final result is in the form of a vector file containing the annotated polygons of the detected sites, which can be easily imported into any GIS software for further work.

Discussion

Based on the test runs with Irish data, the ML models in ADAF not only recognised the known sites, but also identified previously unknown sites in the same area. The model also provides more accurate location data for some of the previously recognised sites. The advantages of automatic detection are that the analysis is not influenced by expectations and experience, as can be the case with manual analysis, minimising the risk of overlooking a potential new site. While some monuments remain difficult to recognise, the model also retains false positives. This means that manual inspection is still required, but the time required for an equivalent, fully manual analysis is significantly reduced.

Many recent research projects have introduced ML workflows for the automatic detection of archaeological objects from ALS data, using various CNN architectures for object detection and semantic segmentation, e.g. Verschoof-van der Vaart and Landauer 2021 or Somrak, Džeroski and Kokalj 2020. The main challenge with these ML models is that they require in-depth knowledge of AI methods and programming skills to (re)use them, which makes them inaccessible to a large part of the archaeological community, especially outside of research and academia. The ADAF software has been developed with special attention to user accessibility. It provides not only a set of programming code and functions, but also a practical tool with a graphical user interface (GUI). This GUI is intuitive and requires no programming knowledge, which distinguishes it from many existing methods for analysing ALS data with CNNs in archaeology.

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540. Intelligent Surveys: The role of AI in the fieldwork of the Gallinazo del Norte Archaeological Research Project (PIAGN)

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Archaeological sites in areas with limited access to high-resolution near-earth and remote sensing (RS) data are difficult to study and monitor due to increasing frequency of extreme climate events and rapid changes in land-use practices. Such circumstances serve to dramatically transform archaeological sites in short timeframes and in some cases, render them unsuitable for traditional study. The Northern Gallinazo site of Huaca Letrada (ca. 300-600 CE) built at the base of the steep-sided mountain known as Tambo Real on the south bank of the La Leche Valley of north coast Peru is one such example. There, difficulties arising due to climate and land-use changes, are compounded by the need to study site components located in steep, rocky terrain, and the inability to access portions of the site found in the undeveloped rural landscape. To combat these challenges, our research aims to: (1) streamline implementation of AI-enhanced strategy for studying archaeological sites with limited access to high-quality satellite imagery or LiDAR data, (2) quantify site degradation/changes resulting from both environmental and human factors, and (3) understand complexity of settlement and activity patterns using advanced multi-dimensional spatial statistical analysis. To do so, we combine a novel range of deep learning architectures (e.g., DenseNet, SRCNN, CNN, Mask R-CNN and YOLO) for image and feature segmentation, prediction and object detection, computer vision techniques such as Hough Transform for linear feature detection (walls, roads, canals), and machine learning methods such as YOLO, a state-of-the-art Convolutional Neural Network (CNN), for supervised learning to detect and classify archaeological features such as walls, roads, and artifacts. The model is trained on a curated and annotated dataset consisting of high-quality labeled images (2D, 3D). To handle low-quality images, we first apply a Super-Resolution Convolutional Neural Network (SRCNN) to enhance the resolution of input images, improving their clarity and making them more suitable for precise object detection. This image enhancement step helps to recover fine details in the data, thus improving the accuracy of feature detection when the images are noisy or blurry. These techniques provide nondestructive, quantifiable, and self-corrective data for study, while our advancing RS/AI approach enables more precise feature detection and archaeological site monitoring in the study area which has grown increasingly unsuitable for traditional pedestrian survey over the past few years. Since our first RS/AI field season in 2022, during which we experimented with UAV and near-earth footage to train our model using 58 images and YOLOv.5, we have made significant progress. Although initially achieving a mAP value of only 19%, application of the technique demonstrated both the feasibility as well as the need to expand our customized dataset and the AI approach. In 2024 fieldwork, we augmented original RS surveys data using pocket-sized DJI UAV, terrestrial lidar scanner (TLS) and LiDAR-enabled smartphones, greatly expanding our dataset to maximize understanding of site organization and conservation. As a growing corpus of publications demonstrates, combined RS and AI techniques permit efficient data capture, enhancing our understanding of in situ archaeological phenomena with greater accuracy (see also Argyrou and Agapiou 2022; Vats and Mehta 2024). By comparison, our system innovates through real-time, on-board AI processing during drone flights, enabling immediate feature detection and adaptive survey strategies - a significant advance over traditional post-processing approaches. The multi-sensor integration framework combines UAV photogrammetry, TLS, and near-earth imagery through fusion pipeline, creating a more comprehensive 2-,3- and 4-dimensional dataset that

leverages the unique strengths of each technology. In this paper, we present our approach for semi-automated survey and change detection, which has evolved from initial YOLOv.5 implementation to a multi-sensor system that achieved significantly higher recall (69% across all feature types) when trained on an expanded dataset of 362 images. This improvement was achieved through analysis of higher-quality 2- and 3-D imagery, though increasing the number of images used for annotation and training remain areas for future development. This system demonstrates the growing potential for AI-enhanced archaeological survey to not only document but actively protect heritage sites through real-time monitoring and adaptive response strategies. For example, instead of manually searching through vast landscapes, we can now use AI to guide the drone to specific targets, making it easier and faster to gather valuable information and disseminate it, with significantly improved results in feature detection (e.g., rock-wall at 45% recall and adobe-wall at 42% recall). This capability has proven especially valuable at the difficult to access Northern Gallinazo site of Huaca Letrada, where illegal land trafficking and extreme climate events make applying traditional survey methods very difficult. Although developed for stressed environments of northern Peru, our framework provides a scalable model for archaeological site investigation and preservation in other areas facing similar challenges of accessibility and conservation.

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138. A Preliminary Study of the Morphology and Spatial Distribution of Funerary Elements in the West and Southwestern cemetery of Wadi al-Ma'awel, Oman

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"In the Omani archaeological context the “Land of Magan”, defined as such by Sumerian sources, was identified and subsequently studied by several Italian and International archaeological missions. Within this context the Sapienza Archaeological Mission in the Arabian Peninsula and Gulf has developed a research to understand the transitional morphologies of the funerary contexts dated back to the Bronze Age and Iron Age.
In this perspective, the article “A Preliminary Study of the Morphology and Spatial Distribution of Funerary Elements in the West and Southwestern cemetery of Wadi al-Ma'awel, Oman,” presents an in-depth spatial archaeological exploration of a diversified funerary context mostly dated to Wadi suq and Iron Age periods. This study examines the funerary morphology and their spatial organization within a broader context of socio-economic changes.
The southeastern cemetery in Wadi al-Ma'awel, in the Omani Al-Batinah South Governorate, provides valuable insight into the funerary practices of ancient societies from the Early Bronze Age through the Iron Age. The site is uniquely positioned between coastal areas and the Al Jabal Al Akhdar mountain formations, which makes it a critical region for studying the spatial dynamics interaction between the nomads of the sea and the pastoral nomads and their different adaptation.
Archaeological Context: Funerary Morphology
The study focuses on understanding the evolution of funerary structures in Wadi al-Ma'awel, examining how these graves reflect broader social and cultural shifts. The Southeastern cemetery contains funerary context from various chronological phases dated back to the passage between the Bronze Age and Iron Age. The authors classify the graves into two distinct morphologies.

Wadi Suq Period Tombs: Dated circa 2000-1300 BCE, it marks the transitional phase between the Bronze Age and the Iron Age in southeastern Arabia. These above-ground structures, consisting of concentric stone wall tombs from this period, are less monumental than the Umm an-Nar structures, reflecting a shift towards simpler and more practical burial practices.
Early Iron Age Tombs: While there is usually quite a significant gap in the documentation and information between the end of the Wadi Suq period and the Late Iron Age tombs, in the Sultanate of Oman. Evidence is present to attest to the reuse of earlier periods such as the Umm an-Nar tombs in the Early Iron Age, as it was evidenced from the Excavation in Bat by Stephanie Döpper. Other instances present the possible identification of a discrete category of the so-called ‘hut tombs’ in central Oman identified by Deadman and backed up by the excavations of Paul Yule. These two instances where it can be attested the Early Iron Age burials do not bring forward a clear morphology of these tombs. Therefore, it places the context of the southwestern cemetery in Wadi al-Ma'awel as an ideal case study to determine if there is a clearer morphology of the funerary context dated to these time period.

Methodology
The research methodology integrates a combination of fieldwork, remote sensing, and Geographic Information Systems (GIS) analysis to study the spatial distribution of funerary elements across the Wadi al-Ma'awel landscape. The authors conducted territorial surveys to identify and record anomalies in the landscape using the QField system. These anomalies, which

include funerary structures, were then analyzed within a QGIS project, allowing the researchers to categorize and classify the features based on their geometry and chronology.
The study focuses on one key topographic unit (TU2), corresponding to the Southeastern cemetery, with the possibility of expanding to another topographic unit (TU3). In the Southeastern cemetery,160 funerary features were recorded, including round, rectangular, and ovoid burials. To further investigate the spatial tendencies of the funerary contexts, the authors employed the Standard Deviation Ellipse (SDE) method, a statistical tool used in GIS to measure the general orientation and clustering of features within a defined area. The SDE method allows the researchers to visualize the directional tendencies of tombs and their relationship to physical features in the landscape, such as proximity to mountains, coastlines, or other topographical markers. The use of SDE in this study provides valuable insights into how ancient societies in Wadi al-Ma'awel organized their burial spaces and how these spaces were influenced by the surrounding landscape.
The methodology to follow seeks to explore the distribution of this context from a statistical point of view and machine learning perspective, to this end after taking field measurements of each of these funerary contexts these numbers will be elaborated with an R script for statistical purposes to identify the clusters and the correlations between these features in terms of measurements.

The methodology to follow seeks to explore the distribution of this context from a statistical point of view and a computational perspective, to this end after taking field measurements of each of these funerary contexts these numbers will be elaborated with an R script for statistical purposes to identify the clusters and the correlations between these features in terms of measurements. Following the development of this R script, the successive steps will see the application of a Random Forest algorithm to perform a supervised classification of the features present in the landscape. Given the fact that this algorithm works by creating individual decision trees and then performing a majority voting for each classification, this algorithm will be applied in this project as a way to understand the most important feature in the decision making process of building a tomb, whether it was the location, shape or the dimensions, to uncover the underlying patterns that could have been in place during the selection of the area in which this cemetery was built in ancient times. This becomes essential in the development of this paper because the identification of the most relevant feature can help understand further the morphology of these tombs and determine the most relevant element that influenced the morphology of these funerary elements.
Furthermore, by applying this sort of machine learning algorithm, previously non-visible patterns can be uncovered and in doing so help understand and predict other possible locations where cemeteries with similar characteristics can be identified, helping in the reconstruction of the funerary landscape of the region. In doing so, furthering the understanding of the spatial distribution of said elements and interaction of the societies that built them with their surrounding environment. This algorithm paired with the geometry identification algorithm will help determine more specific spatial tendencies in the southeastern cemetery and identify characteristics that are predominant in these funerary contexts. The result of these as mentioned before, will be the possible prediction of other cemeteries in the area of study and the identification of underlying patterns in the funerary architecture that could shed light into the particular funerary practices of these societies and the ties that these elements and practices had with the surrounding landscape.

Results and Conclusion

The use of GIS, SDE method, Statistical and Machine Learning approach highlights the importance of landscape archaeology in understanding the relationship between ancient societies and their environment. By analyzing the spatial distribution of tombs, the study provides valuable insights into how burial practices evolved over time and how these practices were shaped by broader socio-economic changes. The authors suggest that further studies should focus on integrating more advanced computational models to deepen our understanding of the complex interactions between humans, landscapes, and funerary traditions.

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511. Integrating satellite machine learning, UAV photogrammetry, and pedestrian survey for multi-scale feature detection in the Argentine Andes

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Introduction

The Cusi Cusi micro-region in the Puna of Jujuy, Northwest Argentina, presents a rugged Andean landscape at elevations of 3800 to 4200 metres above sea level. Here, human activity has left a diverse archaeological imprint, and features such as livestock enclosures, habitational structures, retaining walls, burial mounds, and agricultural terraces bear witness to long-term human occupation (Gerola 2022; Vaquer et al. 2023). Situated within the resource-rich “Lithium Triangle,” this area faces increasing pressures from extractive industries, amplified by recent political reforms that complicate indigenous land rights and environmental stability. These challenges highlight the need for comprehensive documentation of both archaeological heritage and contemporary land-use dynamics.

This paper presents the preliminary results of a multi-scale approach combining satellite data, UAV imagery, and pedestrian survey. The primary objective is to identify features indicative of indigenous land-use systems and agropastoral activities, providing insights into past and present landscapes. By integrating remote sensing and machine learning (ML) with traditional archaeological field methods, this research aims to overcome the characteristic challenges of this complex area.

Methods

Recent satellite imagery served as the basis for machine learning analyses to detect key anthropogenic features across the region. The ML algorithm was trained on manually identified features such as livestock enclosures and agricultural field boundaries, as these are easily discernible in the satellite images. UAV flights were carried out in selected areas to capture high-resolution imagery, which was used to produce georeferenced orthophotographs, 3D models, and Digital Elevation Models through photogrammetry. These then provided a critical basis for validating the satellite feature detection results. Ground-truthing by pedestrian field survey was conducted to verify features identified through remote sensing and to document additional archaeological and contemporary elements. The results were integrated into a comprehensive dataset to provide a nuanced understanding of the landscape.

Results

The machine learning procedure identified more than 700 features across the study area, including livestock enclosures, agricultural fields, and terraces. Training limitations were acknowledged, as the algorithm's feature detection was influenced by the input data. The collected UAV data consisted of over 13000 images, and the resulting orthophotographs provided a current dataset that revealed details that were undetectable in the satellite imagery. Numerous identified features exhibited signs of reuse and modification. For example, agricultural walls and livestock enclosures showed contemporary enlargements of smaller structures into larger units, as revealed in UAV imagery. This provided tangible, up-to-date evidence of ongoing human activity across remote areas, while the pedestrian survey provided local validations of the dataset.

Discussion

The combination of satellite ML, UAV-based photogrammetry, and pedestrian survey proved highly effective for the analysis of this high-altitude Andean landscape. Although ML made large-scale feature identification possible, chronological dating remained challenging, and identified features were not always clear at the satellite resolution. The combined use of UAV imagery and pedestrian survey bridged the gap between large-scale remote sensing and on-the-ground observations, enhancing the interpretative depth of the dataset. The complementary methodologies underscore their potential not only for feature detection but also for capturing active modifications and ongoing human activity that traditional approaches may overlook. The research validated long-term and ongoing indigenous presence, including agricultural and pastoral practices. The combined methodologies provide a solid framework for future large-scale studies focused on anthropogenic landscapes, while highlighting the importance of integrating methods to achieve a comprehensive understanding of these areas.

Conclusions

The multi-scale approach effectively documented landscape features and human activities in the Cusi Cusi micro-region. Satellite-based ML enabled efficient analysis across a large area, while UAV data and pedestrian surveys provided high-resolution and contemporary validation. Together, these methods revealed long-term, dispersed occupation and diverse land use practices, confirming previous ethnographic and archaeological studies and providing a more complete picture of the landscape's historical and contemporary use. These preliminary findings affirm the importance of ground-truthing to complement remote sensing, as certain features can be overlooked in satellite and UAV data, and chronological data is often lacking. This research not only advances documentation strategies in the Cusi Cusi micro-region but also offers scalable workflows for addressing similar challenges in remote, high-altitude areas, highlighting the potential of these methods for documenting and interpreting threatened landscapes in the context of rapid environmental and socio-political change.

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225. MAPHSA: Uncovering Pre-Columbian Landscapes through Machine Learning and Remote Sensing in Tropical South America

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The Mapping Archaeological Pre-Columbian Heritage in South America (MAPHSA) project provides a unique opportunity to integrate transregional datasets of pre-Columbian archaeological heritage and apply machine learning and remote sensing to test models regarding the relationships between tropical vegetation and past human activities. This paper presents two case studies from Colombia and Brazil that aim to identify archaeological sites using advanced image detection and multi-spectral satellite imagery. These methods have proven useful elsewhere (Orengo et al. 2020).

The Colombian case study focuses on detecting palm trees and assessing their relationship with archaeological contexts using deep learning techniques and high-resolution Pléiades Neo satellite imagery. Certain palm species may signal the presence of underlying heritage sites in Colombia’s mountainous tropical forests (Oyuela-Caycedo 2008). Based on previous research, three primary methods were used for automatic detection of palm trees using remote sensing imagery: classical image processing, traditional machine learning, and deep learning. Classical image processing techniques include designing algorithms for tree detection and delineation to identify the crowns of palm trees in high-resolution digital images. This method relied on the use of local maximum filters and analysis of local transects extending from the tops of palm trees. The classical image processing methods for palm tree detection are seriously challenged in areas with dense canopies, where overlapping objects and complex backgrounds hinder accurate detection. Traditional machine learning methods require hand-crafted features, which are then used to train a model for palm tree detection. A key limitation of these methods is their reliance on hand-crafted features, which must be redefined for new datasets. As new data requires new hand-crafted features, traditional machine learning approaches can be both costly and labor-intensive. Over the past years, deep learning methods have demonstrated outstanding performance across a range of computer vision tasks, including remote sensing applications, due to their ability to learn highly complex patterns. These methods can automatically extract high-level features from high-dimensional data in an end-to-end, expert-free manner. Building on the success of deep learning, various approaches have been developed to apply it to the autonomous identification of individual trees, including R-CNN, Fast R-CNN, Faster R-CNN, and YOLO (Prasvita, Arymurthy, and Chahyati 2023).

In this study, we applied a deep learning-based object detection model to high-resolution satellite images to automatically identify Dictyocaryum lamarckianum (Mart.) H. Wendl trees. The model was trained on annotated datasets, detecting individual and clustered palm trees across an area of ~200 km^2. Identified clusters were compared with known archaeological sites, and potential new areas with pre-Columbian human activity were identified. These new areas will be verified through ground-truthing in subsequent stages. This approach resulted in an open-access geospatial database of palm tree distribution, highlighting regions of archaeological interest, along with an optimized deep learning model for detecting vegetation indicative of human activity, which could be adapted to other regions and vegetation types.

In the Brazilian case study, we implemented a multisensor, multitemporal machine-learning approach to remotely detect archaeological sites in the Brazilian Amazon, in areas still under forest cover. The model was trained using georeferenced polygons of known archaeological sites (mostly anthropogenic dark earth sites). A classifier algorithm was applied to multispectral imagery, successfully identifying vegetation signatures associated with new potential archaeological sites across approximately 300 km^2. The findings demonstrate the feasibility of satellite imagery for automatically detecting archaeological sites in the lowland neotropics even in areas that are still covered by tropical forests.
MAPHSA's multidisciplinary approach not only models transregional data integration and enhances heritage data accessibility but also has the potential to uncover previously unknown settlements in the neotropics, providing new insights into historical interactions between human populations and vegetation. Ultimately, this interdisciplinary work aims to deepen our understanding of past interactions between human societies and the natural environment in the lowland tropics.

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217. "Hey SAM, draw a map of Roman Britain in the 3rd century" – Will "Foundation Models" reinvent automatic archaeological object detection?

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Archaeologists eagerly adopted Deep Learning (DL) techniques for finding unknown sites in remote sensing data such as aerial imagery or LiDAR. But often large quantities of training data samples are required for fine-tuning DL models for archaeological purposes. However, this data is often just unavailable or difficult to obtain, especially for rare site types. Moreover, the DL training process is complicated and often requires extensive computer skills to obtain ideal results.

Recently so-called "Foundation Models" have gained much attention as they show spectacular results without any fine-tuning and or extensive computer skills. Probably the most famous variant is ChatGPT (www.openai.com) which takes text "prompts" as input and can generate surprisingly meaningful text sequences as response. But the underlying technology is not limited to text, but recent publications have shown its applicability to images or even videos, and especially to remote sensing imagery.

This research examines the applicability of models such as SAM (Facebook Research), YOLOworld (Ultralytics), and GroundingDINO (IDEA Research) to archaeological remote sensing data. For example, users would provide a drone (UAV) video of an excavation site to the model and, with zero further steps (so-called "zero-shot learning"), get an annotated video as response where objects on the ground are automatically marked according to their type, e.g. mural remains. Or, by clicking on just a few examples of objects of interest in the video such as potsherds ("few-shot learning") or providing textual input such as "broken pottery on the ground" the model would re-focus on that type and mark all potsherds found in the video – at least in theory.

We conducted a series of experiments to show to what extent this new technique can qualitatively match or supersede previous DL approaches. Data examples are drawn from some of the author's earlier projects, including hillfort detection in LiDAR in various European regions, Khmer-era temple reservoirs from the Angkor Wat region in Cambodia in satellite images, and drone videos from the Mediterranean.

Preliminary results show that, if certain methods for input data preparation are applied, foundation methods can greatly simplify the use of DL.

55. Exploring Cropmarks: Leveraging Spectral Physically-based Reflectance Models for Enhanced Archaeological Detection

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Introduction

The detection of buried archaeological remains through optical remote sensing imagery has become a widely adopted technique. Researchers have examined the use of satellite, airborne, and low-altitude platforms, which capture the spectral responses of vegetation growing over shallowly buried archaeological sites [1-2]. Findings indicate that such approaches are effective for mapping and detecting archaeological proxies (cropmarks) across extensive areas. However, limitations persist, largely due to phenological variations in crop growth and specific environmental and soil conditions. To address these challenges, this study aims to develop regional physically based reflectance models that provide insights into soil and plant properties closely associated with crop mark formation.

Methods and Materials

The study employs a comprehensive phenological ground spectral signature dataset, spanning 400 to 900 nm (covering the visible and near-infrared spectrum), collected from a simulated archaeological environment in Alampra, Cyprus, during the period between 2011–2012. This dataset is utilized to estimate the physical properties (soil and plant) of both stressed (i.e., cropmarks) and healthy crops based on the PROSAIL physical model [3-4].

Results

Preliminary findings [5] offer valuable insights into crop mark formation. The PROSAIL model is utilized to construct large datasets of physically-based simulations of the ground-truth spectral data, analyzed by machine learning classifiers, enabled the development of simple binary threshold criteria at specific narrow bands, achieving over 80% accuracy in distinguishing cropmarks from healthy crop spectral signatures. The results indicate that this method is robust and adaptable to various environmental conditions and archaeological settings.

Discussion

The overall findings suggest that employing physically-based models to study cropmarks could enhance archaeological prospection surveys and offer useful spectral boundaries for decision-making and (spectral) discrimination between cropmarks and healthy crops spectral signatures. Further experiments are planned, involving additional spectral datasets over the same area and testing these findings in other archaeological contexts across Europe.

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460. Foundation Models for Archaeological Feature Detection: Advances and Prospects

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To date, Deep Learning models for archaeological feature detection have generally been built on the back of off-the-shelf convolutional neural networks (CNNs) and vision Transformer (ViT) models, which are pretrained on a variety of image types, sources, and subjects that are not specific to analyzing high-resolution satellite imagery. Recent advances in transformer-based vision models and self-supervised training approaches make it possible for researchers to generate foundation models that are more finely attuned to specific domains, without huge amounts of human-annotated training data. We discuss the development of two such models employing Meta's transformer-based DINOv2 framework. The first, DeepAndes, is based on the ingestion of a 3 million chip sample from a two million square km area of high-resolution multispectral satellite imagery of the Andean region. This foundation model has broad utility across the social and earth sciences. The second, DeepAndesArch is fine-tuned labeled archaeological training data collected by the GeoPACHA project to create an archaeology-focused version of DeepAndes. We present the processes involved in generating DeepAndes and DeepAndesArch and discuss prospects for foundation models in archaeological research.

462. Archaeological Distant Reading: Initial Results from an AI Survey of the Andes

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The advent of AI-based imagery survey presents the opportunity to explore new kinds of questions about large scale archaeological distributions. Such questions are not only different in degree (scale) but in kind; they require new modes of inquiry, not unlike how “distant reading” of texts en masse is a different mode of textual analysis from traditional textual reading and hermeneutics. Here, we explore distant reading of the archaeological record by first delineating categories of inquiry, such as human ecodynamics and human-environment coupled systems approaches, settlement pattern analysis, and network-based analysis. We present initial results from our large AI-Assisted imagery survey spanning much of the Andean region, which documented in excess of a million features via object detection techniques, and mass characterization of archaeological landscapes via semantic segmentation techniques. These prospects toward continental-scale views of patterns and processes would be impossible in the absence of such continuous coverage beyond the scale of field-based methodologies. We thus advocate for the value of such perspectives as complementary and additive rather to traditional archaeological modes of analysis.

232. The development of Delos environmental monitoring site

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Delos is an extraordinary site that integrates cultural and natural heritage of global significance, earning its place on the UNESCO World Heritage List. However, it faces a combination of threats arising from climate change and geophysical phenomena, which affect both its monuments and the surrounding environment. In response to these challenges, the Academy of Athens initiated the establishment of an integrated environmental monitoring facility on Delos.

The project involves the development of a comprehensive system to monitor risks posed to Delos's monuments and natural environment by severe atmospheric, oceanographic, and seismic events. The system integrates data from computational models with satellite observations and measurements from a network of ground-based instruments installed on Delos to record seismic, oceanographic, and atmospheric parameters.

For forecasting atmospheric conditions in the area, the limited-area model WRF (Weather Research and Forecasting model) with the ARW (Advanced Research WRF) core was used. The model was implemented using the grid nesting technique to cover the area of interest in Delos with a resolution of 1 km × 1 km. To describe the composition of the atmosphere in terms of gases and suspended particles, the WRF-CHEM chemical-atmospheric model was implemented with two nested grids. The outer grid, with a resolution of 20×20 km, covers the broader region of Europe and North Africa to account for distant pollution sources that may affect Delos (both anthropogenic and natural pollutants). The inner grid, with a resolution of 4×4 km, represents local pollution sources and the evolution of atmospheric parameters influencing pollutant concentrations in the area. The main anthropogenic pollution sources affecting Delos are the urban centers in the region, particularly Istanbul and Thessaloniki to the north, Izmir to the east, and Athens to the west. Additionally, Delos is influenced by the transport of desert dust from the Sahara, as indicated by the results of the WRF-CHEM model. Additionally, the Lagrangian dispersion model FLEXPART has been coupled with WRF to analyze in detail the contribution of local pollution sources, such as the port of Mykonos, to the archaeological site of Delos. To describe and forecast the sea state in the broader area of Delos, the SWAN wave model (Simulating Waves Nearshore) was selected. Developed by Delft University of Technology, SWAN is specifically designed for areas with highly complex coastlines and bathymetry, such as Delos. For the operation of the wave model, bathymetry data for the broader area were created using the global GEBCO database (GEBCO Gridded Bathymetry Data). This database provides a data grid with a resolution of 1/240° (15 arc-seconds) and includes topography values where land exists and bathymetry values where there is sea. Additionally, the SWAN model was configured to operate for the broader Mediterranean region at a lower resolution (10 km × 10 km) to provide boundary conditions for the open-sea parameters. This configuration allows for the calculation of wave parameters outside the high-resolution Delos domain, such as swell waves.

This work highlights the key components of the Delos environmental monitoring facility, along with initial findings derived from the collected data and analysis. This pilot initiative is funded by the Initiative '21 and aspires to serve as a model for application to other heritage sites in Greece and internationally, with the collaboration of organizations such as UNESCO, ICOMOS, and Europa Nostra.

222. Vulnerability of Monumental Structures to Climate Change: The Cases of "Building K" in Epidaurus and the Roman Balneum in Rafina, Greece

Emmanouil Tzannidakis (Hellenic Open University)*; Dorina Moullou (Hellenic Open University); Dimitris Egglezos (Hellenic Open University)

In an era of intensifying climate change and frequent extreme weather events, the structural integrity of cultural heritage sites is increasingly compromised. This study investigates the vulnerability of two ancient sites in Greece—the "Building K" complex in Epidaurus and the Roman Balneum in Rafina, Attica1—both of which face significant risks from the combined forces of climatic and seismic stressors. By integrating civil engineering methodologies with climatological data, this research conducts an in-depth risk analysis to assess the impact of climate change on structural stability at both sites. Using advanced digital tools and methodologies, including the Heritage Hazard Index2 (HHI) and the DEAR-Clima3 application under the IPCC's RCP 8.5 scenario, the study examines the effects of both static and dynamic loads, with a focus on how climate-induced material degradation exacerbates vulnerability to seismic events.

The analysis adheres to European and Greek heritage preservation standards, providing a scientifically grounded framework for evaluating threats to structural stability under increasingly volatile environmental conditions. Results reveal that, while seismic activity poses significant risks, the compounded effects of climate degradation—such as thermal stress, moisture fluctuation, and material erosion—constitute an even greater hazard, particularly by weakening structural resilience during earthquakes. This dual case study advocates for enhanced risk assessment models that incorporate site-specific environmental and material factors, enabling more precise and applicable conservation strategies. Through this interdisciplinary approach, the research underscores the urgent need for sustainable preservation initiatives tailored to the evolving challenges of climate change, offering a proactive model for safeguarding heritage sites around the world.

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436. Resilience of the Roman Balneum in the face of Climate Change at Brexiza, Greece: Unravelling Pathology, Advancing Risk Assessment Methodologies and Adapting Preservation Strategies.

Sofia Peppa (Hellenic Open University)*; Dorina Moullou (Hellenic Open University); Dimitrios Egglezos (Hellenic Open University)

The preservation of cultural heritage sites in the Eastern Mediterranean faces unprecedented challenges as climate change accelerates environmental stressors such as increased temperatures, aridification, and fluctuating humidity levels. This region, rich in archaeological heritage, is particularly vulnerable due to its geographic location and diverse climate conditions, making resilience to climate risk a critical focus for heritage conservation efforts. In recent years, risk assessment has emerged as a powerful approach to evaluating and mitigating the impact of these environmental threats. By integrating site-specific climate data with heritage risk assessment enables more precise predictions and adaptive preservation strategies, tailored to each site's unique vulnerabilities.

This paper introduces a framework for assessing climate resilience, using the Roman balneum at Brexiza, Greece, as a case study. Building on the Heritage Hazard Index (HHI) developed by Kapsomenakis et al., 2023 the study expands the framework with two novel indices—Biological Degradation and Salt Crystallization—to offer a comprehensive view of potential climate-induced degradation. Both indices, benchmarked against historical climate data (1971-2000), and projected across future climate scenarios under RCP4.5 and RCP8.5 are applied to capture the full range of potential environmental changes.

The Biological Degradation Index evaluates site-specific biodeterioration of materials through microorganism richness (D), which depends on temperature, and biomass (B), influenced by temperature and precipitation to measure surface accumulation. For Brexiza, aridification contributes positively to biological degradation resilience, with a relatively decline of 7.75% to 37.75% in D and 2% to 6% in B. Conversely, projected extended growing seasons in humid regions may increase biodeterioration risks from diverse microbial colonization.

The Salt Crystallization Index is divided into unhydrated (sodium chloride, NaCl) and hydrated (sodium sulfate, Na_2SO_4) systems. Salt damage is parameterised by counting dissolution-crystallisation cycles, which are influenced by changes in relative humidity and temperature. These cycles address critical deterioration risks, such as efflorescence from NaCl near coastal sites and structural weakening from Na2SO4 phase transitions. The crystallisation pressures from Na2SO4 transitions often exceed the tensile strength of porous materials, leading to potential material degradation. For Brexiza, calculations indicate a projected reduction in crystallisation cycles—51.08% to 73.23% for NaCl and 41.28% to 71.38% for Na_2SO_4—compared to the baseline, suggesting a potential decrease in material decay.

Finally, this paper proposes guidelines to enhance the HHI framework by addressing the limitations of absolute maximum values across diverse climate regions. Key recommendations include an initial risk classification for each location based on historical climate data, a grading scale for each climate parameter to assess absolute risk, and continuous tracking of both absolute and relative risk changes.

Keywords: Climate Risk Assessment in Heritage Conservation, Heritage Hazard Index (HHI), Biological Degradation Index, Salt Crystallization Index, Climate Adaptation Strategies, Cultural Heritage Resilience.

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Kapsomenakis, J., Douvis, C., Poupkou, A. et al. Climate change threats to cultural and natural heritage UNESCO sites in the Mediterranean. Environ Dev Sustain 25, 14519–14544 (2023). https://doi.org/10.1007/s10668-022-02677-w

264. Assessing Climate and Seismic Vulnerability of the Yeni Mosque in Mytilene, Lesvos

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The preservation of cultural heritage assets requires innovative approaches to address the multifaceted challenges posed by climate change and seismic activity. Monuments and historical structures, particularly unsheltered ones, are increasingly vulnerable to extreme weather patterns and tectonic shifts, which can accelerate material deterioration and compromise structural stability. This study investigates the combined impacts of climatic hazards and seismic risks on the structural integrity of the Yeni Mosque, an Ottoman monument in Mytilene, Lesvos Island, Greece, serving as a case study to demonstrate the application of risk assessment methodologies.

Using existing models to analyze climate indicators—including extreme heat, precipitation, and frost nights—under RCP 4.5 and RCP 8.5 scenarios up to 2100, the study identifies critical environmental stressors affecting the monument (Kapsomenakis et al. 2023). Thermal stress, frost-induced material degradation, and increased weathering emerge as key risks. These climatic impacts are evaluated alongside seismic vulnerabilities due to tectonic activity in the region, emphasizing the need for an integrated approach to assess cumulative threats. A 3D digital model of the monument, created using RTK drone technology, further enhances the analysis by providing detailed geometric data and visualizing areas most vulnerable to environmental stressors.

The findings demonstrate the potential of computational tools to provide predictive insights into the deterioration processes of heritage assets and guide conservation planning. By integrating climate projections with seismic risk assessments and 3D modeling, this research highlights the importance of data-driven methodologies for developing sustainable preservation strategies. The study contributes to ongoing efforts to model and mitigate the effects of climate change and other environmental stressors on cultural heritage, offering valuable implications for at-risk monuments globally.

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298. The Effect of Climate-Induced Compound Events on Porous Materials in Greek Heritage Monuments

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The preservation of historical monuments is of great significance in countries with rich cultural and architectural heritage. Greece's rich heritage consists of numerous monuments built with porous materials that are vulnerable to degradation caused by climate conditions. These conditions concern single or compound events that have an additive effect on the surface of porous materials. These compound events cause salt crystallization in the case of halite (NaCl) or salt transition and crystallization in the case of common system Mirabilite (Na2SO4·10H2O) and Thernadite (Na2SO4) salts. We have studied compound frost events that cause damage to the surface of materials. Using simulated climate models from the CORDEX initiative and one from NCSR Demokritos, we divide the frequency of annual or seasonal values into five categories for the period 1980-2004. Furthermore, we analyse the potential changes in each category's values period during the 2025-2049 timeframe under the two Representative Concentration Pathway scenarios for climate change, RCP4.5 and RCP8.5. Finally, we present examples of monuments that are located in higher categories areas and whose surface degradation has already been studied by scientists.

497. Decoding the impact of air pollution on archaeological building materials: an integrated machine learning and analytical approach

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Introduction

The impact of air pollution on archaeological and historic building materials has become an increasingly significant focus in cultural heritage research over recent decades. The characterization of degradation layers, which often serve as critical indicators of environmental stressors, necessitates the application of complementary multi-analytical techniques. However, key challenges persist, including the effective combination of portable and benchtop instrumentation, the synergistic use of elemental and molecular data and the time-intensive processing required, especially for highly heterogeneous materials (Gibbons et al. 2020, 105905; Odelli et al. 2021; Mitsos et al. 2022, 236–243).

This study aims to address these challenges by integrating machine learning techniques into a robust methodology for multimodal data analysis. By utilizing machine learning tools for pattern recognition and predictive modeling, it enhances the interpretation of data from multiple analytical techniques to enable accurate characterization of degradation layers on archaeological materials. A total of 89 samples were collected from significant monuments in Greece, including the Temple of Hephaestus and the Byzantine Church of St. Theodoroi (urban environment), a Classical-era burial ground in the area of Ellinikon (suburban/coastal environment), Classical-era marble sculptures in Piraeus (urban/coastal environment), the Sanctuary of Demeter in Eleusis (industrial environment), and the Tholos of Athina Pronaia in Delphi (rural environment).

Methods and Materials

The study combines data from three complementary analytical techniques, as well as environmental data, to characterize degradation layer samples collected from the surfaces of heritage monuments. Micro X-ray Fluorescence (μ-XRF) was used to provide elemental mapping and quantification of major and trace elements within the samples. Handheld X-ray Fluorescence provided quantification of major and trace elements from in situ measurements taken directly from monument surfaces, including the areas where samples were retrieved. In a similar fashion, portable Raman spectroscopy was utilized to identify molecular compounds such as carbonates, oxalates, and silicates, in situ. Finally, environmental data were integrated, according to the available data for each area under study and included the concentration levels of various airborne pollutants, relative humidity, wind speed and direction.

The acquired datasets consist of handheld and μ-XRF spectra, Raman spectra, and numerical values corresponding to elemental concentrations, with the incorporation of some additional parameters, such as the height and orientation of sampling and the monument's chronology. Preprocessing involved normalizing and aligning datasets to address heterogeneity in sample composition. Dimensionality reduction techniques, including Principal Component Analysis (PCA) and clustering algorithms, were applied to explore correlations between atomic/molecular data and environmental parameters.

Machine learning was incorporated at key stages of the data pipeline. Peak detection and alignment algorithms, combined with Recursive Feature Elimination (RFE), were used to identify the most relevant variables from Raman and XRF datasets for preprocessing and feature selection. Dimensionality reduction techniques, including Principal Component Analysis (PCA) and t-SNE, were combined with clustering algorithms K-means and DBSCAN in order to explore correlations between atomic/molecular data and environmental parameters and visualize the results. Finally, in an attempt for predictive modeling, regression models, including Gradient Boosted Trees and Random Forests, were trained on integrated datasets to predict degradation patterns based on pollutant exposure and monument characteristics.

Results

The integration of Raman, handheld and μ-XRF datasets, combined with machine learning, revealed significant insights into the composition and distribution of degradation layers. Raman spectroscopy helped towards identifying key molecular markers, including gypsum ($CaSO_4 \cdot 2H_2O$), calcium oxalates, and carbonates, and highlighting pollutant-material interactions influenced by environmental conditions. In situ handheld XRF analysis provided rapid identification of major and trace elemental concentrations across different areas of the monuments. μ-XRF Analysis enabled capturing the spatial variability in major and trace elemental distributions, revealing stratified layers of pollutants, with specific orientations showing higher susceptibility to acidic precipitation and particulate pollutants. Machine learning analysis enhanced these findings by uncovering hidden patterns and relationships following clustering algorithms. Additionally, key contributors to degradation were identified, such as sulfur and lead, and their correlation with environmental parameters like industrial emissions.

Discussion

The integration of machine learning into multivariate analytical techniques significantly enhances the characterization of degradation mechanisms in cultural heritage materials. By correlating atomic and molecular data with environmental parameters, the study reveals distinct pollutant-material interactions shaped by site-specific atmospheric conditions. For example, sulfur compounds were more prevalent in industrial environments, while oxalates were linked to interactions between carbonaceous deposits and environmental moisture in coastal regions.
The predictive capabilities enabled by machine learning models offer new opportunities for proactive heritage management. By simulating potential future degradation scenarios, decision-makers can prioritize interventions and allocate resources more effectively. The methodology established here provides an initial replicable framework for further studying pollutant impacts on other heritage sites, advancing the role of computational tools in heritage science.

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527. Damage Risk Assessment of Cultural Heritage monuments - Optimizing the utilization of knowledge gathered from case studies through Machine Learning

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The deterioration of historic building materials, stone as well as mortars, constitutes one of the major risks for Cultural Heritage monuments particularly when taking into account the ongoing climate change and the climate scenarios expected for the future. For the damage risk assessment and the planning of adequate preservation strategies the investigation of material performance and the understanding of deterioration processes is inevitable. The material properties and microstructures of building materials, either authentic samples or replicated materials, can be investigated in the laboratory and their deterioration can be tested in accelerated weathering cycles simulating extreme conditions, such as exposure to temperature changes, humidity fluctuation or salt crystallization. Thus, large amounts of data have been gathered concerning the material performance of diverse stone materials and mortars in relation to their composition and processing of the raw materials. The data collected in different laboratories, though, are not necessarily consistent in terms of determined attributes and workflow of material testing. Nevertheless, a data repository is being set up comprising the data gathered during case studies in our own laboratory and in partner laboratories as well as data collected from a comprehensive literature survey. Some issues to be solved during the set up the present data repository are the adaptation of different datasets, the generation of clear metadata indicating the workflow and if necessary, the supplement of attributes missing in individual case studies. In view of pattern recognition and supplement of missing attributes various machine learning approaches are tested, such as support vector machines, logistic regression, decision trees, and random forest as well as artificial neural network models. In this way, a data model is generated connecting the attributes of material selection and processing with attributes of material performance. The data model can be used to identify the most decisive material attributes affecting decay under specific climate conditions, to predict the course of deterioration and to provide data, which can be used in structural models of Cultural Heritage monuments monitoring their state of deterioration and assessing their damage risk. Eventually, the data model will allow for optimizing the development of sustainable repair and replacement materials in order to preserve and protect our Cultural Heritage monuments under the expected future climate conditions.

484. Development of a Multimodal Transformer for Cultural Heritage Preservation in the Context of Climate Change

David ROQUI (ETIS/C2RMF)*

In recent years, the growth of digital data sources has been accompanied by an increasing diversification of data modalities, such as scientific imagery, climate records, and sensor data. While this diversity offers unprecedented opportunities for analysis, it also poses significant challenges for traditional models that are often limited to processing a single type of data. Unimodal models, though effective in straightforward scenarios, struggle to fully capture the complex relationships present in multimodal data, leading to limitations in both robustness and accuracy.

Multimodal integration provides a pathway to overcome these limitations by combining the strengths of different data types. However, this process is not without challenges, particularly when it comes to maintaining the contextual integrity and meaningful relationships between heterogeneous modalities. Transformers, with their attention mechanisms and flexible architectures, are well-suited to address these challenges. Although initially designed for unimodal applications, they have been extended to multimodal data with notable efforts such as VisualBERT, XLNet, and BERT. Nonetheless, existing approaches often fall short when confronted with particularly complex or varied datasets.

This study introduces a multimodal transformer designed to handle heterogeneous data streams, with a current focus on scientific imagery (e.g., infrared, raking light, and semi-raking light) and sensor data. The proposed architecture follows a four-step process: (1) each modality is encoded separately to ensure its unique features are preserved, using techniques such as convolutional networks for images and temporal models for sensor data; (2) sliding windows are employed to segment data into manageable temporal and spatial chunks, allowing the model to focus on localized patterns and relationships across modalities; (3) the segmented and encoded features are merged in a shared latent space inspired by the Perceiver architecture, enabling dynamic interactions across modalities while maintaining their contextual relevance; and (4) a dual optimization strategy is applied, balancing intra-modality consistency with inter-modality synergy to maximize the overall information gain.

We apply this methodology to the field of cultural heritage preservation, focusing on three significant heritage sites: Bibracte, Strasbourg Cathedral, and Saint-Pierre Chapel. The goal is to predict a degradation index by integrating sensor and imagery data, enabling a deeper understanding of the interactions between environmental factors and material changes over time. Beyond these specific applications, this approach lays the groundwork for a new generation of tools capable of addressing similar challenges in archaeology and heritage conservation. By tackling the complexities of multimodal data, this work aims to contribute to the development of more accurate and actionable frameworks for preserving cultural heritage in a changing world.

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220. Mapping and Analyzing the Cultural and Archaeological Heritage of Manfredonia (Italy) for Public Archaeology

Michele Basta (Univerity of Bari)*

Cultural and archaeological heritage represents a crucial resource for understanding human history and fostering connections between communities and their past. The municipality of Manfredonia, with its rich array of cultural assets, offers a unique case study for exploring the integration of modern digital technologies and public archaeology methodologies. This research project aims to address key challenges in heritage management, including accessibility, engagement, and preservation, by utilizing tools like Mobile GIS, QGIS, and participatory methods to bridge the gap between stakeholders and resources.
Public archaeology, by definition, involves the direct participation of local communities in the identification, management, and valorization of their heritage. In recent years, technological advances have transformed field archaeology practices, enabling more nuanced analysis of spatial distributions, artifact densities, and cultural landscapes. In this context, Mobile GIS has emerged as a versatile tool for data collection, analysis, and visualization, allowing researchers to capture the complexities of archaeological assets in a dynamic and collaborative manner.
This study has three primary objectives:
To systematically map and categorize the cultural and archaeological assets of Manfredonia; to analyze the accessibility, ownership, and management structures of these assets, highlighting patterns and identifying underutilized resources; to propose strategies for integrating public archaeology into the broader framework of heritage management using participatory and digital tools.
By focusing on these goals, the research contributes to the ongoing discourse on sustainable heritage management and the role of technology in democratizing access to cultural resources.
For the methodology, the research was conducted in three distinct phases: data collection, database creation, and geographic representation.
The initial phase involved the compilation of an inventory of cultural assets, incorporating both quantitative and qualitative data. Sources included historical texts, institutional databases, online archives, and previous inventories. Qualitative data were gathered through interviews with local stakeholders to assess ownership, management practices, accessibility, and potential value. This dual approach ensured a comprehensive understanding of the cultural landscape.
The collected data were organized into a structured database using Microsoft Excel and later imported into QGIS for geographic representation. The database included fields such as: Name: Identifying the asset. Type: Categorizing the asset by function or nature (e.g., rural structures, defensive buildings). Georeferencing: Spatial coordinates for mapping. Ownership and Management: Identifying stakeholders responsible for each asset. Accessibility: Rated on a scale from inaccessible to highly accessible. Potential Value: A qualitative measure of the asset's cultural, historical, and economic significance.
The final phase involved visualizing the assets using GIS technologies. Heatmaps and scatterplots were generated to illustrate spatial patterns, accessibility levels, and potential value. These visualizations enabled researchers to identify clusters of high-potential assets and areas requiring targeted intervention.
The study identified 202 cultural assets within the municipality of Manfredonia, categorized into types such as rural structures, defensive buildings, religious sites, and Neolithic villages. Rural structures constituted the majority, accounting for over half of the total assets. These findings highlight the predominance of rural heritage in Manfredonia's cultural landscape and underscore the need for specialized management strategies to address their unique challenges.

Accessibility and potential value were assessed for each asset, revealing significant disparities. While urban assets such as religious sites and palaces demonstrated higher accessibility, rural assets often suffered from limited access and visibility. However, several rural assets with high potential value were identified, indicating opportunities for targeted investment and promotion.
Ownership analysis revealed that 80% of the assets were privately owned, posing challenges for public access and collaborative management. Publicly owned assets, managed by entities such as the Municipality of Manfredonia and the Bonifica Consortium, exhibited higher levels of accessibility and utilization.
Geospatial analysis identified clusters of cultural assets in both urban and rural areas. Urban clusters were associated with better infrastructure and higher public engagement, while rural clusters highlighted underutilized assets with untapped potential. Heatmaps revealed areas of concentrated heritage, offering insights for strategic planning and resource allocation.
The findings underscore the transformative potential of integrating digital tools and participatory approaches in heritage management. Mobile GIS and QGIS enabled researchers to visualize complex datasets, facilitating data-driven decision-making and community engagement.
Key challenges included the high proportion of privately owned assets and the limited accessibility of rural heritage. Addressing these issues requires collaborative frameworks involving local authorities, private stakeholders, and community groups.
Public archaeology plays a pivotal role in bridging the gap between communities and their heritage. By involving local residents in the mapping and management process, this study fosters a sense of ownership and responsibility, encouraging long-term stewardship of cultural resources.
The use of Mobile GIS and QGIS highlights the importance of technological innovation in modern archaeology. These tools not only enhance data collection and analysis but also democratize access to heritage information, enabling broader participation in decision-making processes.
Based on the findings, the following recommendations are proposed. Stakeholder Collaboration: establish partnerships between public authorities, private owners, and community organizations to enhance accessibility and management.
Targeted Investments: focus on high-potential assets with low accessibility to maximize their cultural and economic impact.
Capacity Building: provide training for local stakeholders in digital tools and participatory methodologies to ensure sustainable management.
Public Engagement: develop outreach programs and events to raise awareness and encourage community involvement.
Digital Platforms: create online repositories and interactive maps to promote transparency and facilitate resource sharing.
This study demonstrates the potential of integrating digital technologies and public archaeology methodologies in heritage management. By mapping and analyzing the cultural assets of Manfredonia, it offers a replicable framework for addressing challenges such as accessibility, ownership, and engagement. The findings highlight the importance of collaborative approaches and technological innovation in preserving and promoting cultural heritage, ensuring its sustainability for future generations.

279. Planning a digitally integrated future: GIS and BIM for roman architecture, the case of Pompei Archeological Park

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The digitization processes flooding all scientific domains are investing the field of cultural heritage and archaeology; as demonstrated by previous experiments and studies, the exceptionalities of heritage historic assets, also clash with the layout of software (and data schemas or protocols) that are not really built in consideration of the specific needs of these assets.
The structures under the tutelage of the Archaeological Park of Pompeii, constitute an even more exceptional case study, in which the architectural features have been almost entirely preserved, in the context of the archaeological excavations. Because of this configuration, any digital management tool constructed upon the planned conservation needs of this site, necessitates both the features of BIM, (Building Information Modelling) and GIS (Geographic Information Systems), and a seamless integration of the two.
This article wants to give a quantitative appraisal of this interoperability issue, always mentioned but not accordingly demonstrated, by establishing what information gets lost during the digitization processes and the adherence to the most popular data schemas.
More specifically, a semantic mapping between the entities part of the process is explained: the knowledge structures and data schemas compared are the popular open format standards for BIM and GIS, namely IFC and CityGMLThey are compared with a taxonomy created specifically for Roman Vesuvian architecture. A custom-made correspondence matrix indicates the results of the comparison amongst the concepts belonging to different schemas, determining their instrumental value at the hand of archeologists, conservators and site managers.
The mapping is the first step taken towards the design of an integrated system alike, where the latest research on integrating the two technological domains is respectful of the recommendations coming from the archeology experts, which the system is in service of.

1. Introduction

The project focuses on the interoperability between BIM and GIS frameworks, applied to the field of archaeology. By unifying BIM with a GIS database, the project aims to consolidate data types and allow for automatic, semantically consistent data extraction, supporting better decision-making in the management of archaeological sites, with a keen eye on the tools already tested in the latest scientific literature, and known to the archaeological community.
At the beginning of the research process, some questions were addressed, more specifically:
(a) do current GIS and BIM data schemes satisfy the requisites to represent Vesuvian architecture; (b) does one data schema support these needs better than its counterpart (c) how can BIM and GIS methods be integrated within an archaeological context.
These questions are recurrent in literature: what the presented work is trying to achieve is to give data-based evidence to solve them, using the evidence of precise case studies offered, where the data schemas were applied and evaluated.

2. Methods

The initial phase of the research (i) involved reviewing the state-of-the-art of Archaeological BIM (ArchaeoBIM) and GIS integration applications.
Phase two (ii): in this phase the chosen case study was investigated: a Pompeian house and bakery (VIII 6,1), a complex building reflecting various construction techniques with both

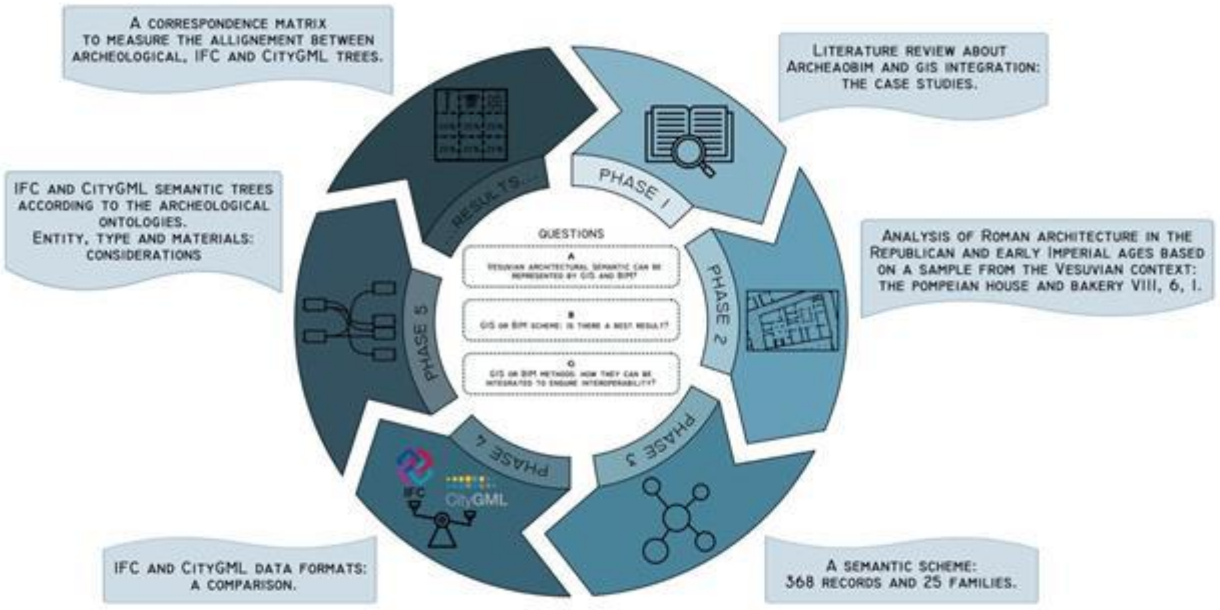
residential and productive functions. This case exemplifies the unique architectural and functional aspects of Pompeian buildings and serves as an ideal testing ground for interoperability between the previously mentioned solutions.
The third phase (iii), involved defining a semantic schema for Roman architecture, using the dataset offered by the case study. Thanks to the expertise of the researchers involved, the analysis proceeded to cover all other entities within the Pompeii Archaeological Park. The analysis produced 368 records within 25 families of architectural evidence, organized across disciplines.
Afterwards, phase (iv), came the analysis of IFC and CityGML formats: a close comparison was conducted between Industry Foundation Classes (IFC), the standard for BIM data exchange, and CityGML, a GIS data format. IFC offers a rich semantic schema in hierarchical structure and identity attributes, ideal for architecture-focused representations. IFC’s structure is standardized, open, and internationally recognized, combining a rigid hierarchical model with an analytical-synthetic framework. This model ensures each element has a distinct position within the hierarchy of projects.
CityGML, instead, is designed for urban-scale representations, encompassing morphological data for both built and natural environments. It also possesses a dual structure (geometry and identity) but operates on the Geography Markup Language (GML). CityGML uses thematic modules (e.g., "building," "vegetation," "transport"), which offer fewer attributes and relationships compared to IFC. Both cityGML and IFC have valid important features, which is why their integration is necessary.
In phase (v), the team developed semantic trees for BIM and GIS, creating a cross-referenced structure that translates the archaeological ontology into IFC and CityGML frameworks. For instance, the "wall" entity in archaeology maps to "ifcWall" in IFC, with construction technique attributes defined by "ifcWallType" and material attributes linked via "ifcRelAssociateMaterial." Meanwhile, in CityGML, "wall” exists as surface entities (cityGML “wall surface"), a material juxtaposed as a “texture” (relationships like those - between an object and material - are more visualization-focused in CityGML) and no explicit parameters and attributes are available for the construction techniques. However, the construction techniques, (e.g. “opera vittata mista” for the wall) are always at the forefront of the archeological ontology. These issues, evidenced once the schemas are applied to the reality-based datasets, pose several semantic dilemmas and choices that would impact the quality of the models, and their long-term shareability and preservation.

3. Ongoing results

At the end of the mapping process: a correspondence matrix was developed to measure alignment across the archaeological, IFC and CityGML semantic structures. This matrix prioritizes "entity" as 50% of the matching score, "type" as 25%, and "material" as 25%. Full alignment is rare, with varying degrees of correspondence; based on these parameters the weight of the semantic choices made upstream, within the limit of the data schema, is evident.

4. Conclusion

The current findings highlight the limitations of IFC and CityGML in capturing the material-structural nuances of archaeological sites, necessitating further refinement or possible new standards for seamless integration. Future work will include the analysis of data schemas and ontologies specific to the archaeological domain.



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46. Testing and integrating machine learning models in a user friendly app to estimate original scraper mass.

Guillermo Bustos-Pérez (Max Planck Institute for Evolutionary Anthropology. Department of Human Origins)*

Lithic scrapers are an important component of stone tool assemblages. They are present from the first Oldowan stone tools through to modern ethnographic studies of hunter gatherers (Gallagher, 1977; Semaw et al., 2003). Progressive resharpening of a scraper edge through retouch is considered to be a major driver of their morphological variability. Estimating the amount and percentage of mass lost by a scraper through retouch can inform about behaviors of past paleolithic groups at the technoeconomic level (effects of distance to raw materials, patterns of product selection and transport), cognitive capabilities (ability to maintain a desired morphology for an edge), and associated use (combining use-wear and morphology).

Several approaches using flake attributes which remain stable through reduction (such as platform size, maximum thickness, exterior platform angle, etc.) have been proposed to estimate scraper original mass (Hiscock and Tabrett, 2010). This has allowed to make comparisons at the assemblage level (Barton and Riel-Salvatore, 2014). However, predictive estimations at the individual scraper level have remained unsatisfactory: correlation values between actual and predicted mass were not good enough (r2 usually provided a 0.8 value), experimental assemblages were not tested in the framework of multiple resharpening episodes, and their applicability in lithic analysis has remained limited. Furthermore, new experimentations using these group of variables seem to indicate that a limit on their inferential power has been reached (Bustos-Pérez and Baena Preysler, 2022). This research approaches the estimation of original scraper mass with a new set of variables and in the framework of machine learning workflows (data collection and preparation, model training and evaluation, and deployment for users).

134 experimentally produced flakes were successively retouched, providing a dataset of 698 resharpening episodes. After each resharpening episode, four attributes were recorded: remaining scraper mass (in grams), height of retouch (in mm), maximum thickness (in mm), and the GIUR index (which ranges from values of 0 for unretouched flakes, to 1, when retouch covers the dorsal surface of the flake; Kuhn, 1990). Four Machine Learning algorithms were trained and compared: multiple linear regression, supported vector regression with a linear kernel, random forest, and gradient boosting machine (GBM). Evaluation and comparison of the regression models was done using mean absolute error (MAE); root mean square error (RMSE), and mean average percentual error (MAPE) which indicate how far predictions fall away from the true value. Additionally, models were also evaluated on their ability to predict the percentage of mass consumed by retouch, and the variance inflation factor (VIF) of each variable was calculated from the multiple linear regression in order to evaluate possible effects of multicollinearity.

Results indicate that the random forest (Breiman, 2001) is the best performing model, with highly accurate values when estimating original scraper mass ($r2 = 0.97$; MAE = 3.297; RMSE = 5.917; MAPE = 6.775) and percentage of mass consumed by retouch ($r2 = 0.84$). The performance of random forest can be related to several advantages that makes it a more robust model when estimating original scraper mass: they are able to model interactions between features, outliers have little effect on the modeling of predictions, and they are able to handle non-normal data. VIF from the multiple linear regression indicate that possible multicollinearity between predictors is of no consequence (all features presented VIF values bellow 10). Results also provide limits for the prediction of original scraper mass when this sets of variables are used. Underestimations of original scarper mass (and therefore of percentage of mass consumed by retouch) will be present on very large flakes which have undergone multiple episodes of retouch with more than 50% of mass consumed.

In order to make the adoption of this approach easier for lithic analysts, the random forest model has been integrated in an open-source, user-friendly Shiny app. The shiny app (named "Original Scraper Mass Calculator"; https://guillermo-bustos-perez.shinyapps.io/Original-Scraper-Mass-Calculator/), allows for batch calculation of scrapers or individual estimations by manually introducing the data. This case shows how to approach an archaeological specific problem (estimating original scraper mass), implement a more robust predictive approach (a random forest model), and allow for its widespread adoption by lithic analysts (through a Shiny app).

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113. The Challenge of Digging Data: Roman Villae Maritimae and the Creation of a Data Repository

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Introduction

The opportunity to study the microcosm of Mediterranean maritime villas and to establish a data system for the reuse of published bibliographic material arises from my doctoral research project in Cultural Heritage and Production Sciences at the University of Catania, funded by CHANGES – Cultural Heritage Active Innovation for Sustainable Society – SPOKE 6 CUP E63C22001960006 (supervisor: Professor Daniele Malfitana). This research project, through a survey of all sites fitting the definitions of ‘maritime villa’ and ‘coastal villa’ (Lafon 2001), aims to define one or more architectural typologies of Roman residences in the Mediterranean region, whose fundus extended over the sea rather than inland.

The development of a research project primarily based on the study and analysis of previously published sites, characterised by heterogeneous excavation and documentation methodologies, can appear exceedingly challenging. Added to these obstacles is the considerable amount of data obtainable from each individual site, dispersed over a vast geographical area and spanning a chronological range of nearly five centuries. Establishing a unified reference system for managing both recorded and recordable archaeological data may indeed represent a formidable challenge. Undertaking such a project – through the use and reuse of data compiled by others (Pasquetto et al. 2017, 3) – equates to conducting an archaeological excavation, not in the field, but digging into the data, extracted from a substantial body of bibliographic material.

Methods and materials

In this seemingly ‘mission impossible,’ digital technology becomes essential, serving as a means to integrate diverse data sources (primarily bibliographic, cartographic, and archival) and to manage complex information flows. This approach provides robust tools for analysing, archiving, and developing new data types and categories that meet the FAIR principles (Findable, Accessible, Interoperable, Reusable), aligning with the increasingly crucial concept of open science. Constructing the digital framework required careful consideration of dataset management, the level of standardisation and abstraction needed to describe the collected information, and strategies for unifying both cartographic records – where site plans differ in creation period and graphical rendering – and descriptive records into a consistent language. The sites examined were published in studies across various European and non-European languages, each with unique technical terminology and reflecting the linguistic norms of their respective publication eras. For this reason, most catalogue entries were recorded using the specific Latin term, preserving the original semantic function found in ancient sources to prevent semantic ambiguity (Mazzaglia 2016, 260).

The creation of the dataset, based on information drawn from scientific literature, aims to form an extensive repository organised according to chronological, topographical, and architectural criteria. This repository serves as the foundation for obtaining relevant, systematically organised data, allowing for cross-referenced insights that address the study’s objectives. Physical space is the common denominator among the studied evidence, with the 'maritime' context as the defining feature of this building type. Since the research boundaries align with the geographical scope of the Roman domain, the establishment of a GeoDB and the use of a GIS environment were imperative, as they enable the storage, management, and integrated analysis of descriptive and geospatial data.

Each villa's layout is represented with a suitable level of differentiation for construction phases. The supporting data structure organised into geographic 'information layers,' allows for the storage and integrated analysis of much of the information derived from the bibliographic review. All architectural elements useful for defining construction types are highlighted. Each room and space in the different sections of the villas (the pars urbana, pars fructuaria, pars rustica, and balneum) is descriptively categorised by function. Additionally, following the entity-relationship (E-R) structural model, an explanatory interface is available, which details construction characteristics and provides information on specific findings such as inscriptions, coins, hydraulic elements, decorative features, functional elements (such as torculi, wells, cetariae, fornaces), and significant architectural elements (such as monumental facades and vaulted coverings).
Each recorded piece of evidence, organised into thematic layers, is linked to both general bibliographic references (for an overview of the villa's status quaestionis) and specific sources (for comparisons and highlighted elements).

Results
Beyond the anticipated outcomes of the project (such as defining one or more new architectural typologies), we also expect to reveal greater connections between the typological structure of the catalogued villas and other recurrent elements (e.g., necropoleis, aqueducts, port facilities, roads, stationes and mansiones, etc.), which the chrono-topological dataset is already beginning to highlight. Completion of the research and the foundational GeoDB could serve as a structured data resource whose potential, particularly through future integration into shared models, may contribute to establishing a reference framework for the scholarly community.

Discussion
An ongoing area of discussion is identifying the ideal digital platform to sustainably support and maintain the data derived from this research over time, enabling continuous updates and serving as a foundation for further research development.

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391. Quantitative analysis of bone density for mammoth tailbone fossils using X-ray computed tomography imaging technology

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Fossils gradually weather and deteriorate over time, forming internal pores. The intrinsic physico-chemical properties of fossils, such as porosity and crystallinity, can strongly affect the preservation of the fossils (Porpora et al., 2022). Assessing the condition of a fossil is critical for its preservation and conservation, as internal pores serve as indicators of fossilization stages, necessitating precise quantitative analysis and evaluation.

While various methods exist for analyzing porosity, X-ray computed tomography (CT) stands out as a nondestructive technique applicable to both cultural and natural heritage studies. CT has been recently introduced in the field of Cultural Heritage diagnostics, where it can be used for the investigation of different works of art, as it preserves the integrity of the object and gives morphological and physical information on its inner structure (Morigi et al., 2010). It provides morphological and physical insights into internal structures by displaying radiation transmittance as gray-scale images, where pore information appears as black pixels.

Although qualitatively determining pore distribution is straightforward, quantitatively defining the boundary between pores and nonpores requires meticulous image analysis. Reproducibility and reliability of quantitative results become challenging when pore thresholds are determined subjectively without advanced image processing. This study analyzed the threshold characteristics of X-ray CT images of mammoth tailbone fossils to calculate three-dimensional (3D) porosity and evaluate the efficacy of different calculation methods.

The thresholding analysis included manual inflection points on X-ray CT gray-scale graphs and an automated algorithm integrated within the software. The manual method categorized thresholds into three types based on gray-scale gradients: Type A (closest to the material), Type B (representing the weathering layer transitioning from material to pore), and Type C (closest to the air layer). Conversely, the automated method focused on regions of interest with pore distributions. Cross-sectional X-ray CT images where both bone and pores were discernible were analyzed.

Threshold values for Type A were determined as 10,659, 11,090, and 10,754, representing complete bone regions, while thresholds for Type C were calculated as 6,230 and 6,412, corresponding to complete air layers. Intermediate values, representing the transition zone where bone gradually changes into air layers, were identified as 7,774, 7,771, and 7,548 (Figure 1). Multiple X-ray CT tomograms were analyzed to ensure statistical reliability of the threshold values.

Porosity calculations revealed that the manual method produced values of 19.6% for Type A, 10.8% for Type B, and 6.5% for Type C. In contrast, the automated algorithm calculated a porosity of 21.8%, classifying both air and weathering layers as pores. Consequently, the algorithm-based method overestimated actual porosity, suggesting that Type B thresholds are more accurate for porosity estimation.

This study demonstrated that porosity and nonporosity in mammoth tailbone fossils exhibit a gradual transition influenced by weathering and deterioration. While the absolute values of porosity for the four methods remain uncertain, presenting results as a stepwise porosity rather than a singular value appears more reliable for objects with gradual property changes. Future application of this methodology to specimens with distinct boundaries between pores and nonpores, as opposed to spotty weathering transitions, could enhance the reliability of porosity analysis using X-ray CT imaging.

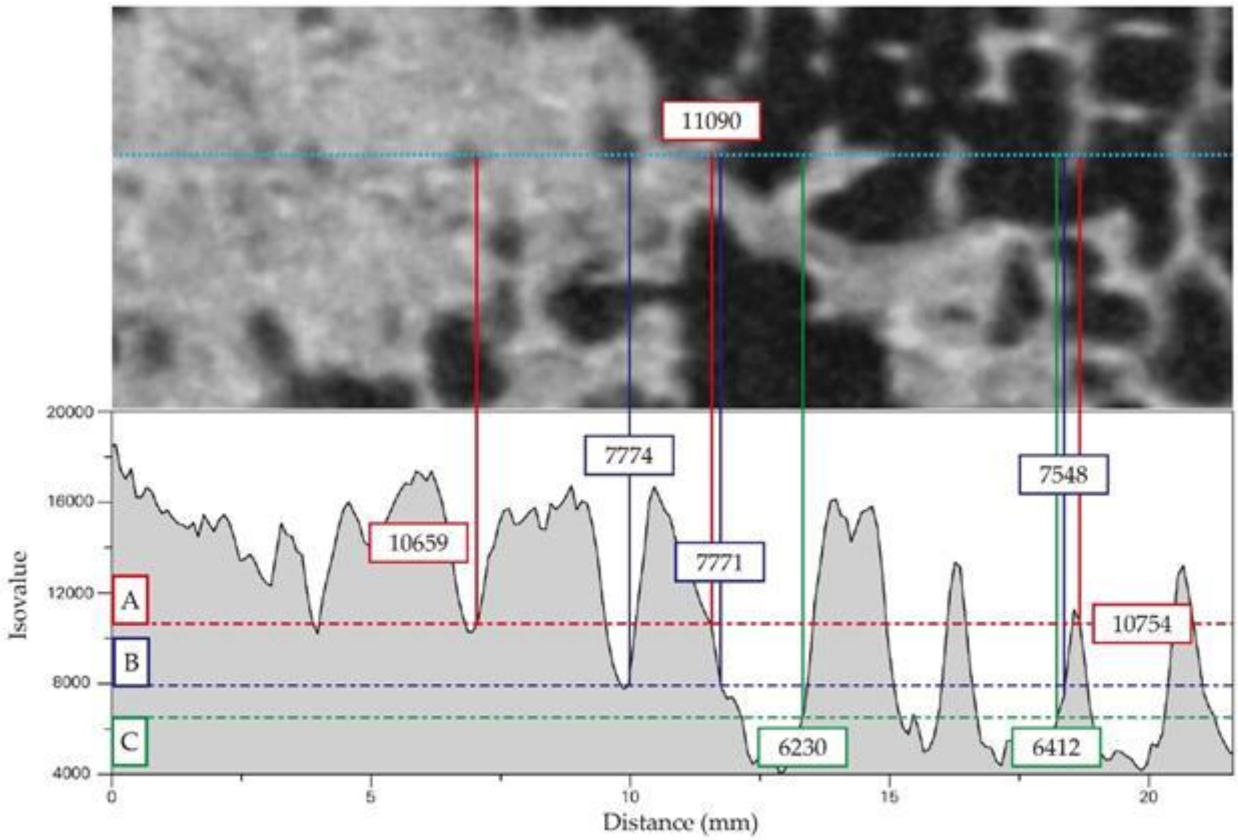

Figure 1. Analyzing Gray Histogram Inflection points.

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22. How Squirrels can help to feed Wikidata and the Wikibase Ecosystem. Examples from the Wikiprojects “Ogham Stones”, “Holy Wells“, “Linked Reindeers in Alta”, “Linked Open Samian Ware”, and the “fuzzy-sl” Wikibase

Florian Thiery (LEIZA)*

Introduction

The creation and implementation of Linked Open Data (LOD) and its foundation in the W3C standard, the Resource Description Framework (RDF), has become a central method for publishing scientific data across disciplines. RDF facilitates the creation of a common, interoperable knowledge base that accommodates heterogeneous data sources. In archaeology, this is increasingly complemented by community-driven platforms within the so-called “Wikiverse,” such as Wikidata, FactGrid, and Wikibase(.cloud), which provide accessible and collaborative environments for managing and linking structured research data. By aligning with the principles of FAIR (Findable, Accessible, Interoperable, Reusable) data, these platforms support the open availability and interoperability of archaeological datasets, promoting an inclusive and participatory Open Science ecosystem. This framework enables scholars from various fields to collaboratively build on each other’s work, resulting in a more interconnected and meaningful global knowledge graph.

As more archaeological projects adopt a shared LOD infrastructure, the potential for federated data queries and cross-project analyses increases, enriching the research landscape. For instance, initiatives such as the Research Squirrel Engineers Network (RSEN) and the Samian Research Database, hosted by the Leibniz-Zentrum für Archäologie working with mostly citizen scientists all over Europe, have integrated their primary SQL-based relational databases (e.g., PostgreSQL/PostGIS) into Wikidata and other Wikibase instances, by transforming these platforms into secondary data hubs. Wikidata, as the currently largest source of LOD, plays a pivotal role as a data hub, facilitating the linking of archaeological and humanities data across diverse research domains. A key strategy in this context is the creation of property IDs in Wikidata, which serve as external identifiers to bridge multiple knowledge graphs and enhance interoperability between datasets.

Wikibase instances, such as FactGrid, further extend this capacity. FactGrid is a collaborative knowledge base designed to host and interconnect data from humanities research, offering archaeologists a flexible platform for linking excavation records, historical data, and other research materials. Similarly, the “fuzzy-sl” (Fuzzy Spatial Locations) Wikibase instance addresses challenges related to uncertain or vague findspot locations, using metadata qualifiers to manage spatial uncertainty explicitly. The following sections will examine five specific projects in Wikidata and within the Wikibase ecosystem, focusing on the challenges, workflows, and data modelling solutions they have developed.

Wikidata/Wikibase Projects

1. Wikidata-Project “Ogham Stones” by the RSEN (Thiery 2024b): This project focuses on cataloguing and linking data related to Irish Ogham stones, ancient inscribed monoliths that provide essential insights into early medieval language, culture, and identity in Ireland. By using Linked Open Data and platforms like Wikidata, the project seeks to enhance the accessibility and

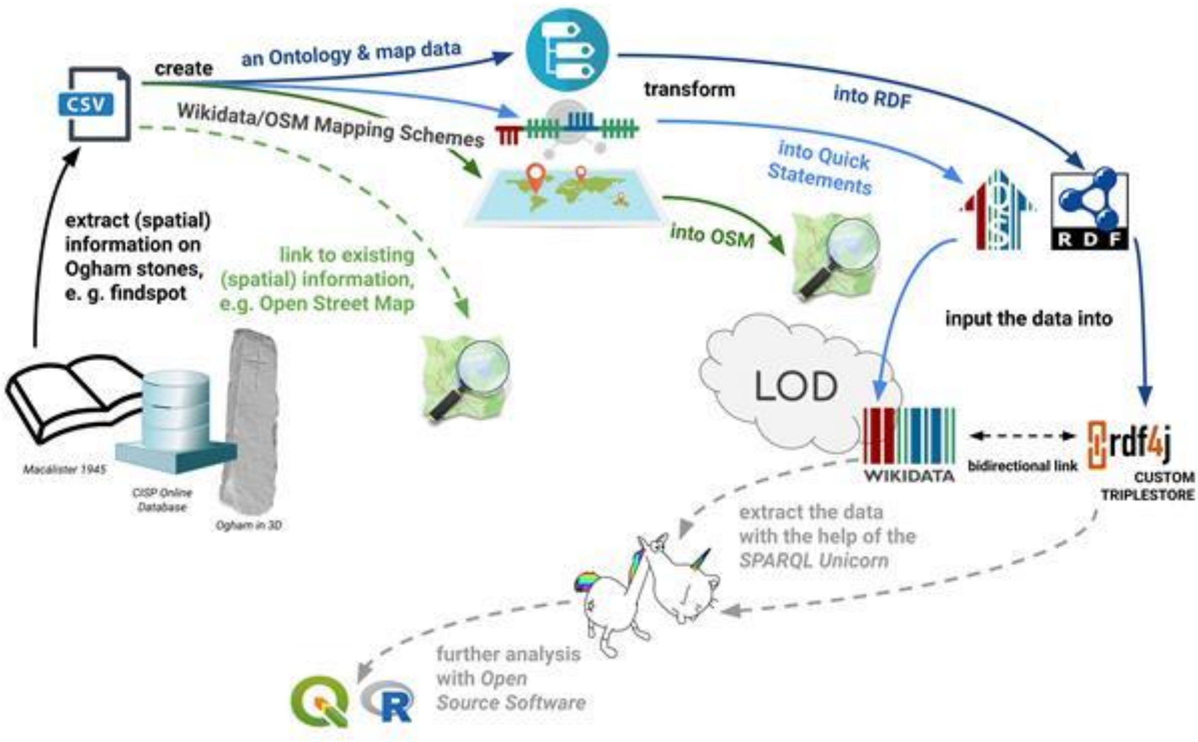
cross-referencing of these inscriptions across archaeological and linguistic research. Wikimedia Germany funded it in 2020/21 and follows a workflow, cf. Figure 1.
2. Wikidata-Project “Holy Wells” by the RSEN (Distel 2024): The Holy Wells of Ireland project documents the historical, cultural, and religious significance of sacred water sites across Ireland, many of which are linked to early Christian and pre-Christian traditions. This project aims to digitally map and connect information on these wells using Wikidata to facilitate interdisciplinary research in archaeology, folklore, and religious studies.
3. Wikidata-Project “Linked Reindeers in Alta” by the RSEN (Thiery 2024a): The Alta Rock Art project focuses on documenting and linking the extensive prehistoric petroglyphs found in Alta, Norway, with particular attention to depictions of animals (such as reindeer), boats, and human figures. Using data modelling and Wikidata integration, this project enhances the analysis of these motifs and their cultural context in Arctic prehistory.
4. Wikidata-Project “Linked Open Samian Ware” [1] by the LEIZA: The Samian Research Database documents over 250,000 potter dies used in producing Roman Samian ware (Terra Sigillata), a distinctive type of Roman pottery. Curated largely by citizen scientists, this project utilises Linked Open Data. It mirrors the data in Wikidata to enrich the study of Roman ceramics and foster public engagement with archaeological research.
5. Wikibase-Project “Fuzzy Spatial Locations (fuzzy-sl)” [2] by the RSEN: The fuzzy-sl project (hosted in a Wikibase on wikibase.cloud) addresses spatial uncertainty in archaeological datasets, particularly about findspots associated with the Campanian Ignimbrite eruption [3], silver coinage from Croton [4], and Irish Ogham stones [5]. Using metadata qualifiers to model ambiguous or imprecise locations, the fuzzy-sl database enhances the representation and analysis of spatial data in archaeological research [6].

This paper will demonstrate how various projects utilise Wikidata — its software, data, and underlying model — and other Wikibase instances, such as FactGrid and “fuzzy-sl,” within the context of computational archaeology. These platforms are employed for various purposes, including data enrichment and linking, knowledge graph construction, data modelling, ontology development, querying and analysis, and data publication and sharing. The paper will explore key challenges such as ensuring data quality, modelling uncertainty, and handling archaeological data's inherent fuzziness and imprecision. It will also address strategies for accommodating diverse data models, such as CIDOC CRM, to ensure interoperability with other knowledge graphs, including the NFDI4Objects Knowledge Graph.

In addition to discussing these conceptual challenges, the paper will provide insights into practical workflows, scripts, and techniques for importing, exporting, enriching, and recognising data within Wikidata and Wikibase environments. The discussion will include an evaluation of Wikidata’s advantages and limitations as a central data hub, extracting and linking statements from various sources, and the application of SPARQL for querying, including examples, common challenges, and visualisation techniques. Finally, the paper will reflect on the broader Wikibase ecosystem and the possibilities for sharing research data through Wikidata.

Footnotes:

[1] https://www.wikidata.org/wiki/Wikidata:WikiProject_Linked_Open_Samian_Ware
[2] https://fuzzy-sl.wikibase.cloud/
[3] https://tinyurl.com/2bdzqyhu
[4] https://tinyurl.com/285mage9
[5] https://tinyurl.com/29gyd7sa
[6] https://fuzzy-sl.wikibase.cloud/entity/Q84



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375. The WikiProject Archaeology

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Wikidata, like all Wikimedia projects, is a community driven and open platform. As such, the issues with data quality, coverage bias, and accommodating different data models, can only be addressed by becoming an active member of the community.
Wikidata already provides the necessary functinalities to help the community to self-organise, one of it being Wikidata:WikiProjects. The WikiProjects are targeted towards user groups wanting to jointly work on a specific topic or task.
In 2022 the WikiProject Archaeology was created to help in bundling items, properties, datasets and other projects in Wikidata that are related to archaeology (Q23498) in general. Ultimately, the intention of the WikiProject is to serve as a single entry point for archaeology related information on Wikidata and provide a platform for discussion.
The session provides an ideal framework to present the Wikiproject and allows for group members to meet in person. New group members are welcome any time and can join by adding themselves to the list in the section 'Participants'.

185. Humans are you there? Comparative approach of two distinguishable methods for human installation detection: automatic structure detection and archaeological predictive models

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Background:
Archaeology has a long tradition of modelling and prediction theory applied to human occupation (Hodson, 1970), which can take many different forms, on which will focus on two of them. The explosion of remote sensing images and their accessibility (Argyrou and Agapiou, 2022) gave new possibilities for detecting past human activity and has led to the development of automatic structure detection. This method, based on remote sensing images (UAVs or satellites) and using some algorithm, produces a binary answer to the question: "is there a site or not?" by classifying the input images (Davis 2019). On the other hand, an older tradition, which comes from Bayesian modelling, has given rise to the method of archaeological predictive model (APM). Based on an ensemble of covariates, the model will produce a probability of suitability for human settlements and occupations (Kamermans et al. 1999, p. 22). If these two methods aim to answer a similar question on the presence or absence of past human occupation at a location, their approach and traditions seem very different. This presentation aims to produce a review of the developments of both techniques through time and their current state of the art. We will also compare their domain of application, the model architecture's, results and their respective methodology. Finally, we aim to discuss the theoretical aspect of the opposition between these two methods and how future workflows could overcome the lack of embedded/combined approaches.
Subject:
We analysed over 60 articles pertaining to archaeological structure detection and APMs, then extracted and categorised different structural elements of the two methods. We considered the pre-training strategy, input data, type of model employed, and evaluation to be the main elements of comparison. If preprocessing is often assessed in automatic structure detection and can be seen as standardised in certain cases, it is rarely the case in APMs applications. The amount of input data is much more important for APMs, while automatic structure detection relies mostly on LiDAR or ALS images. Automatic structure detection field has adopted deep learning innovation with application of Convolutional Neural Networks (Altaweel et al., 2022), while APMs shows a stronger inertia with models still relying on decision tree based or ensemble learning architecture. Concerning evaluation, if automatic structure detection studies can be easily compared with one another, it is almost impossible for APMs, as the quality of the input is often highly uncertain.

Discussion:
While both methods aim to answer a similar question, automatic structure detection and APMs do not follow similar paths. The close connection between automatic structure detection and innovative approaches in terms of models or input can be directly linked to its high economic potential, since the application of automatic structure detection is an ideal way of minimizing time and money in construction projects, avoiding costly and unexpected archaeological excavation. Additionally, focusing on a unique object (e.g. cairn, pit, tell) allows archaeologists to deal with one specific problem related to their field of research. On the other hand, APMs, while

coming from an older tradition, struggle to find a place with new computing approaches. If the criticism of a fundamental determinism in this approach (Kohler, 1988, p.19) has already been debated and minimized (Coombes and Barber, 2005), it has rotted a suspicion still present today. The main limitations of APMs rely on the quality of the input (survey data) and its strong bias, as well as the difficulty of assessing the true absence of archaeological sites in the modelling approach.

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324. Culturally Contextualized Intelligent Matching: User Profiling Analysis and Model Development based on ACUX typology for Matching Personas and Evaluation of User Experience.

Fotios Pastrakis (University of the Aegean)*; Markos Konstantakis (Aegean University); George Caridakis (University of the Aegean)

In a world where global tourism has increased, it has become a major part of multiple cultures. This phenomenon necessitates solutions to classify travelers with specific characteristics based on their preferences and traveling habits into user personas, providing a model for serving the right needs of each individual in a personalized way, enhancing their cultural user experience. Travelers encompass a wide variety of characteristics with high diversity, such as those of cultural tourists, which can be attributed to many factors based on the attitudes and behaviors of people. Culturally Contextualized Intelligent Matching is a methodology for crafting recommendation systems for tourism by enhancing eight user personas based on the ACUX (Augmented Cultural User Experience) typology, making it easier for tourists to select future destinations. These eight personas are the outcome of previous research on typology conducted by Konstantakis (2022), providing insights and mathematical representations that will help develop a model based on his research. As a result, personalization will be provided by the ACUX typology and can be combined with the customization offered through the interface of an application to help users select cultural destinations according to their personas more easily and quickly.

Starting from a user profiling analysis, we build a baseline to understand users' needs by analyzing attitude, as the initial and current representation of their habits and preferences as travelers. In parallel, we create the opportunity to analyze further behavior of the user, for future and long-term reference, by collecting multiple outcomes out of multiple experiences. Focusing on the present, users complete a survey that helps us define the amalgam of their unique persona, thus a combination of all elements from various personas generated from ACUX typology, crafting a clear picture of their current needs. To create a continuous feedback loop for the future, users will have the ability to change their preferences and adjust their habits accordingly for a personalized experience. At the end of each experience, users will be able to evaluate their in-app experience by completing an additional survey that will provide valuable insights on the overall user experience in and for the application.

In this research, several tools have been utilized such as Figma and Miro for diagrams, models, design, and abstraction analysis. Google Forms has been used to gather and analyze feedback from human participants, ensuring compliance with EU laws regarding users' rights. These are combined with the Object Oriented User Experience model as a method of modeling objects and adjusting them into user personas. The goals of this research are to create a more standardized way to approach users' needs with respect to their uniqueness.

401. Fundamental Issues in Archaeological Reconstruction of the Past: New Insights from Refitting Studies and the Simulation of Site Formation Processes Using Evolutionary Algorithms-based Model Exploration Methods

Sebastien Plutniak (CNRS)*

Introduction
It is common-sense to consider that archaeology concerns the reconstruction of the past. Indeed, determing what can be reconstructed from a set of archaeological observations (generated on the field using survey or excavation methods) and how this reconstruction can be carried out are among the more fundamental problems in archaeological theory and methodology. States of the past archaeologists aim to reconstruct regard various sorts of entities and processes, more or less complex: an individual object (e.g. a vessel), an artefact assemblage, a dispositional process, a technical sequence, a seasonal behaviour, a building, a society, etc. Each of these entities raises particular issues and the list of acceptable objectives is, in itself, a debated question in archaeology. In this context, the study of fragmented objects is of particular interest due to its elementary and fundamental nature. Indeed, the study of "refitting" pieces of objects regards the simplest and most robust possible archaeological statement: stating that two object pieces were part of the same thing, at some moment in the past. Consequently, refitting studies constitutes a particularly relevant case to address, from their simplest instance, the general problems regarding past reconstruction in archaeology.

Methods
Recent research in refitting studies offered advances in the concepts and methods used to deal with fragmented objects. In particular, the TSAR (Topological Study of Archaeological Refitting, Plutniak 2021) approach draws on graph theory to model and analyse sets of refitting relationships distributed in archaeological spatial units (e.g., stratigraphic layers, pits, etc.). This approach is implemented in the R archeofrag package (https://CRAN.R-project.org/package=archeofrag) and in a GUI web-based application (https://analytics.huma-num.fr/Sebastien.Plutniak/archeofrag/), making it easy to use to all archaeologists. Nevertheless, the lack of reference data to compare results from the field in a specific context continues to raise serious issues in refitting studies. Considering the current absence of documented and published (experimental or field-observed) refitting data sets, computer-based simulation offers a workaround (Brantingham, Surovell, Waguespack 2007)). In this perspective, the archeofrag package includes a simulator, similar in design to an agent-based model.
Let us consider a set of objects observed on the field (at t0, see Figure). Determining refitting relationships results in defining a set of partially (due to missing pieces) reconstructed objects (as they existed at t−1). Using the archeofrag simulator allows the production of multiple possible site formation processes –namely deposition and alteration processes, including fragmentation and movement within and between spatial units– from t−1 to t0. Simulating with different initial parameters helps determine the most likely scenario from t−1 to t0: in particular, simulating with a single or two initial spatial units –layers, for example– gives insights about the relevance of the distinction between those two layers.
However, archaeologists' aim and ambition are about determining "initial" states, meaning the longest story from the moment the considered objects of inquiry (e.g. a fragmented vessel and the vessel assemblage) were complete. Consequently, a current challenge is to address what happened in the time gap between the moment corresponding to the partial reconstruction of

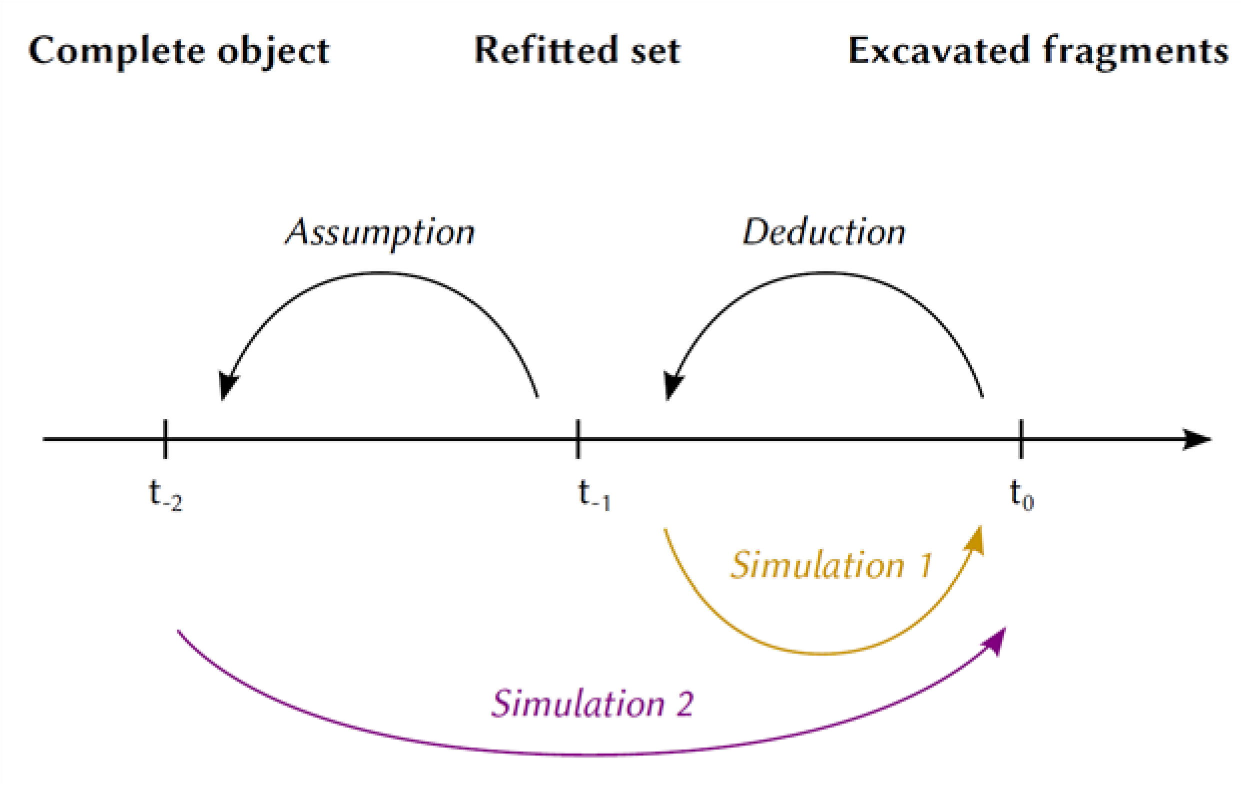
objects (t−1) and, earlier, the “beginning” of the site formation process, i.e. the theoretical initial and original state when all the objects of the assemblage were complete (t−2). Multiple scenarios of fragmentation and movement are possible. Given a deposition model (e.g. the model implemented in the archeofrag simulator), the aim is to determine which original state(s) at t−2 best simulate the fragmentation and movement processes that might have led to the archaeologically observed t0 state. In practice, this question raises serious issues since assumptions about the initial parameters of the simulation are required (e.g. the initial number of objects and spatial units, the initial distribution of objects in the spatial units, etc.) and the combinations of possible values for those parameters are too numerous to consider, leading to combinatorial explosions.
To overcome this barrier, we rely on recent “model exploration” methods based on evolutionary algorithms and distributed high-performance computing. In this context, the “Origin Search Exploration” method (OSE) is of particular interest. This method enables determining possible combinations of initial parameters of a model, regardless of the combinatorial explosions. Conducting an OSE analysis requires, first, a definition of 1) the parameter values for an observed state of a model (e.g. the values describing the state at t0), and 2) the ranges of possible initial values for each parameter of the model. Second, running the OSE procedure leads to the determination of which combinations of values best generate the observed state and, consequently, the most probable initial state(s) at t−2.

Material

This paper reports on the first results from applying this approach to a series of refitting datasets from various archaeological contexts, including Neolithic pottery from Southwestern Europe and pottery from a rock shelter site in Borneo. Computation of OSE is carried out using the implementation available on the OpenMOLE platform (https://openmole.org) which provides a convenient framework to apply model exploration methods (Reuillon, Leclaire, and Rey-Coyrehourcq 2013).

Results

As a proof-of-concept, preliminary results from this first application suggest rich avenues and potential for extended applications about various archaeological problems (beyond taphonomy: human action in sites) addressed from diverse types of objects (beyond pottery: lithic, bones, etc.) and spatial units (beyond layers: pits, trenches, etc.). Results demonstrate how advanced computational approaches can benefit archaeologists in two manners: 1) to solve proper archaeological problems regarding the validation of observed spatial units, both about the analysis of site formation processes and of human activities and 2) to address theoretical issues regarding the philosophy of archaeology and the definition of its elementary entities and argumentative operations.



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182. Protecting Heritage through Fire Risk Assessment in Sacred Indigenous Landscapes of Santa Marta

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Protecting culturally and archaeologically significant landscapes from forest fires is essential, particularly in regions where sacred sites hold profound historical and spiritual significance. This study evaluates fire risk in the Santa Marta region of Colombia, with a focus on the Línea Negra—a network of sacred sites encircling the Sierra Nevada that is central to the heritage and identity of local indigenous communities. By leveraging a Random Forest (RF) model trained on MODIS fire data from 2014 to 2023, this research investigates how various environmental and bioclimatic factors, such as slope, elevation, curvature, flow accumulation, land cover changes, and climatic variables (e.g., precipitation) contribute to fire susceptibility in this culturally valuable area.

The Random Forest model was chosen for its robustness and superior predictive accuracy compared to traditional regression models, and it performed exceptionally well in identifying high-risk fire zones within the Santa Marta region. This model's predictive power makes it particularly suited to managing fire risk in areas like the Sierra Nevada, where preserving indigenous heritage is paramount. By combining MODIS fire data with spatial data on terrain and vegetation characteristics, the model offers a spatially explicit fire risk probability map, enabling targeted interventions and informed decision-making.

The generated probability map reveals distinct fire risk patterns across different zones, influenced by both elevation and vegetation. In the central high-altitude regions of the Sierra Nevada de Santa Marta, the model predicts very low fire probabilities, shown as dark areas on the map. This low fire risk can be attributed to the specific ecological conditions of mountainous terrain, including lower temperatures, higher humidity, and dense vegetation cover. These conditions create natural fire resistance, and the scarcity of actual fire points in these areas confirms that the model accurately captures this aspect of fire dynamics. The RF model's capacity to highlight this relationship between elevation and fire risk is crucial, as it allows fire management resources to be strategically allocated in regions that need them most.

Conversely, areas surrounding the Sierra Nevada, particularly at lower elevations to the south and west, exhibit higher predicted fire probabilities, indicated by yellow to green colors on the map. These lowland areas are more vulnerable to fires due to a combination of drier conditions, more flammable vegetation types, and potentially greater human activity, all of which contribute to higher fire susceptibility. The strong alignment between these high-probability zones and actual fire occurrence points suggests that the model effectively identifies environmental and anthropogenic drivers of fire activity. This ability to delineate between high-risk lowlands and fire-resistant highlands offers a more refined understanding of fire patterns in Santa Marta, underscoring the critical role of topography and human influence.

While the model shows high accuracy overall, some discrepancies arise in certain areas. False positives—zones with high predicted risk but low observed fire occurrence—may reflect areas where recent precipitation or localized land management has mitigated fire risk. On the other hand, false negatives—observed fires in areas with low predicted probabilities—indicate that some influencing factors, such as transient weather events or recent land use changes, may not be fully captured by the model. These results suggest that further model refinement could enhance predictive accuracy, particularly by incorporating additional dynamic variables like monthly precipitation or data on human activity. The model's current success, however, demonstrates that it is a powerful tool for understanding fire risk distribution, providing a foundation for more advanced analyses.

The study's findings are significant for heritage-focused fire management in Santa Marta. By identifying fire-prone zones near the Línea Negra, this research informs targeted strategies to protect culturally and ecologically valuable areas. Fire prevention efforts, such as controlled burns or increased monitoring, can be prioritized in the lower elevations with higher predicted risk, while less intensive measures are applied to the fire-resistant highlands. This approach aligns with the broader goal of integrating ecological preservation with cultural conservation, highlighting the need for fire management practices that respect both environmental resilience and the cultural values embedded in the landscape.

Looking forward, further research could improve model performance by integrating more detailed predictors and conducting temporal analyses to account for seasonal variations in fire risk. Additionally, validation using metrics like Area Under the Curve (AUC) and precision-recall scores could offer more rigorous assessments of the model's predictive capability. Overall, this study underscores the value of combining advanced modeling techniques with cultural conservation goals, advocating for a holistic approach to fire management that addresses both environmental and cultural imperatives. The insights generated here provide a strategic framework for safeguarding the resilience of indigenous heritage and maintaining the ecological integrity of the Santa Marta region, reinforcing the interdependence of natural and cultural landscapes in fire management planning.

539. Mapping architectural Comparanda: AI Methods for Large Scale Analysis of the Archaeological Record for Reconstruction of Greco-Roman Architecture

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Introduction

With the rise of digital technologies in archaeological reconstruction and heritage visualization, the London Charter established principles to ensure that digital heritage visualization would be intellectually and technically rigorous. This quest has become more urgent with the explosion of generative AI tools that enable anyone to create surreal and seemingly realistic images of cultural heritage. Most of these off-the-shelf tools generate text and images via opaque processes that cannot be verified and hence fail to conform to the guidelines of the Charter of London. In contrast, our work develops novel machine learning methods to analyze and identify interpretable patterns in the large body of archaeological record from the Greco-Roman architecture.

Among the archaeological data generated from excavations, building remains are of the largest scale and the most complicated to understand and reconstruct. The mission of archaeology is to document their state of preservation in drawings, text and numerical measurements, reconstruct their initial form, and interpret them. The challenge is that data is always partial and fragmentary to various degrees. To reconstruct a building, archaeologists must identify the known (invariable) and the missing (variable) parts of the building and identify among the whole archaeological record other parallel and precedent comparable designs (architectural comparanda) based on geography, chronology, typology, or patronage from which they can infer the variable parts. This process is very laborious and never conclusive as there is not always consistency in the state of preservation, the level of detail or the format of the publications, and the interpretative framework and the available evidence change over time in the history of scholarship, and often there are more possible hypotheses. To systematize this effort, archaeologists may create taxonomies for the classification of artifacts and use statistical analysis, however, the use of these methods is still very limited. Our project is grounded on the applicability and transferability of this methodology in generativeAI, that has the unprecedented capacity to analyze vast amounts of archaeological records at scale, create a vast dataset of buildings annotated with their architectural principles and linked to their “comparanda” based on a variety of criteria, to enable the more ambitious goal of accurate and traceable automatic reconstruction of architectural plans from archaeological findings.

Among the different styles, GrecoRoman architecture is an excellent case study for the development of AI-based methods, because it consists of a certain vocabulary of architectural components, related with certain relationships, proportions and sequences. A major challenge is the highly variable nature of the archaeological data, such as textual descriptions, measurements, drawings. Manually analyzing such records at scale is impractical for experts to perform. We are developing natural language processing (NLP) techniques and language models to parse this unstructured and diverse data, extract the relationships between the various buildings directly from the pdfs of the archaeological records, analyze this data at scale, synthesize and visualize it in a network of buildings (network nodes), linked to their “comparanda” based on various criteria (links), and expand this network via statistical inference.

Methods and materials

Our methodology includes a series of stages. First of all, we focus on dataset creation. Over the decades, disparate teams of archaeologists have described their findings in archaeological records that might contain drawings, images, measurements, organized tables, textual interpretive analysis, and conjectures about relationships between buildings. These records do not have a standard format and might contain information at varying levels conveyed through different communication strategies. The first step in our approach is to identify and collect all relevant archaeological publications and process them minimally to initialize the landscape of the network we are building. This involves the curation of the list of major archaeological journals, book series and other sources of archaeological publications in pdf format, and we are using a combination of query and scraping methodologies to search these sources for relevant archaeological records and extract the data to build our network. We develop methods for refinement of this list of records, which contains false positives and false negatives, by building lightweight predictive machine learning systems with active learning strategies (Settles 2009) that will evaluate statistically the occurrence of relevant Greco-Roman features in them, to discern the relevant archaeological records from other kinds of documents.

Second stage is the formulation of a taxonomy of relationships between buildings. This phase of the project is focusing on designing a taxonomy of the relationships between components exemplified in the buildings. These relationships vary from modeling simple temporal and geographical correlation and patronage to more complex underspecified relationships like stylistic and typological correlation. This taxonomy will serve as ideal grounding for the automatic large-scale analysis of archaeological records.

The third stage is the extracting information from archaeological records, that focuses on the computational analyses of images, tables, and relevant text with the help of generative AI and machine learning methods, with the goal to extract relevant information from the unstructured archaeological documents to populate the structured fields imposed by the taxonomy identified above. Specifically, we are focusing on training computer vision (CV) and natural language processing (NLP) systems to identify systematic patterns in the documents that indicate information related to the elements of taxonomy. We propose to use and adapt open-source language models, open-source neural-network based pretrained tools for layout analysis, and NLP, and vision-language multimodal models, techniques like ColPali (Fayesse et al. 2024)

Discussion

Our goal is to harness the capacity of generative AI to analyze vast amounts of archaeological records at scale, which is impossible to do manually, create a vast dataset of buildings annotated with their architectural principles and linked to their "comparanda" based on a variety of criteria, and in the future enable AI-generated reconstructions to be linked to this dataset, so that these reconstructions are accurate and traceable. The immediate major impact of this unprecedented large-scale analysis on humanistic inquiry is that it will suggest connections that might have eluded the scholars, thus identifying possibly misrepresented or underrepresented aspects of cultural production and subtle differentiations or correspondences in the material record that reflect cultural and political influences and intercultural connections. Ultimately, we propose to develop AI to bridge the gap between state of preservation and reconstruction, automate the reconstruction process, and generate accurate and traceable focus iterations of buildings referencing their various possible architectural comparanda.

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236. OpenAI vs. Open Source - Evaluating the Performance of Large Language Models on Extracting Structured Data from Archaeological Texts

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The application of generative Artificial Intelligence (genAI) in archaeology has the potential to automate the extraction and analysis of data from academic texts. This study investigates the performance of ChatGPT compared to an open-source large language model (LLM) in extracting information from various archaeological texts. We apply these methods to two case studies: extracting radiocarbon dates and extracting species names.

For the radiocarbon dates, we use scholarly papers focused on the Neolithic period in the Netherlands. Radiocarbon dating is crucial for establishing chronologies in archaeology, but manually extracting and verifying these dates from a multitude of research papers is both time-consuming and prone to error. For the species extraction, we use Dutch excavation reports, and use the manually composed BoneInfo database as test data.

Our research involved evaluating two types of genAI models: OpenAI's ChatGPT and Mistral, an open source model. The evaluation was based on their ability to accurately identify and extract radiocarbon dates and species, together with additional information, such as context, sample material, and amount of materials found. For both models, we force the output to be a CSV, and compare this to handcrafted data. We defined performance metrics focusing on precision, recall, and F1-score to assess the models' performance on extracting relevant dates.

Initial results show that ChatGPT is relatively successful, with 89% F1 on species extraction, and 84% F1 for radiocarbon date extraction. We also see that the LLMs find correct information not present in the human created test data (true false positives). This shows the ability of these models to not only take over tasks completely, but also supplement existing data. And this further cements the idea that there is no such thing as a “gold standard” in archaeology; most train/test data is flawed in some way.

Besides the results of the LLMs, we will also present baselines to compare the results to, discuss ethical issues surrounding the use of these models, and present some information relating to the practical issues and cost of using LLMs vs. simpler methods and baselines. Finally, all code and data will be available after the conference, to allow other researchers to verify our work, and apply the methods to their own data.

542. Improved Information Retrieval for unstructured textual data in Indian Epigraphy using Retrieval Augmented Generation (RAG)

Srinidhi Balasubramanian (IIITDM Kancheepuram)*; Harish Krishnamoorthy Murali (University of Waterloo); Rohini P (IIITDM Kancheepuram)

Introduction

Indian epigraphy is vastly diverse and complex, with around 90,000 to 200,000 inscriptions and over 80% of all our knowledge about the history of India before 1000 AD is derived from these epigraphs. Throughout the 19th and 20th centuries, inscriptions were edited, translated, and published in print journals and periodicals. These print publications are the only access to any epigraphic data today. Thus, unlike structured data found in databases, epigraphic data has largely remained undigitized, unstructured, and fragmented in print publications and as a result, information retrieval remains a manual task. Existing Information Retrieval (IR) methods often fall short due to the unstructured nature of textual data. New information retrieval methods for Indian epigraphy should be able to handle noisy, unstructured data with little or no training.

Large Language Models (LLMs) with state-of-the-art language understanding and generation capabilities seem a promising approach to the given problem. These models require little or no further training, which is the prime motivation for using LLMs for IR tasks in Indian Epigraphy. However, a key challenge in employing LLMs is that when faced with domain-specific or knowledge-intensive tasks, LLMs tend to hallucinate, i.e., return incorrect answers confidently. To address these limitations, the use of a Retrieval Augmented Generation (RAG) based IR system was explored. RAG is a two-step process of retrieval and generation, where it first retrieves relevant documents to a user's query from an external database and then uses LLMs to generate a final answer. Multiple LLM-based retriever designs were explored as a part of this work to improve the retrieval and generation.

Methods

The dataset preparation involved acquiring english text (translations) of inscriptions predating the 6th century AD. These inscriptions, originally in Prakrit and Sanskrit languages and written in Brahmi script, belong to the Satavahana, Western Kshatrapas, and the Ikshvaku kingdoms. A total of 32 diverse inscriptions, consisting of around 7k words and around 11k tokens, finally constituted the dataset. For the retrieval and generation modules, GPT models - GPT 3.5 Turbo with text-embedding-ada-002 as the embedding model and GPT 4 with text-embedding-3-large were used. Due to the costs of running LLMs and limited resources, the dataset size was constrained. 20 question-answer pairs for the test dataset were created.

It was observed that the retrieval based on specific named entities in the query resulted in better retrieval of documents. Named-entity Recognition (NER) was employed for this, and then most important entities were extracted from each query using zero-shot prompting and one-shot prompting. Further it was observed that the retrieved chunks were often incomplete, the information retrieved was insufficient. To mitigate this loss of information, 'dechunking' was employed. Dechunking is here defined as the reconstruction and retrieval of the original document from the retrieved chunk.

To summarize, the query was first subject to entity resolution using NER and top-k chunks were retrieved for each entity. Dechunking was applied on the set of retrieved chunks. This final set of documents was used by the LLM to generate the answer.
The evaluation of the retrieval modules and generation modules were done separately. Retrieval was evaluated using standard metrics - Precision, Recall, and F1. Generation was self-evaluated using the LLMs, with the model evaluating for Completeness, Hallucination, and Irrelevancy.

Results and Findings
In terms of retrieval performance, dechunking resulted in higher precision and recall values. While recall dipped slightly, the overall F1 score was higher consistently in cases where dechunking was employed. It was also seen that NER helped with better precision scores in 3 out of 4 cases. However, one-shot prompting proved unfavourable for GPT 3.5 but greatly favourable for GPT 4o. Further, since the retrieval of relevant documents are prioritized over the non retrieval of non-essential documents during the process of dechunking, a lower retrieval score when compensated with a higher precision is not undesirable.
Evaluating generation, GPT 3.5 was consistently better in terms of completeness and irrelevancy while the answers generated by GPT 4o exhibited lesser hallucination.

Discussions
This research demonstrates the potential of Retrieval-Augmented Generation (RAG) and Large Language Models (LLMs) for tackling the inherent complexities of Indian Epigraphy. The improved RAG approach integrating dechunking and Named Entity Recognition (NER) has demonstrated significant improvements over the traditional RAG architecture in both retrieval and generation tasks.
Future work will focus on expanding the dataset size and diversity to include a broader range of inscriptions, which will enhance the model's robustness and generalizability. Experimenting with various Large Language Models (LLMs) will allow for comparative analyses, and possible open-source and cheaper alternatives. This work seeks to set a foundation for the integration of Generative AI and language models in epigraphy and archaeology, to contribute to the ongoing efforts to digitize and make accessible the rich epigraphic heritage of India."

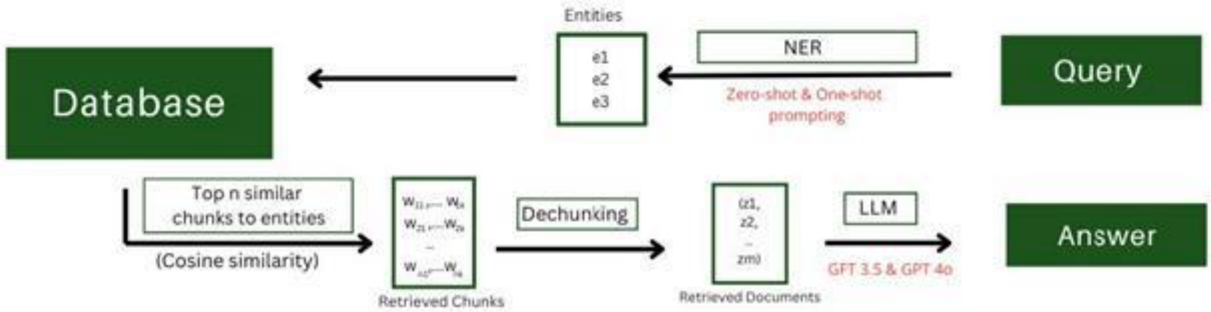

Figure 1: RAG including NER and dechunking

Table 1: Evaluation Metrics for Retrieval.

LLM	Dechunking	NER	Precision (P)	Recall	F1
GPT 3.5	No	No	0.383	**0.725**	0.480
GPT 4o	No	No	0.350	0.675	0.443
GPT 3.5	Yes	Zero-shot	0.404	**0.725**	0.502
GPT 4o	Yes	Zero-shot	0.421	0.600	0.482
GPT 3.5	Yes	One-shot	0.375	**0.725**	0.482
GPT 4o	Yes	One-shot	**0.521**	0.600	**0.548**

Table 2: Evaluation Metrics for Generation.

LLM	Dechunking	NER	Completeness	Hallucination	Irrelevancy
GPT 3.5	No	No	40.83%	35.00%	24.17%
GPT 3.5	Yes	Zero-shot	57.84%	20.59%	21.57%
GPT 3.5	Yes	One-shot	**59.07%**	20.56%	**20.37%**
GPT 4o	No	No	49.12%	**5.26%**	45.61%
GPT 4o	Yes	Zero-shot	51.96%	8.82%	39.22%
GPT 4o	Yes	One-shot	55.83%	12.50%	31.67%

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238. Building AGNES - a Search Engine using Text Mining and Large Language Models to Unlock the Knowledge in Archaeological Literature

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Archaeology is a destructive process in which, after excavation, the evidence primarily becomes written documentation. As such, the archaeological domain creates huge amounts of text, from books and scholarly articles to unpublished fieldwork reports ('grey literature'). Easy access to the information hidden in these huge text collections is a substantial problem for the archaeological field. Searching for and analysing these documents for archaeological research and heritage management is a time consuming task when done by hand, and will often lack consistency.

In the EXALT project at Leiden University we have been working on the development of a semantic search engine for archaeology in and around the Netherlands, called AGNES, indexing all available, open-access texts (>150,000 documents), which includes Dutch, English and German language documents.

Before AGNES, it was only possible to search through the metadata of these documents, mainly via national research databases and repositories. However, these metadata are often limited and sometimes inconsistent, and don't capture the 'by-catch opportunity'; i.e. a single Bronze Age find within a large Medieval excavation. With AGNES, we can search through all of the text in a smart way, which allows for better literature research and has led to the re-discovery of important archaeological finds and contexts across the Netherlands.

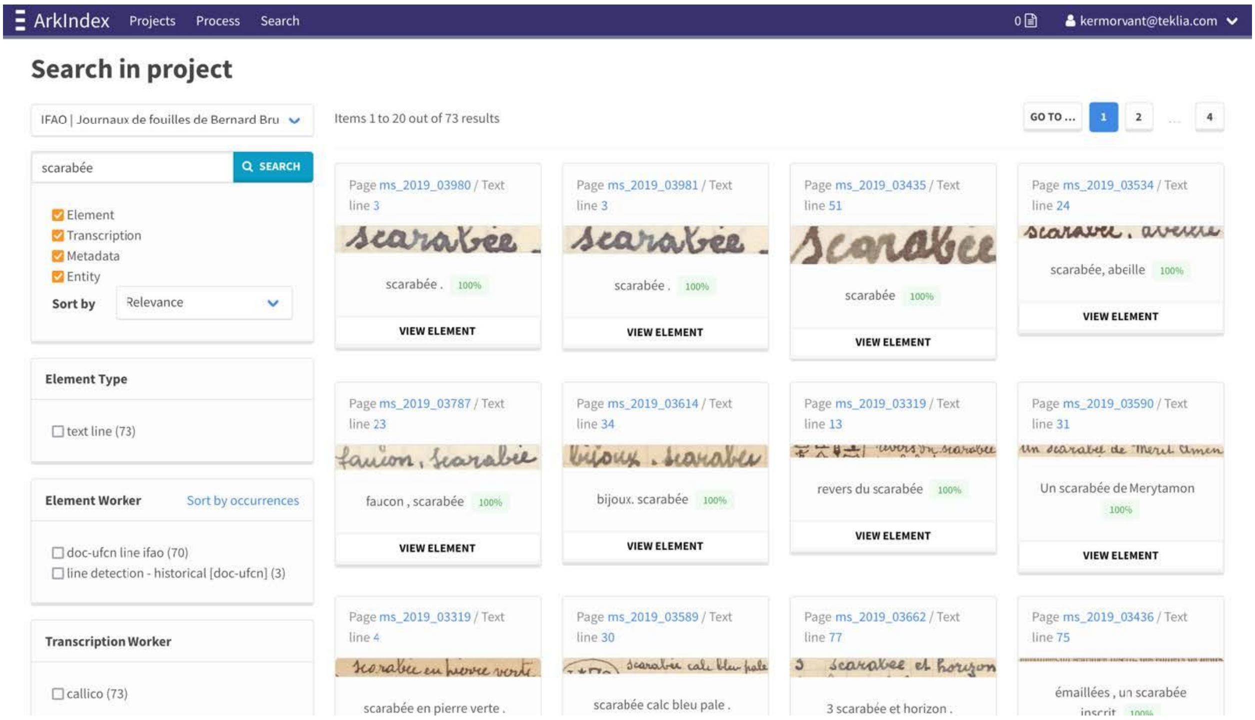
In this presentation, we will present our work on using a Large Language Model (LLM) to enhance search, discuss the latest version of AGNES, present the results of two case studies, and share lessons learned over the past 8 years of this project.

Finally, we will briefly discuss some ideas for future research, where we want to build an archaeology specific Retrieval Augmented Generation (RAG) system, which leverages the power of generative LLMs combined with specific information retrieved from a document collection, to stop hallucination. This would lead to a chat interface with which archaeologists can interrogate and analyse huge amounts of texts.

129. From field notes to digital archive: AI-assisted indexing of Bernard Bruyère's excavation journals of Deir el-Medina (1922-1955)

Cédric Larcher (Institut français d'archéologie orientale); Christopher Kermorvant (TEKLIA)*

Excavation journals are an essential part of archaeological documentation, but are often under-utilised due to their limited accessibility. This paper presents the processing and enrichment of Bernard Bruyère's excavation journals from Deir el-Medina (1922-1952), comprising nearly 900 pages of handwritten text and illustrations. We implemented a hybrid workflow combining automatic text recognition, handwritten text recognition (HTR) and manual enrichment to process these documents. A custom HTR model, trained on 3,738 lines of annotated text, achieved a character error rate of 4.5%. The resulting digital archive, accessible through a dedicated platform, contains 36,506 lines of transcribed text, 5,479 illustrations, 268 maps and 360 hieroglyphic inscriptions, all enriched with metadata. The platform enables full-text search with precise line locations, browsing by illustration classification, and metadata-based queries. This project demonstrates an effective methodology for transforming historical archaeological documentation into searchable digital resources while maintaining scholarly standards.



172. Bridging the Past and Future: The Role of AI in Transforming Archaeological Data and Archives

Alphaeus Lien-Talks (University of York, Historic England, Archaeology Data Service)*

This paper explores the transformative capabilities of artificial intelligence (AI) in the field of archaeology, focusing on how AI technologies can enhance the FAIRness, accessibility, usability, and interconnectedness of digital archives, legacy datasets, and multilingual resources. AI-driven methodologies are reshaping how archaeological data is processed, analysed, and interpreted, offering new possibilities for uncovering patterns and insights across diverse and historically significant datasets. By integrating AI into various facets of archaeological research, practitioners can achieve more streamlined access to historical data and foster innovative ways to connect disparate sources. This paper highlights both the successes and challenges associated with AI applications in archaeology, drawing on case studies from archaeological archives including bioarchaeological and multilingual grey literature to illustrate the potential and limitations of these tools. In doing so, the findings underscore the need for interdisciplinary collaboration to address ethical considerations, data quality issues, and technical constraints, ultimately proposing a roadmap for effectively integrating AI to foster new insights and enhance the global reach of archaeological knowledge.

133. AI Chatbots for Archaeology: OLiT-T and ArkasAI Data Analyst

Benjamin Štular (Research Centre of the Slovenian Academy of Sciences and Arts)*; Edisa Lozić (Research Centre of the Slovenian Academy of Sciences and Arts)

This paper introduces two AI chatbots tailored for archaeological research and education: OLiT-T and ArkasAI Data Analyst. OLiT-T, based on large language models (LLMs) enhanced with curated archaeological data, serves as an interactive tutor for users of the Open LiDAR Toolbox, facilitating high-precision airborne LiDAR data processing. ArkasAI, similarly built on LLMs and augmented with computational algorithms, supports advanced statistical analysis for the Arkas 2.0 archaeological database, which houses data on over 8000 Slovenian archaeological sites. These chatbots provide archaeologists and students with accessible and scalable tools for data analysis, enabling efficient data retrieval, multilingual support, and sophisticated analytical capabilities. While rapid advancements in AI may diminish the technical novelty of these tools by CAA25, this presentation emphasizes insights on user engagement, practical application, and future directions.

535. Gimme! Gimme! Gimme! (A Reliable Access Method for ChatGPT 4o in Archaeological Heritage Prompting)

Haley Schwartz (Universitat de Barcelona)*; Tania Gonzalez Cantera (Universitat de Girona)

Introduction

Researchers claim that publicly available generative AI is the future of the AI subfield of machine learning (Munn et al., 2023). ChatGPT-4's launch, a tool developed by OpenAI, attracted public attention in early 2023. ChatGPT is based on the LLM called GPT-4. GPT-4 is pre-trained with a large dataset of information as a step prior to generating a response to a human prompt (Cobb, 2023). It is necessary that in the face of new technologies and technological approaches, before dismissing their use for whichever reason, we evaluate its use and the benefits within archaeological heritage (Cobb, 2023). To highlight pitfalls and shortcomings in conjunction with demonstrating the potential advantages of conveniences of use. With the growth of ChatGPT for public use it is even more important to see what the public is using – what knowledge is potentially being created and any impacts Generative AI created archaeological knowledge has.

Background

This paper aims to evaluate the use of Generative AI tools, specifically focused on the ChatGPT-4 model, in the context of prompting for archaeological heritage knowledge generated by this tool. There needs to be an evaluation of the exact method in which one is accessing Generative AI tools. It is necessary to determine potential differences in responses from Generative AI models to highlight the advantages and disadvantages in the access method used. What are the different platforms in which one can access this model and what is the level of differences between responses? By understanding the potential different narratives provided by ChatGPT-4 in prompting about archaeological heritage, it is possible to gain insight into the types of interpretations users are presented with.

Two case studies were conducted to evaluate different interpretations and narratives associated with two categories of archaeological heritage: Contested Heritage and Heritage Tourism. Within the context of Contested Heritage, the lens was to evaluate the appearance of political ideologies and biases present within information generated about these sites. Within the Heritage Tourism context, the goal was to evaluate the narratives presented about archaeological landscapes available to visitors.

Materials and Methods

Materials

This project evaluated the responses from the ChatGPT-4 model using three different access methods: 1] the OpenAI user interface; 2] Replit, an online platform that allows users to compile and run code via a browser – in this case utilizing python and an API key to query ChatGPT; and 3] ELM – an access platform to ChatGPT developed by a university. Per this specific research, the prompts themselves were not analyzed as data, though it is important to note the impact the prompts used will have on the response. The focus was entirely on the potential differentiation in responses from the same prompts and same model – through different platforms.

Methods

Three prompts were created per case (i.e., Contested Heritage and Heritage Tourism) and then applied across three different platforms using the ChatGPT-4 model. Once the responses were catalogued, they were evaluated to determine any potential differences between the responses.

The primary analytical method was qualitative, specifically Critical Discourse Analysis (CDA) – purely because the evaluation of political ideologies and interpretations of archaeological heritage landscapes necessitated a 'close-reading' approach including the interrelation between discourse and the socio-historical context.

Results

There are similarities in ChatGPT responses for both presented case studies: there are significant differences in the type of response that is provided relative to the access method of the Generative AI tool. Specifically, there is inconsistencies in the ChatGPT-4 model responses, as evidence by prompting said model through three platforms. For both case studies, there was a clear outline of details, capability of responding to the prompt, and narrative.

The OpenAI user interface provided responses that were the most detailed and accurate. In the case of the Contest Heritage context, there was a variation in the model's capability to answer the prompt based on language (i.e., in Spanish: no answer; in English: answer). Whereas, in the Heritage Tourism context, other sites were referenced, and more categories of information were provided. Both Replit and ELM had fewer substantial responses, though the responses from Replit followed a more cohesive and clearer narrative pattern in comparison to OpenAI, with ELM having a more disjointed response. The type of language used by each platform also differed from each other, with significant facts or additional information left out.

Overall, the results clearly highlight that the OpenAI user interface was the best option for utilizing ChatGPT-4 purely because there are such vast differences in the level of responses depending on the platform used. Additionally, the results indicate that there needs to be more discussions on the lack of standardization in responses – even when using the same model.

Discussion

Each access method is limited by different levels of accessibility and usability for the public. With OpenAI, that user interface is the most likely to be accessed by public users – regardless of one's computational training background – there is ease of use. Whereas Replit and any other similar platform is limited to users with background knowledge of API keys and computer programming. Lastly, ELM is a platform developed and operated by a university, in which the use is limited to students or employees of the university operating this platform. The subsequent contexts, semantics, and narratives provided by ChatGPT-4 through different platforms has a direct impact on creating consumable biases and interpretations of archaeological heritage.

The user's choice in which platform will be used results in vastly different responses. It doesn't matter if the user is interested in political ideologies linked to contested heritage or interpretations of neolithic monuments, the context through which one prompts (i.e., OpenAI, Replit, ELM) will have a direct impact on both the type of knowledge generated and consumed by the user.

If one can accept that generative AI tools, like ChatGPT, are a new wave of knowledge creators it brings about the necessity to discuss the implications this has on a multitude of fields of study. Especially, with the levels of inherent subjectivity in fields like archaeology, heritage and anthropology, where knowledge is ever evolving and dependent on the intrinsic lack of the concrete in these fields.

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39. Limitations Of Generative Artificial Intelligence Reconstructing Prehistoric Archaeology

Joan Barcelo (UAB, Spain)* Eudoxia Tzerpou, Deniz Kayikci, Borja Urbistondo

Generative artificial intelligence (GenAI) has emerged as a powerful tool in various fields, including archaeology. However, its application in reconstructing prehistoric archaeology presents unique challenges and limitations that warrant careful consideration.

In this presentation we argue that the fundamental limitation of generative AI in prehistoric archaeology not only stems from the inherent uncertainty and incompleteness of archaeological data used for training. The spatial and temporal relationships between artifacts, features, and environmental factors are complex and not always easily quantifiable for AI systems. Current AI systems may not adequately capture this interpretive flexibility, potentially leading to overly deterministic or simplified reconstructions.

Furthermore, the "black box" nature of some AI algorithms can make it difficult to understand how reconstructions are generated. This lack of transparency poses challenges for scientific reproducibility and peer review in archaeological research

To address these limitations, we propose a theoretical framework that emphasizes Hybrid Approaches, Uncertainty Quantification, Data Diversity, Interpretive Pluralism, Ethical Guidelines, Transparency Protocols, Interdisciplinary Collaboration: Fostering closer collaboration between archaeologists, AI researchers, and ethicists to address the unique challenges of applying AI to prehistoric contexts.

Realizing the potential of Generative Artificial Intelligence to archaeological reconstruction requires a nuanced approach that acknowledges and addresses the inherent limitations of AI in this context. The key challenges and difficulties in applying these methods in our domain include:

• Dealing with the high dimensionality and complexity of 3D data compared to 2D images. This may require adaptations or extensions of the existing 2D methods.

• Ensuring the extracted texture features are robust to common 3D data artifacts and distortions, such as noise, occlusions, and missing data.

• Developing efficient and scalable algorithms that can handle large-scale 3D archaeological datasets, which may be computationally intensive.

• Integrating the texture feature extraction methods seamlessly into the generative AI pipeline, ensuring compatibility and synergy with other components like 3D shape modeling, material synthesis, etc.

• Evaluating the suitability and performance of the texture feature extraction methods on specific 3D archaeological datasets and the intended generative AI applications, as their effectiveness may vary.

By adopting a theoretical framework that combines technological innovation with rigorous archaeological methodology and ethical considerations, we can work towards more accurate, inclusive, and responsible reconstructions of prehistoric societies. This framework not only addresses the current limitations of AI in prehistoric archaeology but also sets the stage for future research directions. As AI technology continues to evolve, ongoing critical evaluation and adaptation of these approaches will be essential to ensure that generative AI becomes a valuable tool in expanding our knowledge of prehistoric human societies while respecting the complexity and cultural sensitivity of archaeological interpretation.

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404. Transitioning to Digital Field Recording: the Thorikos Experience

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The ancient site of Thorikos (Eastern Attica, Greece), well known for its silver mines and associated industrial installations, has been the focus of archaeological investigations since the 19th century. Since the 1960s, the Thorikos Archaeological Research Project (TARP), a Ghent University and Belgian School at Athens archaeological project, has explored the site of Thorikos and produced important data spanning from the Final Neolithic to modern times on its different mining installations, settlements and cemeteries. In 2021, a new pilot project, “iDig for Thorikos. Operationalization of the Thorikos legacy data collection” was launched to operationalize the legacy data of the TARP, and to deploy a digital recording that would help to produce structured archaeological data in the forthcoming excavations. To achieve this goal, the iDig application, designed by the American School of Classical Studies at Athens under the direction of Bruce Harztler, has been chosen because the software is free to use, can be easily adapted even by non-IT specialists to suit any archaeological workflow and is now used in multiple research projects in Greece. This paper explores the impact of digital field recording at Thorikos, focusing on the benefits and challenges encountered while transitioning from traditional paper-based to digital recording with the iDig app.

During the four-year iDig for Thorikos pilot project, the app was used in two primary sectors: the so-called Southeast Necropolis (2021-2024) and the Theater (2023). iPads were employed to record all archaeological data, which was directly linked to its spatial location through a Raspberry Pi-configured local access point connected to a Leica TS06 Plus or TS07 total station. The iDig interface offers a user-friendly experience with a clear division of information. The left-hand panel provides a list of records, while the right-hand panel displays a spatial visualization of the selected data. This GIS-inspired interface enables users to intuitively explore data within its geographic context. The app is designed to support trench-level recording. However, at Thorikos, due to the specific context of relatively small, closely located trenches and a large number of student excavators, a more centralized approach was adopted: assistant field directors were primarily responsible for data recording using iPads, while students were trained to assist in data entry. The use of iPads for recording drew significant interest from students, who found the devices engaging and helpful for data entry. However, it is worth noting that the structured and standardized format of digital data entry inherently shapes the user's thought process more rigidly than traditional paper-based methods. This shift may encourage consistency but could also limit more spontaneous or creative forms of documentation, which is especially important when forming new students.
The iDig data structure and archaeological glossaries were customized to align with existing TARP standards, as made possible by the iDig app via a text-based preferences file. Drop-down menus ensured consistent terminology and data quality, safeguarding data integrity and validation. Additionally, iDig has been implemented in the finds laboratory running next to the excavation. Data produced by specialists, and notably chronologies based on ceramic typologies, are immediately merged with excavation data and available on the field the next day. The merging of data produced on the field and at the finds laboratory necessitated data synchronization among the different users: manual synchronization between iPads, a feature of the iDig app, was performed daily.

Synchronization is a critical aspect of digital data collection. In the Thorikos project, where a limited number of devices were used, manual synchronization was manageable. However, in larger-scale projects involving multiple teams and devices, automated synchronization methods, such as those utilizing cloud-based servers, would almost become necessary. Implementing such a system would require reliable internet connectivity in the field, which can be a significant challenge in remote or rural areas, and the help of IT specialists.

The use of multiple iPads and a server can significantly increase the initial and ongoing costs of a digital field recording project. In the case of Thorikos, a research grant from Ghent University enabled these expenses. However, the sustainability of such projects can be impacted by the temporary nature of research funding, as the maintenance and upkeep of digital infrastructure often require ongoing support.

While digital tools can streamline many aspects of fieldwork, they do not eliminate the need for thorough post-excavation analysis. Moreover, many excavators who adopt digital recording methods continue to rely on personal notebooks for sketches and quick informal notes, preserving the degree of flexibility that digital systems may lack. At Thorikos, we incorporated features to accommodate the sketches. These handwritten additions are scanned and integrated into the digital database post-excavation, ensuring that valuable, context-specific observations are preserved while maintaining the overall consistency and accessibility of the project's digital records. Despite the use of iDig, a significant time was still required to process stratigraphic data and other relevant information.

Therefore, while digital field recording offers numerous benefits, it is essential to carefully consider the specific needs of the project, the available resources, and the long-term implications of adopting such technologies.

54. Building a Digital Legacy: The Itanos Excavation Database

Isabella Bossolino (Université Libre de Bruxelles)*; Ioannis Chalazonitis (Ecole française d'Athènes); Athéna Tsingarida (Université Libre de Bruxelles); Didier Viviers (Université Libre de Bruxelles)

Context

In recent years, digital tools have become indispensable for documenting, managing, and disseminating archaeological data, especially as fieldwork methods evolve to address the growing demands for data transparency, accessibility, and long-term preservation. The Itanos Excavation Database, developed on the Heurist platform, demonstrates the impact of digital frameworks in enhancing the organisation, accessibility, and longevity of archaeological information. Created to support the documentation of excavations conducted by the Université Libre de Bruxelles and the Belgian School at Athens, the database consolidates diverse datasets, including US context sheets, objects, photographs, drawings, and data from physical anthropology, archaeozoology, and palaeobotany.

Digital fieldwork documentation has gained increased recognition in recent literature as an essential component of modern archaeology. Studies highlight the role of these tools in facilitating more integrated and dynamic approaches to data management, as well as their potential to foster collaborative, interdisciplinary research. By drawing on recent publications, this paper will position the Itanos Excavation Database within the broader landscape of digital archaeology, examining how such tools can reshape data workflows, support data curation, and promote the sustainability of archaeological records.

This paper will offer a detailed overview of the Itanos Excavation Database's structure, content, and applications, illustrating its value not only as a repository but as an active research tool that enables archaeologists to engage with and reinterpret field data continuously. In doing so, it underscores the importance of adopting digital methodologies to meet the evolving challenges of archaeological practice in the digital age.

Heurist as a Digital Research Platform

Developed by the University of Sydney, Heurist is a versatile, web-based database platform specifically designed for researchers who need a robust yet accessible environment for managing, analysing, and publishing diverse datasets. Tailored for the digital humanities, Heurist requires no specialised programming skills, making it approachable for researchers across a range of disciplines. Unlike traditional databases, which often demand extensive customisation and technical expertise, Heurist provides a suite of pre-configured templates and schemas that suit various research objectives. Researchers can further adapt these templates, allowing Heurist to meet highly specific project needs.

A key strength of Heurist lies in its flexibility and scalability, enabling projects to grow and evolve without the need for major restructuring. The platform incorporates data visualisation tools and supports complex relational data, making it ideal for projects involving multiple data types — such as texts, images, and geospatial information — and intricate data interrelationships. Heurist's powerful querying capabilities facilitate the analysis of large datasets, and its data-sharing features support both controlled access and open dissemination of information. Well-suited for collaborative research, Heurist allows multiple users to access and edit records concurrently, backed by a comprehensive audit trail that tracks all modifications.

The Itanos Excavation Database

The Itanos Excavation Database has been purpose-built to document the archaeological findings from the Itanos site in eastern Crete, excavated by the Université Libre de Bruxelles (ULB) and the Belgian School at Athens. This site holds considerable historical importance, encompassing multiple cultural layers from the Archaic to Byzantine periods. The database utilises Heurist's customisable schema to capture the complex and varied nature of the archaeological data collected during the Itanos excavations.

Organised into distinct modules, the database systematically records different types of data, including single-context sheets (stratigraphic units), artefacts, photographs, drawings, as well as records in physical anthropology, archaeozoology, and palaeobotany. Each module includes detailed metadata, documenting not only the physical characteristics of each artefact or context but also their spatial and temporal relationships. This structure enables researchers to trace the provenance and chronological development of artefacts, enhancing our understanding of the historical significance of Itanos.

One of Heurist's standout features in this setting is its capacity to manage complex relationships across datasets. For instance, the Itanos Excavation Database links stratigraphic units to associated artefacts, ecofacts, and bioarchaeological records, mirroring the interconnected nature of archaeological evidence. Additionally, Heurist's support for image storage enables the inclusion of essential visual records for material culture analysis. Through its dynamic querying and filtering capabilities, Heurist allows users to investigate specific data subsets, such as artefacts from a particular stratigraphic layer or ecofacts related to a specific historical period.

Applications and Insights

The Itanos Excavation Database serves multiple roles, supporting ongoing research and providing a durable digital archive for excavation data. By offering structured, easily accessible data, the database facilitates comparative studies both within the Itanos site and across other Mediterranean sites. The adaptability of the Heurist platform has enabled us to respond flexibly to evolving research questions and incorporate new datasets, ensuring that the database remains relevant as research on the Itanos site progresses.

In addition, the database is a valuable resource for educational and outreach activities. Students and early-career researchers gain practical experience in data analysis and management by interacting with a repository that reflects real-world archaeological practices. Anticipated future public access will further extend the database's impact, engaging a broad range of audiences — from local communities invested in their heritage to international scholars specialising in Mediterranean archaeology.

The Itanos Excavation Database addresses data management challenges through Heurist's audit features, which preserve data integrity by maintaining a detailed log of modifications, ensuring accountability. A tiered access system within Heurist further enables controlled data sharing, balancing transparency with the protection of sensitive information.

This excavation database exemplifies how platforms like Heurist enhance archaeological research by simplifying data management, fostering collaboration, and supporting knowledge dissemination. As a case study, the Itanos Excavation Database underscores the value of digital tools in archaeology and highlights the flexibility of Heurist as a platform that accommodates the unique demands of archaeological data. As we continue to expand and refine the database, we hope it can offer valuable insights for other archaeological projects aiming to utilise digital infrastructure for efficient data curation and support ongoing research efforts.

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201. The 25 year path towards digital field recording in archaeology

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When I got my Masters degree in archeology in 2001, recording in the field was still a 99% manual proces. This meant that somebody needed to copy all this analogue data to a digital form to make is processable. Bad handwriting, sloppy drawings, dirty sheets of paper and a lack of standardisation meant that some of this analogue data got lost in the transcription process and added double work.

Almost 25 years ago I joined a local archaeological society where I started my path towards digital field recording. There I experimented with a laptop in the field and made paper context forms that were more friendly to transcript into a digital form. In 2006 I became a full-time CRM archaeologist and having a bad handwriting myself, I expanded the experiment of the laptop: not only registering context sheets digitally, but also drawing digitally using a vector program. Digital camera's made their introduction as one of the first commonly used ways to make a digital field recording. Also, the concept of a daily backup became a thing. Because of the limits of a laptop, most work was still done on paper, but with an upgrade. Preprinted context sheets for different kinds of features and tailored to the excavation, made the analogue recording in the field faster and reduced errors in the transcription process. Since I was the one making these context sheets I could adapt them swiftly. The transition from simple spreadsheets to a relational database improved linking the different data at the office.

However, this was still far from fully digital recording in the field. The use of a smartphone, fieldbook or laptop remained highly limited, especially in a dirty excavation. It was the introduction of the modern tablet in 2010 that made a real impact. I instantly bought one and started to experiment with the database application I could use on it. A full transition to digital recording in the field was made during 2011 at my current company: context sheets and section drawings were made on the tablet while at the same time a total station and GPS were used to draw excavation plans digitally from the start. Being in violation with the mandatory analogue practice demanded by the gouvernement, we called it “experiments”. Some of it was really experimenting (learning and making mistakes), most of it was consolidating the way the company excavated, of which the digital registration became an integrated part.

Now, almost 25 years after I got my degree, I'm still a CRM archaeologist and I'm still walking the digital path. Trough reverse engineering, a “challenge accepted” mindset and many scripts the original digital context sheet has evolved into the backbone database of an excavation with many automations and “little minions” (CAA 2025, Session 5), integrations with GIS and containing all the section drawings, photographs, finds and an export of this data for archaeological deposits. This presentation will tell the story of the path I walked and what I have learned so far, the mistakes I made and where there is still room for improvements, development and the integration of new technology.

463. Adopting Mobile GIS: Transitioning from iDig to QField for Excavation Documentation

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Mobile GIS technology has transformed excavation documentation in archaeology by making possible the recording, integration, and analysis of data in real time in the field. Unlike the conventional methods of preserving paper records and different technologies, mobile GIS applications enable archaeologists to collect, edit, and visualize geospatial data directly on mobile devices like smartphones and tablets. Moreover, the availability of user-friendly and open source mobile GIS solutions, such as QField (Fábrega-Álvarez & Lynch 2022), has broadened accessibility and made digital documentation feasible even for projects with limited budgets.
The current work examines the transition from iDig (Uildriks, 2016), a digital excavation documentation system, to the QField ecosystem, a mobile GIS framework seamlessly integrated with QGIS desktop software. This transition was driven by the need to overcome several limitations encountered with iDig, including: a) Challenges with integration into desktop GIS environments, b) Limited data accessibility, c) Data constraints, d) Lack of extensibility and e) Platform dependency. QField, as a mobile GIS solution, addresses these limitations by providing a seamless workflow for data collection, integration, and analysis. Its direct compatibility with QGIS ensures effortless data transfer and analysis, while its open-source nature and platform independence (Android and iOS) promote accessibility and flexibility.
The effectiveness of QField is demonstrated through its application during the 2024 excavation season at Palaiopolis, the ancient capital of Andros (Palaiokrassá-Kopitsa, 2018). As a mobile GIS solution, QField enables the efficient management and analysis of diverse archaeological data directly in the field. In this project, QField was used to manage a range of data types, including notes, drawings, orthophotos, finds, features, samples, units, layers, and trenches, all structured according to a robust data model implemented in a PostgreSQL database. This streamlined workflow facilitated the documentation of the complex archaeological context at Palaiopolis, highlighting QField's ability to integrate and analyze diverse datasets. This, in turn, led to a more nuanced understanding of the site's stratigraphy and occupation history.

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516. From Field to Lab to 3D archive: Evolution of the Keros Digital Recording Programme

Hallvard Indgjerd (Museum of Cultural History, University of Oslo)*; Rosie Campbell (University of Cambridge); Michael Boyd (University of Cambridge)

Between 2016 and 2018, the Keros Project undertook a transformative shift in its excavation methodology, towards a fully digital, paperless recording strategy (Boyd et al. 2021). Utilising the iDig application, the project streamlined field and lab data collection, as well as replacing traditional field drawings with photogrammetric models of each stratigraphic context. This approach not only enhanced the precision and efficiency of fieldwork but also laid the groundwork for the comprehensive integration of excavation data into a unified digital system.

Post-excavation analyses highlighted the need for an overarching digital platform capable of encompassing the entirety of the project's datasets—ranging from stratigraphic records and artefact data, to geospatial data and photogrammetric models. To address this, we envisioned and began developing a 'living' 3D database and archive (Campbell et al. 2024). This dynamic system integrates material from both the 2016–2018 excavations and earlier campaigns (2006–2008), creating a unified intra-site archive. Designed to be adaptable and extensible, this database accommodates evolving research questions, supports multivariate and scalar analyses, and facilitates collaborative workflows by allowing simultaneous access for multiple users with diverse analytical needs.

This work also highlighted shortcomings in the existing recording strategies and challenges with achieving a truly heterarchical and reflexive field praxis. Many of these relate to common issues in digital field recording - ensuring safe and lossless synchronisation across poorly connected work locations with concurrent data entry; striking a balance between interpretive freedom and structured data with controlled vocabularies; adapting varied and domain specific data types and research traditions into a portal and a language accessible to all contributors.

In a bid to tackle these challenges, we are developing a new open source web-based recording platform that will serve as a cornerstone of our excavation strategy for the return to Dhaskalio in Spring 2025. Inspired by the FAIR movement, the system embodies principles of accessibility and interoperability for all data within the scope of the ongoing work, and facilitates creation of FAIR archival data beyond the project. A main focus is directed towards improving the interlinking of data and deconstructing information silos. We aim to link all real-time field data with the 3D GIS archive, integrating spatial and contextual information into a seamless framework. In order to facilitate knowledge sharing across domains and fast, up-to-date overviews, we are experimenting with LLM generated summaries. The system thus aspires to support immediate data visualisation and analysis during the excavation season, enhancing decision-making processes in the field and equalising access to information to all project workers.

This presentation will explore the challenges and achievements of designing and implementing these digital tools, with a focus on how they address the complexities of large-scale archaeological projects. The stages of transformation from analog recording into the first and second generation of born digital field data in the Keros-Dhaskalio excavations fits well into the explanatory model of digitalisation presented by Taylor and Dell'Unto (2021). The adoption of digital recording solutions often starts out with a skeuomorph of the analogue counterpart, which needs time to mature in the user's experience through socialisation with the new medium before the possibilities of the new technology can fully contribute to a transformation of field practices. We believe the paperless excavations of 2016-18 partly moved into the transformatory phase, but hope to show that the current iteration is securely embedded in that stage. By exploring a wider array of technological opportunities in fieldwork and post-excavation workflows, the Keros Project demonstrates an approach to digital archaeological documentation that balances flexibility and collaboration.

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273. Improvements in iDAI.field for sample category to allow workflow descriptions. Making the data FAIR

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iDAI.field is a documentation software originally developed by the IT-Science Department of the German Archaeological Institute (Deutsches Archäologisches Institut, DAI) to meet the recording needs of the Institute's projects during fieldwork. It is an open source software that can be freely reused by anyone interested. iDAI.field integrates features from geographic information systems, from photo management systems and from database management systems. As the use of iDAI.field is widespread within the DAI projects, it is continuously being further developed in response to the requirements identified there. One of the missing features identified is an extension of the data model for documenting natural science data together with the archaeological record.

In this abstract we present the changes we have made to the latest version of iDAI.field, which aims to provide a complete record of information for archaeological samples taken in the field. This goes beyond the information related to the sample location to include information related to the development of the sampling process (e.g., pre-treatment, sieving method, sieve meshes) and post-process (e.g., sample treatment after sieving, subsampling of the fraction, subsampling technique).

The purpose of introducing these specifications in the sample category is twofold. Firstly, to enable more detailed and specific record of the archaeological work. Secondly, to ensure the future use and reuse of this data, as the paradata of the same are exposed. Essential for assessing the quality of the sample, but generally never published or inventoried in detail. In this way, archaeological and natural science data can be contextualized to enable new analyses and insights.

104. Dexarch: Revolutionising Archaeozoological Data Documentation and Collaboration with Mobile Technology

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Introduction

This paper aims to highlight the main benefits of the Dexarch application in archaeozoological research. Archaeozoology, a sub-discipline of archaeology, involves studies of past animal remains such as bones, teeth, and shells found from archaeological explorations or excavations. Documenting faunal remains is critical in archaeozoology, requiring detailed recording of attributes such as taphonomy (study of post-mortem processes affecting remains), measurements, and provenance. Traditionally, researchers have relied on paper-based methods, manually recording findings in field notebooks.

While these manual techniques have been effective for decades, they have significant drawbacks: they are labour-intensive, prone to human error, and introduce logistical challenges, particularly in data sharing and collaboration. In an era where mobile technologies are rapidly transforming how information is gathered and shared, archaeozoology lags behind, while other archaeological sub-disciplines have already embraced digital solutions. This digital gap hinders the progress of research and collaboration.

In any event, the use of open and free mobile apps in archaeozoology has yet to become widespread. The growing demand for digital tools in archaeological research has led to the development of a few mobile applications such as I.L.I.U.M. However, the majority of these tools are general-purpose and not tailored specifically for archaeozoology. A few existing applications, like DigApp and TaphonomApp, provide some support for researchers but are often challenging to use due to complex installation processes and un-intuitive interfaces.

Dexarch aims to bridge this gap by offering a dedicated mobile application that is simple yet powerful, meeting archaeozoologists' unique needs in the field.

Methods and Materials

The development of Dexarch began by identifying and analysing the primary needs of archaeozoologists to ensure the application aligned with the discipline's unique requirements. The design phase included creating user interface wireframes in Adobe Illustrator, which were refined through multiple iterations to enhance usability and ensure intuitive navigation. Built with Flutter, Google's open-source software development kit, Dexarch is designed for cross-platform compatibility; while currently available only for Android, the use of Flutter allows for future expansion to iOS.

Firebase Authentication is used to secure user access, and Firebase Firestore serves as the cloud database. Firebase was chosen for its seamless integration with Flutter and its robust offline data persistence capabilities, provided by Cloud Firestore, a flexible NoSQL database.

Results

Key features include:

- User Authentication: Users can register via email or through Google authentication, ensuring secure access. After verifying their accounts, they can log in to view and manage their data.

- Add and Manage Entries: Users can create new entries for faunal remains, recording various attributes like locational coordinates, taphonomic signatures, and skeletal measurements. Data is collected in four stages: context and coordinates, identification, taphonomy, and notes. This structured approach standardises the data collection process across different users. Additionally, users can upload photos of fields and related elements to enrich the data entries visually.

- Offline Data Entry: Given the frequent lack of reliable internet connectivity in field archaeology, Dexarch allows users to record data offline, caching entries locally. Once the device reconnects to the internet, cached data syncs with the cloud, ensuring no information is lost.

- Offline Location Detection: Dexarch supports offline location services by allowing users to download maps ahead of time. This feature is particularly useful for archaeozoologists working in remote locations, enabling accurate geolocation of faunal remains even without a live internet connection.

- In-App Data Sharing: Researchers can share their entries with colleagues for a specified time period, enhancing collaboration. After the sharing period expires, the shared users lose access to the entry, adding an extra layer of privacy.

- Export and Import Entries: Dexarch supports exporting data in multiple formats, including Excel and JSON, which allows users to easily share their research with others or analyse data outside the application. It also supports importing entries via JSON files, ensuring flexibility in data management.

- Custom Filters and Sorting: Researchers can filter entries based on attributes like location, taphonomy, or site and sort them by parameters, such as date created or date modified, simplifying the management of large datasets.

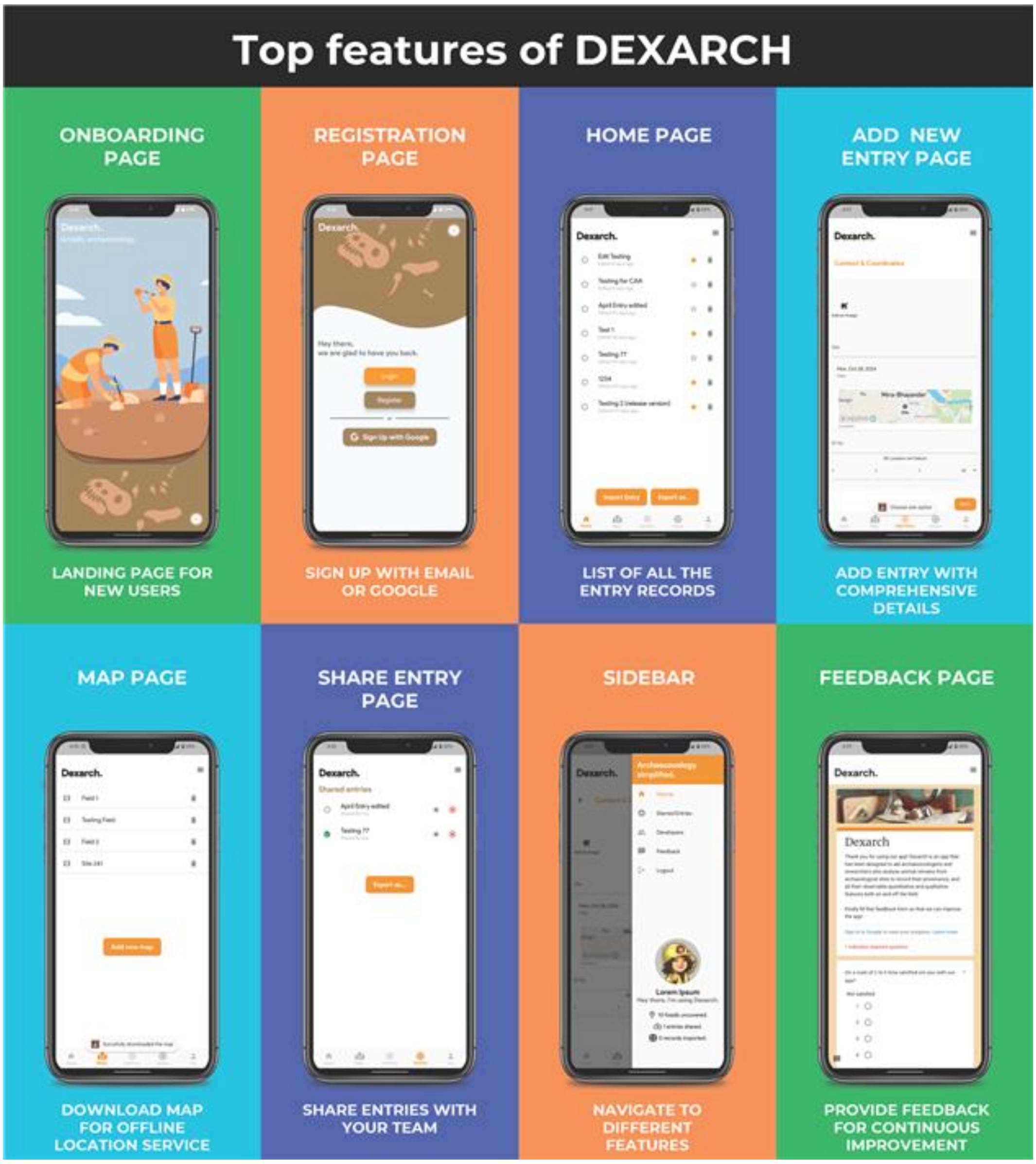
- User Profiles and Groups: Users can customise their profiles and create groups within the app, facilitating team-based research projects. Group members can share entries with each other, streamlining collaboration on multisite or multi-project research.

Discussion

In today's quickly evolving digital world, the ongoing use of paper-based documentation in archaeozoology is becoming increasingly unsustainable, especially as digitisation becomes critical for archival preservation. Museums and archaeological groups are facing serious storage limits for physical records, emphasising the urgent necessity to implement digital data management from the start of the excavation process. This shift promises significant improvements in both time efficiency and resource conservation.

The notion that paper records can serve as a permanent medium is deeply flawed. Paper is vulnerable to physical degradation over time, a process worsened by the often subpar storage conditions in archives, museums, and archaeological sites. Furthermore, paper documentation creates significant logistical issues, such as difficulty sharing and retrieving data. In comparison, digital documentation is a more streamlined and efficient option, providing for quick data access and sharing across platforms and among stakeholders.

Dexarch represents a paradigm shift in this context, delivering a digital solution that not only mitigates these issues but also enhances the overall quality and accessibility of archaeozoological data. Dexarch does not require any prior programming knowledge to be used and is and will always be completely free. It can be easily installed from Google Playstore on any device using Android 7.0 and above, with just a click of a button. Finally, Dexarch is in constant development and will continually evolve to comply with new requirements.



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207. Digging into Digital: Innovations in the Palethnography of Palaeolithic Sites

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In the 1960s, André Leroi-Gourhan introduced the concept and methods of palethnography, advocating for a detailed, ethnographic approach to studying Palaeolithic societies through spatially precise material remains (Leroi-Gourhan and Brézillon 1966). Achieving this ambition requires certain critical conditions: the exceptional preservation of site features with high temporal resolution, the "horizontal" excavation of occupational layers over broad surfaces to facilitate spatial pattern analysis, and, crucially, the meticulous recording of artifacts' extrinsic properties. These requirements limit the application of palethnography to select sites where traditional recording practices—hand-drawn maps, altimetry by optical levels, and paper-based artifact documentation—are favored. While digital methods can offer enhanced precision and reliability, the shift to digital systems introduces a new level of complexity, requiring archaeologists to adopt unfamiliar practices and workflows. For those accustomed to traditional tools, digital recording may seem daunting, while a fully paper-based system remains advantageous in terms of speed and reliability in the field, and offers affordable and durable archival solutions. However, paper methods also present limitations, including potential errors from the lack of real-time validation, and the need for extensive manual data entry and georeferencing.

The open-air Magdalenian site of Étiolles, in the Paris Basin, has been under excavation since the early 1970s and represents a rare opportunity to modernize palethnographic documentation while respecting its core methodological demands. Historically pivotal in advancing palethnographic studies (Caron-Laviolette, Bignon-Lau, and Olive 2018; Olive, Pigeot, and Bignon-Lau 2019), Étiolles has served as a teaching site for generations of archaeologists, many of whom were trained using traditional tools that prioritize simplicity, adaptability, and reliability. However, transforming field records into digitally analyzable formats for in-depth study is a time-intensive, resource-heavy endeavor. This involves digitizing hand-drawn maps and recorded altitudes to create vertical projections, as well as transferring artifact descriptions into digital databases. A longstanding reliance on legacy data has further limited data integration and continuity across campaigns, complicating comprehensive spatial analyses.

Our project at Étiolles, initiated in 2017, set out to develop an efficient, cost-effective digital workflow tailored to the site's needs. Recognizing the importance of a gradual transition, we introduced digital methods in stages to accommodate researchers accustomed to traditional practices. In the first year, digital and paper-based systems were run concurrently on the same artifacts, allowing us to evaluate time savings, data quality, and accuracy while providing evidence of the benefits of the new methods. This careful, phased approach not only demonstrated the effectiveness of the digital system but also helped facilitate its acceptance across generations within the team. This shift to digital methods coincided with a broader generational change within the research team, creating an opportune moment for technological change and underscoring the importance of managing both technical and social aspects of innovation.

By integrating GIS, relational databases, and 3D recording methods directly in the field, we sought to reduce post-excavation burdens, uphold the high precision necessary for accurate spatial and

stratigraphic reconstructions, and facilitate the integration of new and legacy data formats. Using open-source software and custom scripts, we created solutions to sync and integrate different data types, from artifact locations to 3D models, ensuring comprehensive, cohesive records. The system has now been in active use for several years, proving its robustness and adaptability across multiple excavation seasons, even when excavating distinct occupational levels that vary significantly in artifact density and preservation quality. This adaptability has demonstrated that digital field recording can meet the stringent demands of palethnographic study, maintaining data granularity while producing standardized, high-quality records that are immediately accessible for post-excavation analysis. Furthermore, the data collected can be used to assess the conservation quality of artifact concentrations through automated fabric analysis, providing insights into the preservation conditions of these remains. In addition, the inclusion of georeferencing allowed us to connect excavation data with broader geoarchaeological, geophysical, and topographical datasets, transforming previously isolated excavation records into a cohesive, multiscale spatial framework.
The workflow continues to evolve, developed progressively through user feedback and iterative refinement, with each phase building on prior testing and adjustments to better meet the team's needs. Adaptations are also being made for its application to other archaeological sites and contexts. The digitizing method is continuously refined to balance data quality (resolution, relative and absolute georeferencing accuracies), completeness, and manageable data volume. Real-time control of the 3D data acquisition process has made this workflow more efficient, allowing post-processing to begin before acquisition is complete and providing immediate feedback through synthetic photogrammetric quality criteria. Efforts are also underway to enhance spatial data visualization in 3D and to implement further in-field verification checks that ensure consistency between database entries, 3D recordings, and total station data. Additionally, the use of AI-driven segmentation algorithms is under consideration to simplify digital mapping directly in the field, making it more efficient and accessible. Aligned with FAIR principles, we aim to open selected primary data to the public, advancing open science practices in archaeology.
This integrated, adaptable solution has shown substantial time savings and has streamlined complex data synchronization without compromising data quality, precision, or usability. While digital recording takes as long as, or slightly longer than, traditional methods in the field, it enables immediate visualizations, such as 3D models, plans, and profiles, that provide a near real-time understanding of the site. This significantly reduces the post-excavation processing time, accelerating the scientific analysis of findings.
As a long-standing teaching site, Étiolles continues to play a crucial role in training the next generation of archaeologists, providing them with experience in both foundational excavation techniques and innovative digital recording methods that are increasingly essential to modern archaeological research. In a context where prolonged, resource-intensive projects are increasingly rare, we believe this digital system offers crucial benefits for open-air prehistoric excavations and presents a scalable model that can be extended across diverse archaeological settings.

413. From Paper to Point and Back to Paper: Advancing Burial Mound Excavation Methodology

Jakub Stępnik (Department of Archaeology, University of Warsaw)*

In 1902, Erazm Majewski, a pioneer of Polish archaeology, wrote, “In some locations, a very careful search of the upper plane of the mounds is necessary when we encounter traces of digging in the form of vessel shards, ashes, and bones” (Majewski 1902, p. 200). Despite its early recognition, the study of medieval Slavic cremation burial mounds—constructed for local elites between the 8th and 10th centuries AD—remained neglected for decades. While research in the 1970s and 1980s provided a general understanding of these graves, little progress was made beyond descriptive observations yet the methodological background for excavations was established. Since 2010, the Chodlik Archaeological Mission has sought to explore these unique burial structures in the Chodelka River Valley, southeastern Poland.

From the outset, innovative back then, documentation approaches, such as orthophotography, were employed, though the general methodology remained rooted in the practices of the 1970s. Challenges in data collection persisted, as the mounds contain 2,000–4,000 cremated bone fragments scattered on their surfaces. Initially, these fragments were documented manually, one by one. The introduction of tachimeters improved speed and precision but required complex data management, leading to iterative adjustments in fieldwork methodologies. In 2022, I tested a photogrammetry-based method for documentation and data management, which soon evolved into a three-dimensional database. Initially used as a backup, photogrammetry proved more reliable, precise, and time-efficient than previously established methods. By 2024, this technique had revolutionized excavation practices, enabling the creation environment for post-excavation analysis.

The new methodology not only streamlined fieldwork but also facilitated new hypotheses and redefined artifact distribution analysis. Previous reliance on two-dimensional plans limited the interpretation of burial mound features, as it merely increased the volume of excavated mounds without advancing understanding. Photogrammetry addressed these limitations by allowing three-dimensional artifact mapping. Markers placed during excavation were visible on photogrammetric models, enabling rapid spatial data collection in minutes instead of hours. These models were subsequently imported into Blender, where stratigraphic levels were stacked within a single project. Markers were assigned 3D representations with field labels, achieving a comprehensive three-dimensional plannigraphy analised gradually during the excavations process.

Although this process may seem more complex than tachimeter-based measurements, it is significantly more error-proof, independent of geodetic equipment, and maintains precision through a series of benchmarks. Unlike tachimeters, photogrammetry is unaffected by software or signal issues. The only critical factor is the photographer’s skill in capturing quality images.

This approach is particularly beneficial in remote areas where cost, portability, and efficiency are crucial. By requiring only a camera, a computer, and free software, it reduces excavation expenses while maintaining high-quality data acquisition. This makes it a viable solution for local museums and small underfunded projects, ensuring accessibility to modern digital standards.

Sharing this method could empower archaeologists worldwide, offering a versatile tool for efficient and reliable documentation in diverse contexts.

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477. No Gaps, No Glitches! Measurement data processing with Survey2GIS.

Jonas Abele (Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart)*; Steffen Berger (Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart)

The free and open-source software tool Survey2GIS (https://www.survey-tools.org/, https://github.com/survey2gis/survey-tools) is designed to assist in the maintenance of the integrity of geospatial data within primary archaeological documentation.

The transfer of field survey data from archaeological investigations into topologically and semantically correct GIS-compatible geometry data involves several challenges. A program that automates this process is the FOSS tool Survey2GIS.

The primary purpose of the software is to process geometric data, i.e. extracting points, lines, and polygons from attributed point measurements to process archaeological excavation results in a GIS. During the creation of geometries, topological cleanup is performed to eliminate overlapping polygons or unclean line connections for example. Information assigned to individual points during the field survey (e.g., feature type, artifact number) can be automatically added as normalized attribute data to the geometries. Furthermore, Survey2GIS allows for export of standardized GIS file formats such as Shapefile, GeoJSON, or KML. This can be done both via command-line commands and through a graphical user interface.

Survey2GIS has been developed for several years under the direction of the Landesamt für Denmalpflege Baden-Württemberg (Germany). Version 1.5.2 is very stable and reliable. New developments are being made on this basis as part of NFDI4Objects.

One of these new developments is a QGIS plugin (SurveyDataProcessor). It is based on Survey2GIS and aims at process automation. The SurveyDataProcessor is designed to consolidate, normalise and process survey data according to predefined steps. During normalisation, the survey data is first cleaned, followed by the implementation of a data model, such as adding static fields and dynamically generating values using code lists. The result is a normalised measurement file. In the subsequent processing phase, the previously created normalised survey file is accessed and freely definable and combinable Survey2GIS function calls can be applied. The aim is to standardise and automate the generation of geodata from primary documentation survey data.

Another new development is a parser generator. Parsers have been and remain a central aspect of Survey2GIS. Due to flexible parser definitions, parsers allow the processing of survey data in different formats and structures. They also play an important role in the QGIS extension of the tool. Until now, creating a parser required in-depth knowledge of the features and structure of Survey2GIS and was done manually in a text file. The parser generator aims to simplify this process. A parser is automatically generated from form input. The generated parser code can be exported locally as a.txt file.
The presentation will show and discuss the current and future features of Survey2GIS and the QGIS plugin. Practical examples will illustrate how the tool can help to improve data quality and produce clean and accurate datasets.

76. Multiscalar Digital Recording of Archaeological Features and Pottery Remains at the Suwahara Site, Yamanashi Prefecture, Japan

Corey Noxon (Ritsumeikan University)*; John Ertl (Keio University); Yasuyuki Yoshida (Morioka University)

The digital recording of an archaeological excavation inevitably includes many layers. These layers are not only found in the stratigraphy of a site, but also in the multiple scales at which a site can be recorded. One can record a site within the broader landscape, record a site as a whole, record specific features in a site, or focus on individual artifacts. The methods to effectively record each of these layers digitally is often context specific and attempting to combine these layers into a cohesive whole requires additional consideration before digital documentation begins.

This presentation describes how a layered approach was taken at the excavation of Suwahara site in Yamanashi prefecture, Japan in 2024. We discuss the ways in the different layers of digital documentation were approached, how the multiple photogrammetry scans were undertaken to maintain spatial consistency between scans, how those scans were used to provide clear spatial positions and orientations for individual artifacts, and how a semi-automated photogrammetry system was developed to scan those individual artifacts to later return them to their digital spatial contexts, and how a timelapse of the excavation work done on the site can serve as a useful reference for activities undertaken during the excavation season and an easily understood record for the public to gain a better understanding of the excavation process in general.

Suwahara site is located in Hokuto City, nestled in the Southern Alps of Central Japan. Previous excavations have shown the site to be part of a circular settlement that dates back to the Middle Jomon period (c. 2500–2000BCE). The current excavation at the site began in 2019 as a collaborative project with researchers from several universities. In 2023, a concerted effort to include photogrammetry into the excavation documentation began (Ertl, Yoshida, and Noxon 2024). Wide scale scans using drones captured the area surrounding the site. To connect these broader scans with more detailed site and feature scans 3D printed machine-readable targets were used. These targets were staked into the ground and operated as semi-permanent control points for the photogrammetry scans and provided clear, recognizable centerpoints that could be identified even if the automated detection of the photogrammetry program failed.

The main features of the Suwahara excavation are several pithouses. In addition to more traditional line drawings, care was taken to document the stratigraphy of these pithouses using photogrammetry along the outer edge of pithouse (codenamed PJ1) as well as a central belt which was left intact until the end of the excavation. During the excavation of this belt, an intricately made suienmon (water vapor) style pot was discovered in a broken state, deposited in the central portion of the pithouse, a situation that is sometimes thought of as having possible ritual connotations. This central deposit provided a good opportunity to create 3D captures of the artifacts as they were removed from the central belt portion, which could later be paired with later scans of each of the removed artifacts in a controlled environment. As the surrounding pithouse had been repeatedly captured using photogrammetry, these could also be placed within the broader context of the dwelling itself. One of the researchers had previous experience with a similar process at another site, the Sugisawa site in Shiga prefecture, and the excavation at Suwahara provided an opportunity to improve that approach (Yano et al 2024).

3D scans of the central belt were taken before the exposed artifacts were removed. Tags with artifact numbers were placed by these artifacts and photographed to provide a reference for placing the completed artifact scans back within their spatial contexts. After artifacts were collected, additional soil was removed exposing a new set of artifacts. The belt was scanned again, artifact tags placed by the corresponding artifacts and photographed, and then these newly exposed artifacts were collected, continuing the cycle.

In the previous excavation at the Sugisawa site in Shiga prefecture, one of the main difficulties was in processing the large number of artifacts related to the main 3D scan. With individual artifacts requiring 100 or more images to create a 3D model, and with close to 200 individual artifacts to be scanned, the time to capture and process these artifact scans was significant. In order to improve on this process, one of the team members created a semi-automated 3D scanner to help improve the scanning process. The design is a modified version of the ScanRig3D-v0.9 scanner (revolutionscan 2024). The design was modified to allow larger objects to be scanned, improve the depth of field of images taken with the scanner to ensure sharper overall images, improve the lift capacity of the system, and incorporate an alternative lighting system to ensure that well-exposed images could be captured quickly.

An addition to the excavation documentation process for the 2024 field season at Suwahara was the use of a timelapse camera set up daily at the site. This involved using a GoPro camera powered by an external battery and set up on a tall camera pole. This approach had to be adapted several times due to high summer temperatures which finally ended up with an actively cooled case that provided physical shade to the camera and battery and a small fan to cycle out warm air from the system. This final layer of documentation provided a broad and encompassing view of the activities taking place at the site during the excavation season, providing a useful reference for documentation as well as an easily understandable output to share with the public to help them understand how the excavation process works.

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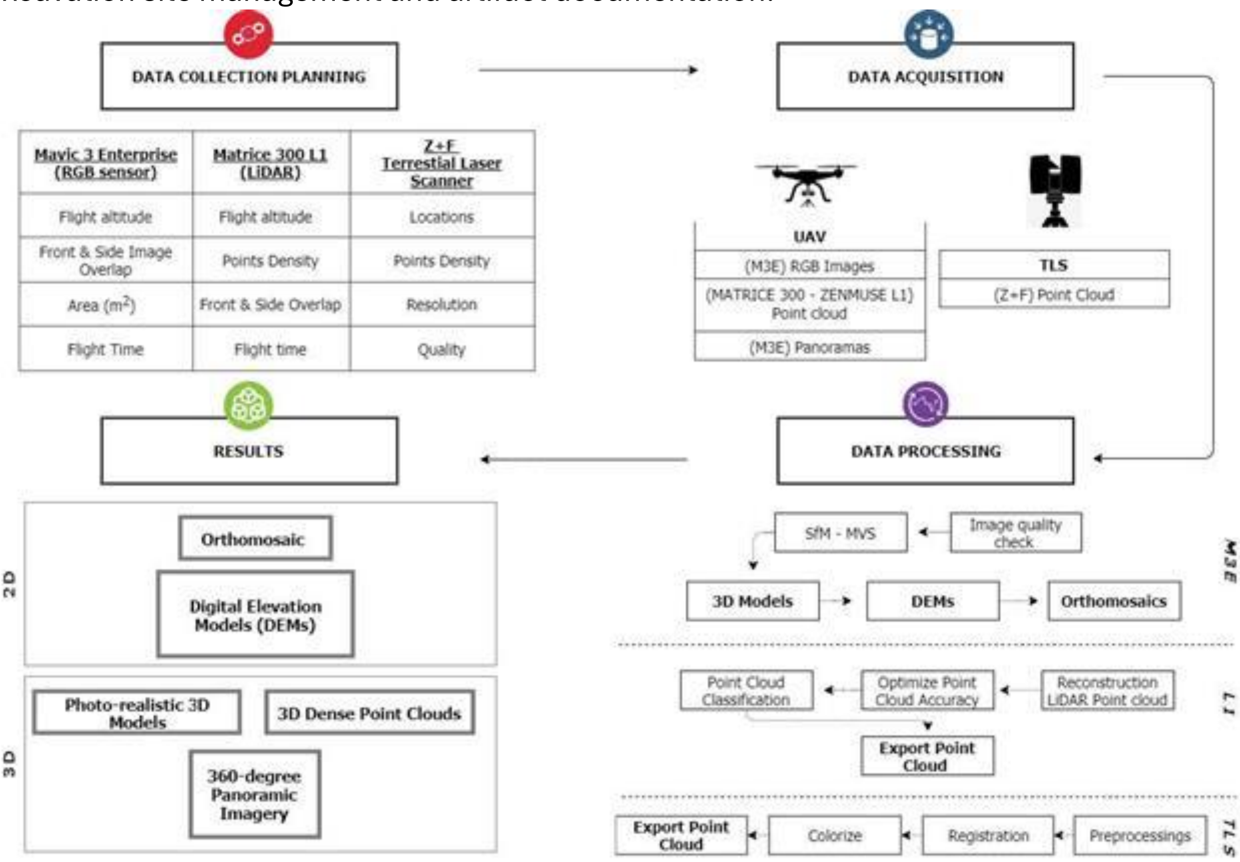
矢野健一・Corey Tyler NOXON・迫田圭一郎・菅井佳穂・井上薫・手嶋響紀・高橋順之・石田雄志・立命館大学杉沢遺跡発掘調査団
2024「滋賀県米原市杉沢遺跡2023年度発掘調査成果と土器棺出土状況の３D画像復元」『日本考古学協会第90回総会発表要旨』

Revolutionscan 2024 “ScanRig3D-v0.9” retrieved from https://github.com/revolutionscan/ScanRig3D-v0.9

303. Advanced 3D Mapping and Documentation of the Rodafnidia Archaeological Excavation in Lesvos Using UAV, TLS, and LiDAR Technologies

Ermioni Eirini Papadopoulou (University of the Aegean)*; Stavros Proestakis (University of the Aegean); Lemonia Moysidou (University of the Aegean); Giorgos Tataris (University of the Aegean); Nikolaos Soulakellis (University of the Aegean); Peny Tsakanikou (University of Crete); Nena Galanidou (University of Crete)

This study presents an advanced approach to high-resolution 3D mapping and documentation of an archaeological site, with a case focus on the Rodafnidia excavation in Lisvori, Lesvos. Rodafnidia is an open-air Early Palaeolithic site with archaeological finds (stone tools) excavated from fluvio-lacustrine deposits (Galanidou et al., 2016). Absolute dating (OSL) places early human activity at least between 300 and 200 Kya. Excavation trenches are located on the Rodafnidia hill, an extensive olive-grove, which emerges as the core of the archaeological site based on the density of surface distribution of archaeological material. Utilizing state-of-the-art geospatial technologies—such as Unmanned Aerial Vehicles (UAVs), Terrestrial Laser Scanners (TLS), and airborne LiDAR—this research addresses a critical gap in current archaeological documentation methods, which often lack the spatial resolution and comprehensive data needed for effective long-term monitoring (Adamopoulos et al., 2023). The importance of this study is underscored by a growing need in archaeological and heritage fields to adopt novel mapping methodologies that capture intricate spatial details, ensuring that excavation sites can be recorded with high resolution, fidelity and preserved for future research in a consistent way. This study showcases modern 3D mapping techniques, using UAV, TLS, and LiDAR to enhance excavation site management and artifact documentation.



319. 3D modeling of archaeological excavations using mobile devices as a complement to high-quality photogrammetry

Chris Motz (University of Michigan)*; Matthew Notarian (Hiram College)

Previous research has evaluated the theoretical accuracy and precision of the LiDAR modules included in Apple's iPad Pro and iPhone Pro mobile devices (e.g., Łabędź et al. 2022; Teppati Losè et al. 2022; Paukkonen 2023). While models captured quickly with consumer-grade mobile devices cannot yet match the quality of photogrammetry produced with mirrorless or DSLR cameras and professional software, or expensive terrestrial laser scanners, models generated on mobile devices do not lack utility. In this paper we discuss some field experiments that explore their potential and assess their precision in comparison to photogrammetry.

We reflect on the experience of the University of Cincinnati's Tharros Archaeological Research Project in summer 2024 using 3D models that were quickly captured with iPad Pros. The models were intended to be used as both companions and backups for high-quality photogrammetric models of stratigraphic contexts created with dedicated mirrorless cameras, fixed targets/control points, and professional software (Agisoft Metashape).

We first describe our novel workflow for rapidly generating and annotating 3D models of excavations in the field with iPad Pro tablets. The excavators created digital models of their trenches using the Scaniverse app, then used the Procreate app to outline the stratigraphic unit in question directly on the model in three dimensions. The final annotated model was uploaded to the project database where it served as a reference for excavators and the spatial recording team, who employed it to help identify and outline the relevant stratigraphic units after high quality photogrammetric models had been fully processed. This hybrid approach thereby addressed one significant challenge in the production and annotation of high-quality photogrammetric models.

We then evaluate the effectiveness of our use of the iPad models as a base for rapid in-field annotation, as tools for communication between field and lab, and, on occasion, as useful backups and supplements to the intensive photogrammetry process. We touch on technological limitations and opportunities as well as issues related to logistics, communication, workflow, and excavation processes.

Finally, we quantitatively and qualitatively compare the models generated with iPads to those produced with photogrammetry, employing a sample of several stratigraphic units. Using CloudCompare, the iPad models are first manually aligned, then finely registered with the Iterative Closest Point algorithm to their companion georeferenced photogrammetric models. Distances are measured between the two models, providing both a numerical and visual assessment of their concordance and variance. This provides valuable data to assess the relative tradeoffs in time, expertise, and cost associated with using iPads or high-quality photogrammetry for 3D recording of archaeological fieldwork.

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388. Digitizing Greek Inscriptions and Alphabets (DIGIA Project): Epigraphic Challenges, Digital Solutions

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This paper aims to examine the applications of digital techniques to the recording of stone inscriptions and graffiti discovered at the Samonion Cape on the eastern coast of Crete. A multidisciplinary research team comprising archaeologists, epigraphists, computer scientists, and technical staff was established for the purpose of carrying out the epigraphic survey and the digitization of inscriptions during the summer of 2024. Due to the distinctive characteristics of the site, the paramount significance of the epigraphic discoveries, and the pressing need for their immediate documentation and conservation, the utilization of digital techniques was imperative. The Samonion Cape, located at the easternmost extremity of Crete, was historically a convenient location for ships travelling from east to west and vice versa. The available literary and archaeological evidence suggests the existence of a sanctuary dedicated to Athena Samonia in the area, the remains of which are likely to be submerged in the sea at the present day. From an archaeological perspective, the inscriptions thus far located (numbering more than 50) are of exceptional significance, as they represent a body of evidence dating back to the Archaic period (7th-6th century BCE), which is characterized by a lack of literary sources and a paucity of epigraphic evidence in Crete. The exceptional significance of the find, coupled with its pivotal role in the ongoing discourse on the evolution of alphabets, literacy and writing practices in both public and private spheres, renders its study and publication not only desirable but also imperative.

The inscriptions are situated in an area that experiences extreme weather conditions, including strong winds throughout the year. Moreover, the proximity of the stones to the sea, the loose material on their surface, and the ongoing construction activities in the area present a significant risk of complete destruction of the finds. The stones' rough surface and deterioration due to exposure to weather conditions have made conventional techniques, such as the use of special filter paper and 2D photography, ineffective for achieving optimal results. In the absence of buildings or other points of identification, and given the homogeneity in geomorphology, it is necessary to use geolocation techniques to relocate the inscriptions and elucidate their relationship to one another, as well as their possible relationship with any archaeological remains that may exist in the area.

It was thus imperative to evaluate the feasibility of innovative methodologies, encompassing both epigraphic survey techniques and digitization of epigraphic findings, to determine the most optimal outcome. In order to facilitate the efficient identification and documentation of inscriptions, a bespoke application utilizing ArcGIS Maps was developed and installed on the mobile devices of the research team. The application enabled the real-time geotagging of locations, the capture of photographs and videos of the surrounding area, the input of audio notes, and the input of free-text observations or the completion of predefined fields. The project leader, situated 1,000 kilometers away, was able to access all synchronized data that had been mapped in real time.

In terms of methodology, the following techniques were employed for the location and documentation of the inscriptions:

Reflectance Transformation Imaging (RTI): Given the advanced state of weathering observed in the majority of inscriptions exhibiting particularly shallow carvings that are not discernible to the naked eye, the classical RTI method was employed for its exceptional clarity and detail in revealing the hidden features. Preliminary experiments were conducted on samples drawn from the EREP archives and on stone inscriptions housed at the Visitable Museum Store in Makrygialos, Pieria, with the objective of refining and modifying both the methodology and equipment settings, and thus ensuring optimal conditions for field application. The modified RTI method proved effective in uncovering details in inscriptions that had previously been misread [1], thereby confirming its efficacy. The selection of appropriate equipment and its procurement was tailored to the challenging conditions presented by the site, which was characterized by rugged topography and strong winds.

Laser Scanning: A high-precision laser scanner (EINSCAN HX) which offers accurate measurements was used. This technique enabled the three-dimensional recording of the stones, allowing researchers to measure the dimensions and depths of the carvings and to obtain comprehensive views of the objects, including curves and edges.

The combination of RTI with laser scanning proved an effective approach, enabling researchers to reach reliable conclusions by highlighting inscription details from different perspectives. The project was faced with a number of logistical and environmental challenges, including the transportation of equipment from northern to southern Greece, manual conveyance of equipment within an inaccessible field site lacking roads, the instability of equipment due to strong, continuous winds, and extreme heat and sunlight, which necessitated the conduct of laser scans at specific times.

In conclusion, the experimental application of digitizing inscriptions in a variety of settings and conditions, including outdoor environments, will ultimately inform the optimal methodology for inscription digitization. The additional processing undertaken in the laboratory allows for the extraction of alphabetic characters, which, in comparison to other archaic Cretan alphabets, provide: (a) The development of Machine Learning models for the purpose of dating the inscriptions, (b) the creation of fonts, and (c) the deployment of such resources in open databases and educational activities. Ultimately, the deployment of the ArcGIS Story Maps platform enables the provision of a readily accessible tool for non-specialists, thus facilitating the dissemination of all information gathered from the field, including 3D models, RTI data and epigraphic notes, in a narrative format on a publicly accessible website. This initiative effectively reimagines the site as an immersive digital museum, accessible to all and enhancing engagement with the cultural heritage of Greek civilization.

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Keywords: Epigraphy, Archaic inscriptions, graffiti, digitization techniques, RTI, Laser Scanning, ArcGIS Maps, Cape Samonion, Crete.

171. Spatiotemporal reconstruction of pot burial excavations

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Introduction

Archaeology has a long tradition of employing visual representations to document the archaeological process. Advances in three-dimensional documentation techniques have motivated the archaeological community to embrace 3D solutions, marking a significant paradigm shift (Roosevelt et al. 2015). In-field 3D recordings have enhanced the excavation practice by offering diverse and informative perspectives (De Reu et al. 2014), yet the transition to accessible interactive multimedia applications for the inspection of documented material and processes remains limited.

This study focuses on the small-scale excavation case of pot-burials, a process that, given the dimensions and fragility of ceramic vessels and their contents, makes thorough documentation essential for post-excavation analysis and interpretation. The main goal was to establish a reliable complementary approach for typical documentation and recording of a pot-burial excavation, by integrating the temporal as well as the fully spatial dimensions of the excavated object.

Key objectives included the development of an interactive time-lapse of the excavation utilizing Structure-from-Motion (SfM) photogrammetry and an established interactive 3D visualization solution, while assessing the methodology's practicality for documentation, labor investment, and educational potential. The findings could significantly benefit both archaeological research and public engagement.

Materials and Methodology

The unexcavated pot-burial comes from the excavation of the Phaleron Delta Cemetery in Attica, Greece, which yielded a total of 2115 burials, dating from the 8th to the 4th century BCE. During the excavation campaigns (2012-2020), several pot-burials were block-lifted and preserved at the laboratory for future excavation.

The suitable methodology for the task was dictated by the pot's preservation state and shape. Given the initially limited access to the pot's interior, SfM photogrammetry was selected as the reconstruction method of choice, since it could more easily handle occlusions, compared to structured light active scanning. Furthermore, it constituted a more convenient technique to employ on the field and in the confined space of the laboratory, alike. Due to the shape of the object, no more than 50 photographs per object were required as the input for the geometry reconstruction of each excavation stage, making visual documentation an easy and fast process.

The reconstructed 3D geometry of each excavation phase was brought up to scale, using a scale reference and co-registered to establish a properly aligned set of textured models, using Meshlab software (Ranzuglia et al., 2013), with an average error bound of 1 mm. The initial meshes were then simplified, to match the requirements of the final interactive application (mid-range or mobile graphics capabilities). The fact that a large part of the pot and the surrounding material remained unchanged during the process, supplied the necessary landmarks for the alignment of all individual pot versions, as the gradually removed parts of the successive strata could not be used for registration. The foam bedding of the pot-burial was retained in the final 3D models for a more realistic reconstruction and aesthetic blending with the virtual laboratory environment specifically modelled for the application.

The interactive time-lapse excavation inspection application was developed in the Unity game engine, due to its versatility and output to many different, commonly used platforms. A proper development life-cycle was established, starting from a requirement analysis for the interaction and functionality via interviews. A constrained orbit camera and a very intuitive slider to control the temporal axis were the primary controls of the application, controlling the viewpoint and the stage of the excavation, simultaneously, if required. Interactive arrow markers were used for 3D annotations on the various instances of the 3D model of the excavation, supplying the user with notes and metadata provided by the expert(s).

Evaluation

The laboratory excavation was done in nine levels and did not yield preserved skeletal human remains but grain-sized skeletal fragments and two miniature ceramic vessels - grave offerings. Ten 3D models were reconstructed with SfM photogrammetry, one for each level.

The digitization process was found suitable for laboratory in-field excavation documentation in terms of accuracy, evaluating the results against measurements from the actual object and time requirement, since each photographic session was 5-7 minutes and did not interrupt the excavation's timeline. During post-excavation, a total of 17-25 minutes was required for the complete process of each reconstructed model.

The end-user evaluation included tasks and questionnaires for a small group of participants, focusing on application effectiveness, efficiency, and engagement. Feedback was largely positive, with participants finding the application user-friendly, intuitive to use and engaging.

Discussion

This work shows the possibility of creating a virtual application of a small-scale excavation focused on recreating the temporal its aspect. Although the interactive application was developed around a particular use case, the (laboratory) setting and all scripting functionalities can be used to accommodate different specimens, thus compensating for the length of the development process. Moreover, the set principles for the reconstruction and the application design and implementation could also be adopted to a larger scale excavation site for the fieldwork progression.

The findings indicate that the application not only provides an engaging representation of the archaeological methodology but also fosters active user participation. By allowing users to explore excavation stages and the pot's contents in a 3D environment, it transforms them from passive spectators into active participants. Cultural heritage and learning institutions could use such methods to present the intangible concept of an excavation and promote experiential learning that improves one's ability to retain new information.

Virtually experiencing the site and acquiring the spatial context of each object could aid the archaeological "slow" approach to thinking and interpretation, allowing the archaeologists to virtually re-experience the unrepeatable process. Additionally, digital documentation can reduce the subjective nature of the archaeologists' reports and accelerate data sharing with the scientific community.

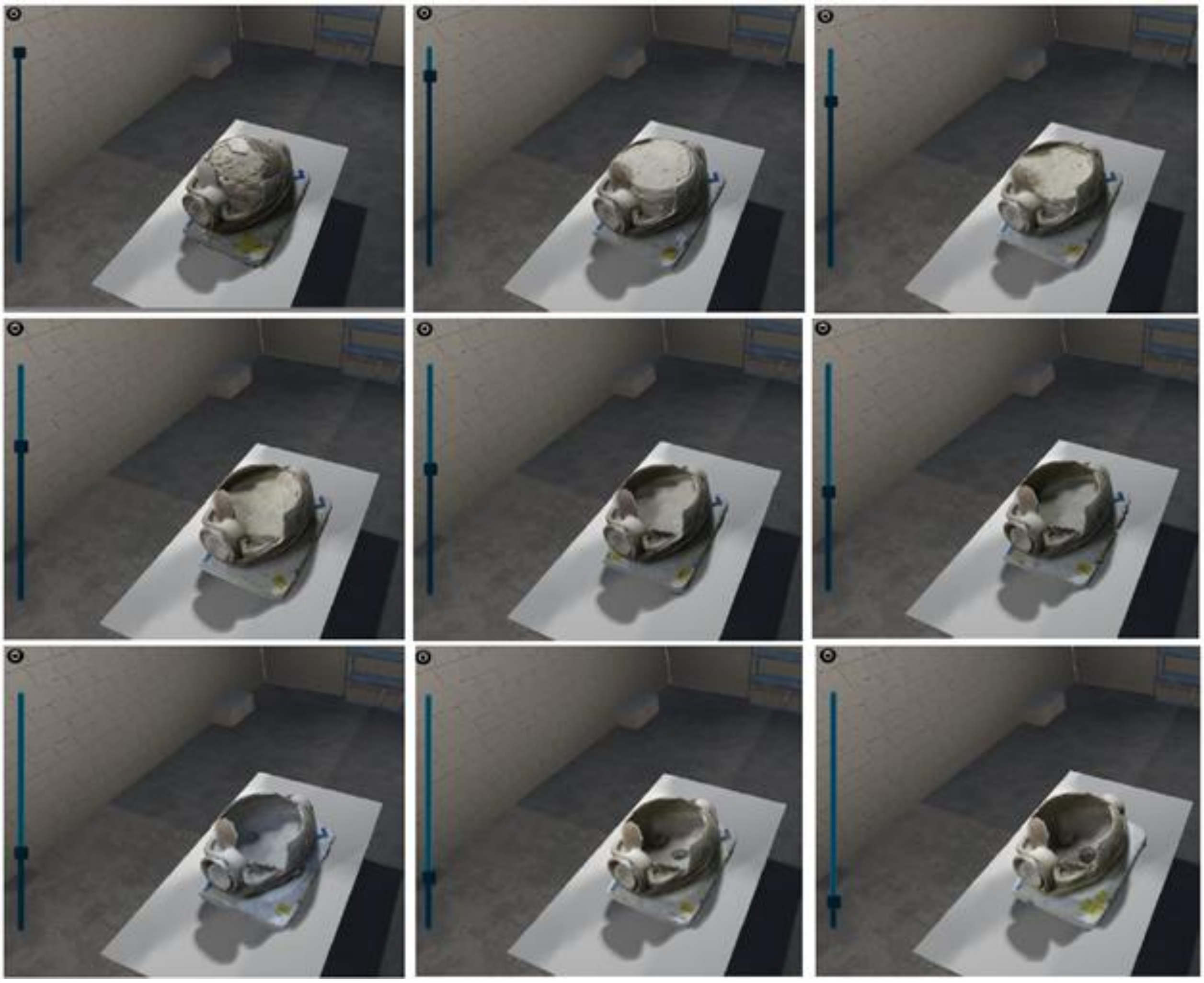

Figure 1. Screenshots from the various stages of the excavation.

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48. "Holographic Archaeology": Mixed Reality implementations in archaeological field- and laboratory work. New perspectives and challenges

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Introduction

The aim of this presentation is to provide an overview of the capabilities and challenges of the implementation of Mixed Reality (MR) technology in archaeological research. The hardware option that is used for this project is Microsoft's HoloLens 2, released in 2019. In order to evaluate it, two distinct case-studies have been chosen, the one related to archaeological fieldwork and the other linked to laboratory work, and more specifically for zooarchaeological purposes.

In regards to the first case-study, the aim is to test the ability of the HoloLens 2 to document and record archaeological features in situ. Another target was to assess how and to what extent this tool can be implemented in the workflow of an archaeological survey and/or excavation. As far as the second case-study is concerned, the target was to create a prototype of a virtual reference collection for animal bones in a MR environment which is focused more on rare and wild animal species, as these are, in most cases, not adequately represented in conventional reference collections.

Background and significance

Mixed Reality is a Human-Computer Interaction (HCI) environment that intertwines the real and the virtual world. This system allows for different levels of immersion and realism to be integrated, as the virtual content can play the role of any other real object in the user's view, anchored in a specific location and viewed from different angles or not respecting any rule of physics at all and float in the surrounding space. This results in an immersive experience that is still connected to the real world (Bekele et al. 2018, 4).

The implementation of MR technology in the Cultural Heritage sector has been around for more than two decades by now, serving a multitude of targets. These include providing new ways to motivate people to learn about a specific feature, ranging from an artifact to as site, in a more intuitive manner. AR and MR technology has provided new ways to visualize and interact with archaeological data not only for the wider public but also for active researchers with expertise in archaeology and cultural heritage. Of particular interest are the AR and MR tools implemented for the documentation and visualization of excavation data, either on- or off-site (Dilena and Soressi 2020, 8-9).

Additionally, the creation of reference collections in digital environments has been one of the main points where computational methods have been applied to zooarchaeology (Spyrou et al. 2022, 2-3). One of their main advantages is that they can

enhance more traditional tools of zooarchaeological research, namely illustrated guides of animal bones found in books.

Methodology

In order to apply MR methods during fieldwork for documentation and recording purposes, the Documenting And Triaging Cultural Heritage (DATCH) prototype open-source software was used, developed by the University of Central Florida (PI: Dr. Scott Branting). The site chosen for testing DATCH was Chalcis, Greece in cooperation with the "Beyond Chalkida: Lansdcape and Socio-Economic Transformations of its Hinterland from Byzantine to Ottoman Times" (HMC) project, led by professor Joanita Vroom. DATCH allows the user to draw features using hand gestures,

such as the stones of a wall, as it is demonstrated in the figure. Other features of this software include taking measurements, either 2D or 3D, and creating grids, a valuable tool for setting excavation trenches and/or surveys grids. Using the HoloLens' depth camera, the software can also create a 3D mesh of the space it is currently in, resulting in a simplified mapping of the surrounding environment.
As far as the MR animal reference collection is concerned, this platform was developed using the Mixed Reality Toolkit (MRTK) open-source software in the Unity game development engine. Imported 3D models of wild animals from Sketchfab (https://sketchfab.com/), available for free from the Lapworth Museum's collection, are used as the basis for this digital reference collection with the aim to create a prototype of a supplementary edition for the physical reference collection.

Results
Drawing and measuring archaeological features in the site of the two towers of Mytikas, south-east of Chalcis, was successful, even when working under direct sunlight. DATCH offers a quick and efficient way to create simple drawings of structures, following the contour of the masonry blocks. Making measurements and creating tags for highlighting and/ or identifying certain features, such as postholes or inscriptions found on the tower's masonry, can enhance these drawings and be a valuable tool for visualizing features in a more intuitive manner, even after fieldwork is over.
On the other hand, while using the prototype of the virtual reference collection in Leiden University's Laboratory of Archaeozoological Studies, the 3D content was viewed in tandem with real specimens of the same species – a male Hippopotamus amphibius in this case (Figure 1). Working with both types of objects at the same time was seamless, manipulating the 3D model in such a way that was similar to the specimens of the conventional collection. Furthermore, the 3D specimen can also be enlarged, allowing the user to emphasize on specific parts of its morphology, enabling detailed observations – particularly important for certain specimens, such as the teeth of the animal.

Figure 1. View of the Virtual Animal Reference Collection through HoloLens 2, while testing in Leiden University's Laboratory of Archaeozoological Studies. The user can interact with the 3D model and compare it to actual specimens. In this case a juvenile (3D model) and an adult Hippopotamus amphibius are being compared. (Source: the author)

Discussion

Both case-studies highlight the potential of implementing MR technology in archaeological research, serving a multitude of different research problems. Not only is it used to visualize digitized structures, it can also provide novel ways to interact and interpret them. When dealing with animal bones it can assist the identification of animal remains and/or academic teaching of anatomy too. MR can provide new perspectives for how archaeologists interact with the past, movable or not, consisting an important asset when used to enhance more traditional tools. A major challenge when dealing with immersive technologies is getting past the initial “wow-factor” and providing a useful and accessible experience. As more and more hardware solutions are becoming available, MR could become an integral part of archaeological research, allowing the integration of digital toolsets in multiple archaeological settings.

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347. Creating a Digital Twin of the Early Helladic Cemetery of Asteria Glyfadas: Challenges and Innovations in Field Documentation

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Introduction

The archaeological site of Asteria, located on the Pounta peninsula of Athens, provides critical insights into Early Helladic civilization. Directed by Constantina Kaza Papageorgiou, excavations have unearthed a metallurgical laboratory dating to the late 4th/early 3rd millennium BC and an underground multipurpose cemetery developed shortly after its abandonment. The cemetery, featuring Cycladic figurines, obsidian tools, and ceramic vessels, reflects vibrant trade and communication networks across the Aegean. This study aims to create a digital twin of the cemetery, addressing the evolving role of digital tools in field archaeology. The research focuses on how digital twins can enhance the management, analysis, and accessibility of archaeological data, while adhering to best practices and emerging standards in digital recording.

Methods and Materials

The project integrates advanced digital techniques with traditional documentation. High-resolution photogrammetry and laser scanning captured spatial data, while Geographic Information Systems (GIS) served as the backbone for linking spatial datasets with archaeological attributes. Recognizing the limitations of GIS in managing 3D data, the methodology incorporates specialized 3D data management tools to address challenges in handling heterogeneous and complex datasets. Legacy data, including hand-drawn maps and older excavation records, were digitized and standardized for integration. The digital twin employs a modular data management system, ensuring interoperability and long-term usability. Adhering to emerging standards in the field, such as CIDOC-CRM, ensures the project contributes to the sustainable sharing and preservation of archaeological knowledge.

State of the Art in Digital Twins

Heritage documentation systems often root their approaches in the volumetric or geometric representation of heritage assets, such as point-cloud or BIM-based models. While these systems excel in documenting the shape and volume of physical components, they face significant limitations. They are unable to fully accommodate documentation elements not tied to a physical component, thus restricting interoperability and integration across systems. This fragmentation inhibits cross-referencing capabilities, such as comparing materials or restoration techniques across different assets. Furthermore, intangible heritage elements are frequently overlooked, leaving a critical gap in comprehensive documentation approaches. This study aims to overcome these limitations by incorporating methods that unify tangible and intangible elements into a cohesive, interoperable digital framework.

Results

The digital twin of the Asteria cemetery provides a comprehensive representation of the site, merging 3D data with traditional documentation. This integration facilitates advanced analysis, including spatial queries and cross-referencing of burial practices with artifact distributions. The system's architecture ensures seamless data management, overcoming challenges related to the heterogeneity of archaeological datasets. Usability tests demonstrated the twin's potential for interdisciplinary research, virtual exploration, and educational outreach. New insights into

Early Helladic trade networks and burial practices emerged, showcasing the advantages of integrating contemporary and legacy data.

Discussion
This study highlights the transformative potential of digital twins in archaeological documentation and analysis. By addressing the challenges of integrating 3D data with traditional methods and adhering to data management standards, the project contributes to best practices in digital heritage research. The methodology offers a replicable framework for managing complex archaeological datasets, with implications for other multi-phase sites. Future directions include the integration of AI-driven analytics to further enhance interpretive capabilities. By leveraging recent advancements in digital twin technologies, such as those reviewed in Niccolucci et al. (2023) and Rossi & Bournas (2023), this project exemplifies innovative approaches to cultural heritage preservation and dissemination.

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61. The forgotten heritage: The shrines of the Maryut Lake region, a GIS project study and digital fieldwork survey

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Since 2013, the Centre d'Etudes Alexandrines (CEAlex – CNRS / Ifao) has been developing a comprehensive archaeological map of the Maryut Lake region , located at the western margin of the Nile Delta in Egypt. This project aims to thoroughly collect and document all data on the ancient Mareotis, a region currently undergoing a phase of urbanization and increased industrialization which threatens archaeological sites. To what extent can Islamic shrines, as potential markers of archaeological sites, illuminate our understanding of the history and evolution of the cultural landscape of the Mareotid region.

During our field surveys, cartographic and spatial analyses, along my doctoral research , we discovered numerous still-venerated shrines. These are sacred spaces dedicated to various figures, including Sufi saints, local Islamic scholars, and even Bedouin tribal leaders. These peculiar features in the study area are mentionned and located in old maps, usually signified by a specific symbol and with various mentions of Arabic origin, which may refer to the deceased person, such as "Sîdi", "Sheikh", "Maqâm Waliy", or to the structure, such as "Santon", "Manâma", "Maqâm", "Darîh" or "Qabr".

Shrines in the Maryut Lake region represent an important aspect of Islamic culture and heritage in the western Nile Delta. They often form the nucleus of cemeteries or settlements, ranging from small villages to larger towns.

By analyzing maps dating from 1801 to 1990, along with satellite imagery, and utilizing the distinctive architectural features of these shrines, we have successfully compiled a digital inventory of these sites. To date, 276 shrines have been identified and precisely located within the region.

Beyond their cultural and historical significance, shrines in the Maryut region serve as valuable indicators of potential archaeological sites. Nearly half of these shrines are located on tells (koms) and karms, signifying antique settlements.
Our recent spatial survey revealed that only 163 (59%) of the total shrines in the Mareotid region are still extant and precisely located. The locations of approximately one-fifth of the shrines remain uncertain, requiring further field surveys to confirm their existence and pinpoint their positions. The remaining fifth have already been lost due to urban and agricultural development that has taken place since the late nineteenth century.

Our observations and site visits reveal that many surviving shrines are in a precarious state. Numerous factors threaten their existence, including: a lack of maintenance leading to damage from erosion; their isolated locations in the countryside or desert; and targeted destruction by some Salafi groups, particularly during the period of instability following 2011.

To address these challenges, a new research project, "The Shrines of the Maryut Lake Region" was launched in June 2024, supported by CEAlex and funded by the Barakat Trust. This project aims to deepen our understanding of these shrines and highlight their significance within Islamic history. The project will document their current condition, emphasize their spiritual and heritage value, and ultimately provide a comprehensive database to policymakers to advocate for their preservation.

This three-year expected project involves a multidisciplinary team of photographers, sociologists, land surveyors and cartographers. The first year is dedicated to meticulously documenting, photographing, and precisely locating all shrines in the Maryut Lake region.

In the second year, we will try to contact the ministry of the Awqaf of Egypt and the General Sheikhdom of Sufi Orders, the two main authorizations responsible of the shrines in Egypt, in order to access to their archives and have official information on the holy owners of these shrines, in order to nourish our GIS database. Moreover, a GIS webpage will be planned to create, dedicated to our project with principle information and geo-location of each shrine.

And concerning the last year, we will aim to contact diverse scholars, sociologists and historians, with the goal to develop the project to understand the nature of the development and the surviving interest of these very particular monuments for the community.

The project will lead the team to collect all old documents and photos concerning the shrines of the Maryut Lake region, from locals and officials, in order to organize several public seminars to spotlight on the critical situation of the shrines and to bring awareness of the importance of contributing the conservation of these monuments within the local communities.

This ongoing research on Islamic shrines in the Maryut Lake region promises to further refine our understanding of the region's cultural heritage and contribute to the development of sustainable strategies for its protection in the years to come.

Figure 1. Shrines of the Maryut Lake region.

Figure 2. Shrines of Sidi Masoud.

136. Using spatial analysis and portable GIS to enhance surveys in a challenging environment. A case of application for the El Tigre Project, Guatemala

Rémi Méreuze (CNRS - UMR 8096 ArchAm | UMR 8215 Trajectoires)*; Julien Hiquet (UMR 8096 ArchAm)

This paper explores innovative methods to enhance archaeological surveys in the challenging environment of the Maya Biosphere Reserve, Guatemala, within the El Tigre Project. This area is extremely rich in cultural heritage and contains archaeological sites dispersed across the dense forest that covers the landscape. Many of these sites are situated far from currently inhabited areas, making them both difficult to access and requiring efficient, high-impact survey strategies to maximize the limited time available during field seasons.
The Maya Lowlands, with their combination of dense vegetation, complex topography, and the presence of bajos (seasonal swamps), present unique obstacles for archaeological fieldwork. Terrain features, such as swamps and vegetation concentrations, and the overall remoteness of many areas demand a refined survey methodology that can adapt to these natural conditions. Socio-political factors also impact fieldwork, further emphasizing the need for an efficient survey strategy to help during the limited field season time.

To address these challenges, we developed a methodology designed to optimize surveys. The idea is to get a map of archaeological potential and cross it with a cost model of the survey area. Central to this approach is the use of portable GIS, which offers archaeologists real-time, field-ready mapping capabilities essential for navigating and documenting remote sites with precision (Fábrega-Álvarez and Lynch 2022). Parallel to the quest for an increased survey efficiency and a better understanding of the Maya settlement patterns and environmental adaptations, the research aims to illustrate a deeper use of archaeological information and GIS.

The large LiDAR survey was operated by the Pacunam Foundation and the National Center for Airborn Laser Mapping at the University of Houston for the region of Northern Peten, Guatemala. It covers a remote area of 270 km^2 of dense tropical forest where dozens of sites are scattered, part of them unknown to science until the project began. It has provided a foundational layer for identifying key archaeological features and conducting remote sensing analyses. Using the high-resolution LiDAR data alongside initial fieldwork findings, we mapped probable zones of dense vegetation, bajos, and other natural obstacles to develop a cost map, reflecting the landscape. This model incorporates notes from on-the-ground surveys, allowing us to refine the cost map based on firsthand observations of the terrain.
For data management, the project used an archaeological database stored in the GeoPackage format, mainly operated through QGIS, which served as the basis for creating a distribution of archaeological potential across the surveyed area. This database integrated features identified via remote sensing with preliminary survey results to highlight promising areas of interest. We then used these parameters and spatial distribution to establish a network of connections between key archaeological zones and the base camp, allowing us to visualize potential survey routes and their associated travel costs.
To optimize survey routes, we set up a traveling salesman solution (Curtin et al. 2014) to investigate through the cost model that was produced from it. This approach helped us estimate probable travel times and identify efficient routes that minimized time in challenging terrain, with each planned survey session capped at a maximum duration of five hours. The use of the traveling salesman solution would allow for better planning of survey logistics, ensuring that survey teams

could effectively cover areas of high archaeological potential within time and resource constraints.

The integration of GIS and QField markedly improved survey efficiency and data quality in the El Tigre project. By integrating the project's database and GIS within QField, field teams were able to quickly and accurately identify and document archaeological features even in dense vegetation. Data collection was streamlined as each point, line, and polygon captured during the survey was immediately stored with geographic coordinates, reducing the need for time-consuming data processing after field activities. This approach helped us decide of the best strategy of which path to follow with a global idea of the time it would take (figure 1). Additionally, the use of QField minimized data loss or recording errors, as information was directly entered into a digital format with minimal manual handling.

Spatial analysis conducted on the survey data revealed insights into the spatial organization and settlement patterns of the Maya in the El Tigre region. The high-resolution mapping enabled by GIS and QField facilitated the identification of subtle topographical features, potentially indicative of Maya environmental adaptation strategies, such as water management structures or terracing systems. The real-time nature of QField allowed for immediate decision-making, where team members could adjust survey boundaries or focus areas based on initial observations, enhancing the adaptability of the survey process.

The implications of this research extend beyond the El Tigre project, underscoring the potential of QGIS and QField to transform archaeological fieldwork in challenging environments. The integration of GIS and mobile applications like QField can significantly enhance data quality, efficiency, and survey coverage, especially in landscapes where dense vegetation and limited visibility hinder traditional survey techniques. This approach promotes not only efficiency but investigates new ways for archaeological and environmental data exploration.

Furthermore, the real-time data collection facilitated by QField supports interdisciplinary collaboration by making survey results immediately available for analysis and interpretation by team members. The successful deployment of this methodology in the El Tigre project demonstrates its scalability and adaptability, suggesting that similar projects could benefit from the same technologies to study archaeological landscapes.

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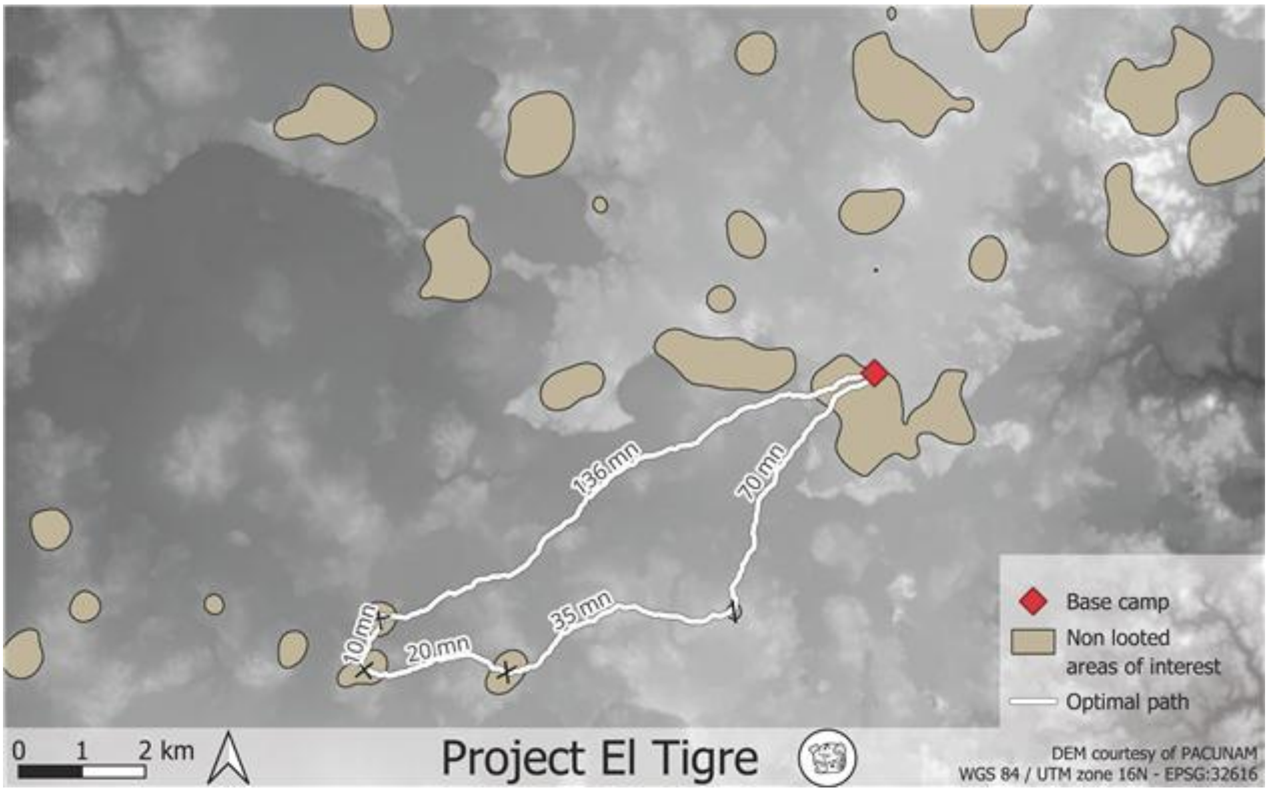
136 mn
70 mn
35 mn
20 mn
10 mn
Base camp
Non looted
areas of interest
Optimal path
0 1 2 km
Project El Tigre
DEM courtesy of PACUNAM
WGS 84 / UTM zone 16N - EPSG:32616

458. Application of Photometric Stereo to the Study of Rock Art in Chauvet Cave

Antoine Laurent (IRIT/TRACES); Benjamin Coupry (IRIT); Thomas Sagory (MAN); Jean Melou (IRIT)*; Carole Fritz (CNRS); Jean-Denis Durou (IRIT)

1 Introduction

Photometric stereo (PS) is a photographic method of 3D reconstruction that remains relatively unknown in heritage sciences. It allows for the separate estimation of surface relief and colour. Similar to archaeologists who rely on the movement of shadows to interpret relief, PS is based on measuring light intensity to reconstruct surface volumes. It is often referred to as a “laboratory method” due to its deployment constraints, which require careful control of lighting. Given this restrictive designation, we will examine how it works to assess its relevance to the needs of archaeology.

To highlight the relief of an object, it is recommended to vary the lighting while keeping the pose of the camera — its position and orientation — fixed. This principle is used in RTI (Malzbender, Gelb, and Wolters 2001). However, while RTI enables the interactive simulation of variable lighting, it is not strictly a 3D reconstruction method, unlike PS, which nonetheless relies on the same type of data. After a brief description of PS, we present in this work how to apply this in the context of studying rock art.

2 Methods

Photometric Stereo The physical model we adopt is the Lambertian one, which is well suited to archaeology, given that many objects are both opaque and diffusive. This model expresses the grey level I(p) of an image point p in the following particularly simple form:

$I(p) = \rho(P)\ n(P)^\top s(P)$ (1)

In (1), $\rho(P) \in R+$ denotes the albedo (the colour) of the point P in the scene which is projected at p into the image, $n(P) \in R3$ the unit outgoing normal to the surface at this point, and vector $s(P) \in R3$, called the illumination vector, characterises the direction and intensity of the incident luminous flux in P.

This calibrated approach of PS (Woodham 1980) assumes that the illumination vector s(P) is known, without necessarily assuming that it is uniform, i.e. independent of P. By introducing as a new unknown $m(P) = \rho(P)\ n(P)$, Equation (1) becomes linear. Moreover, the use of N lighting $s^i(P)$, $i \in \{1,\dots,N\}$, can make the estimation of m(P) well-posed. Indeed, (1) can be rewritten as:

$$\begin{bmatrix} I^1(\mathbf{p}) \\ \vdots \\ I^N(\mathbf{p}) \end{bmatrix} = \begin{bmatrix} \mathbf{s}^1(\mathbf{P})^\top \\ \vdots \\ \mathbf{s}^N(\mathbf{P})^\top \end{bmatrix} \mathbf{m}(\mathbf{P}) \qquad (2)$$

As soon as $N \geq 3$ lighting vectors $s^i(P)$ are used, and these vectors are not all coplanar, the matrix of the second member of (2), obtained by concatenation of these vectors, is of rank 3. Therefore, the solution in m(P) is unique. Knowing that n(P) is of norm 1:

$$\mathbf{n}(\mathbf{P}) = \frac{\mathbf{m}(\mathbf{P})}{\|\mathbf{m}(\mathbf{P})\|} \quad ; \quad \rho(\mathbf{P}) = \|\mathbf{m}(\mathbf{P})\| \tag{3}$$

Light Calibration

The main challenge in implementing PS lies in calibrating each light source by estimating its orientation and intensity as accurately as possible.

Of course, using a pre-calibrated RTI dome allows bypassing the lighting calibration phase. The use of RTI data for PS is therefore highly appropriate.

Without a dome, it is necessary to place a calibration target in the scene. The simplest solution is to use a sphere of uniform colour. Not only does this object have the widest possible variety of normal orientations, but the normal is also perfectly known at any visible point of the silhouette. The lighting is then determined by inverting Model (1). The use of a calibration sphere does make it possible to use calibrated PS in a wide variety of contexts and at low cost, but care must be taken when positioning the sphere in the camera field. If it is possible to dispense with the use of such a calibration sphere, this will considerably improve the scope of application of PS.

The scene to be reconstructed can itself be used to estimate the various light sources (Coupry et al. 2025). Indeed, as long as the normals are known at a number of points P ≥ 3 in the scene, it is possible to estimate the lighting and albedo at these points using Model (1). This method relies on prior knowledge of the normals at a sufficient number of points in the scene. We obtain this knowledge by observing that each illumination si varies at frequencies lower than the albedo ρ and the normal n. In other words, if we estimate the global relief of the scene, i.e. without bias in the low frequencies, using an appropriate method, inverting Model (1) allows us to obtain a good estimate of the illumination. To do this, we can use a 3D mesh obtained by photogrammetry, which does not require any registration between both 3D reference frames, if one of the photogrammetry shots is taken from the pose used for PS.

3 Results and Discussion

PS was tested under real conditions on the walls of Chauvet Cave. Unlike other methods, such as multi-view stereoscopy, which is very popular, PS naturally preserves the resolution of the input images (as the calculation is performed pixel by pixel). This makes fine details observable. The albedo map and the normal field obtained for the “Cheval gravé” in the “Gallerie des croisillons” are presented in Figure 1. The magnification shown on the bottom row highlights not only the finger tracings, but also bat claw marks.

Does PS truly help with interpretation when the scene has a nearly uniform colour?

The large “Mammouths raclés” (approximately 2m × 4 m) were entirely created by finger strokes, removing a layer of clay film/deposit from the surface to reveal the white of the wall. PS data acquisition was carried out at a distance of 2.5m from the wall. The results show that it is indeed possible to reconstruct the chronology of the tracings. This uniform surface could not be digitized with such precision using laser scanning or photogrammetry.

It should be noted, however, that in general, the use of a sphere positioned within the camera field is not suitable for decorated caves, as the preservation of the floors severely limits movement and prevents the placement of a tripod near the wall, except in certain areas like the “Mammouths raclés” panel. This makes it difficult to deploy PS on panels located further from the pathways.

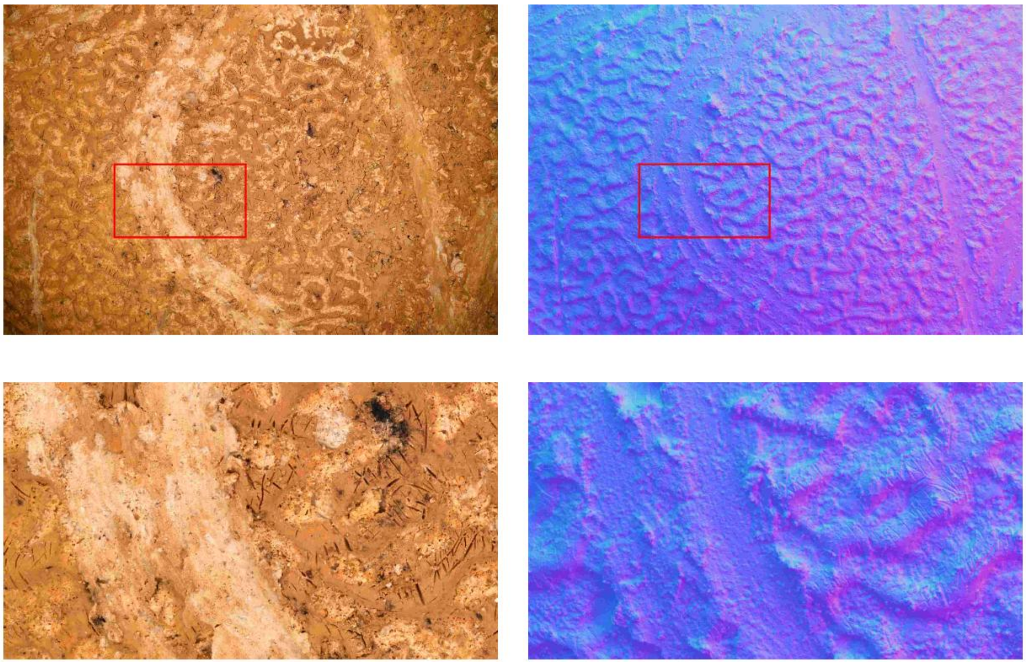

Figure 1: “Cheval gravé” from the “Gallerie des croisillons” (Chauvet Cave, France). Top row: estimated albedo and normals. Bottom row: magnified views of the area outlined in red, clearly showing the finger tracings as well as bat claw marks.

PS offers several advantages for the reconstruction of cave walls, particularly its ability to digitize untextured surfaces, to estimate both the relief and colour of a scene, and to process data quickly in a parallelizable manner, while preserving the resolution of the input images. However, this technique has its limitations. Indeed, the result obtained is a normal field, which can be integrated into a depth map, but this does not constitute a true 3D reconstruction. Additionally, the method relies on the Lambertian assumption, which is not always valid.

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419. Exploring the Use of TLS Intensity Data: Challenges and Advances in Rock Art Research

Maria Sotomayor Chicote (University of Cologne)*

This paper explores the application of terrestrial laser scanner (TLS) intensity values for the analysis and documentation of rock art paintings. In recent decades, rock art research has significantly benefited from digital techniques, including remote sensing methods such as DStretch and Structure from Motion (SfM). These approaches have proven effective for the documentation and enhancement of rock art, yet they encounter specific limitations in addressing the gradual degradation caused by environmental exposure and human vandalism. DStretch, for instance, has been widely applied to enhance digital images through standardized color calibrations; however, it is limited in its ability to reveal certain pigments invisible to the naked eye, highlighting the need for multispectral imaging methods.

Building on the work of Jalandoni et al. (Jalandoni, Winans, and Willis 2021), which demonstrated the utility of TLS intensity data in detecting obscured black pigments within Gumahong cave, this research extends the methodology to a broader context. Specifically, it evaluates the potential of TLS intensity data to enhance the documentation and preservation of rock art in the Peñablanca region, which hosts the highest concentration in the Philippines, encompassing twelve of the twenty-two known sites nationwide.

Critical factors influencing pigment detection- including geological and environmental site conditions and scanning parameters, such as angle of incidence and range -are analyzed through quantitative methods. These assessments contribute to the development of a standardized workflow for the identification, documentation, and preservation of rock art, potentially adaptable to similar contexts.

The Peñablanca region contains Southeast Asia's earliest directly radiocarbon-dated (14C) rock art, dated to 3750–3460 cal BP. Despite its cultural significance, this rock art is increasingly threatened by environmental degradation and human vandalism. A comparative analysis of surveys conducted in 1976–1977 and 2019 reveals that only 37.6% of previously documented figures remain identifiable (Jalandoni et al. 2021). Additionally, modern graffiti complicates efforts to distinguish ancient rock art from contemporary vandalism. In San Carlos cave, for instance, the prevalence of linear motifs intensifies this challenge. Preliminary findings suggest that TLS intensity values ranging from approximately 0.02 to 0.06, observed in Gumahong Cave, correspond to modern graffiti, whereas rock art tends to exhibit higher intensity values. First testing in San Carlos cave confirmed these patterns, highlighting the potential of this approach to differentiate between rock art and graffiti.

This paper will present the results of research conducted for a MA thesis, focusing on preliminary findings and limitations encountered in the application of TLS intensity values for rock art analysis and emphasizing the advantages of this method over other multispectral imaging techniques, such as hyperspectral imaging (HIS). The adaptability of TLS for simultaneously capturing high-resolution 3D spatial data and analyzing pigments across different spectrums- dependent on the wavelengths and settings of the scan -makes it particularly suitable for the challenging environments of rock art sites. By contrast, HIS, while effective for recording spectral data, is often hindered by irregular lighting and geometric distortions in rock shelters and caves due to the difficult implementation of hyperspectral instruments in such contexts (Defrasne et al. 2023).

Moreover, this work contributes to the ongoing discourse on data reusability in archaeological research. It explores whether and to what degree TLS datasets originally collected for geometric analyses represent an untapped resource for intensity-based investigations. The findings underscore that the utility of such datasets depends on specific factors, including the wavelength and settings of the original scans, which may not always be optimized for pigment detection. Nevertheless, preserving high-quality scan data remains crucial for future applications. In conclusion, this study not only delves into the application of new methodologies for rock art research but also highlights the potential value of archival TLS datasets, promoting sustainable practices and setting the stage for future investigations.

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59. Reconstructing Aegean Bronze Age wall paintings through drawing. From using watercolors to digital images. What's next?

Nikos Sepetzoglou (CAA)*

Context:
This paper focuses on the process for reconstruction drawing of the Aegean Bronze Age wall-paintings. Due to the absence of written sources from that period, the restoration of pictorial depictions becomes the main tool in order to approach and interpret the image and the iconography of that era. One of the main features in this attempt is the interpretation of the fragmented frescoes. As it becomes evident from the archaeological research, the "art" of wall-painting was widely practiced and became the typical way of "cladding" and decorating interiors of buildings of "palatial" nature, as well as in particular public and private edifices. It also served the intentions of the socio-religious system (Vlachopoulos 2018). Through a variety of examples this paper discusses the methodology of the reconstruction process and it explores the relation of the practice of drawing to the interpretation of the fragmented wall-paintings themselves.

Main argument:
The process for understanding archaeological finds is a reciprocating game between the socio-theoretical framework of the interpreter and the historical or cultural framework of the object. It is not enough to observe data: one should energize them by questioning (Hodder and Hutson 2003). Reconstruction drawings are widely used in archaeological monographs, articles and illustrated albums, but also as guiding images that accompany the fragmentary wall paintings in museums and archaeological sites. However they often produce a virtual reality that also refers to matters of form and aesthetics, and do not always function as tools for a deeper understanding of the surviving picture. It is crucial that the original fragments stand out of the proposed reconstruction and that the modern interventions are clearly indicated. A typical example of this problematic is the work of A. Evans in Knossos, who tried to give a complete picture of the Minoan culture, proceeding with extensive restorations of the architectural remains and the particularly fragmentary wall paintings (Hamilakis 2002). On the contrary and unlike with most Minoan and Mycenaean examples, the wall paintings from Akrotiri at Thera are preserved in a very good condition, allowing a deep study of Bronze Age painting. And this, because with the catastrophic eruption of the Thera volcano at the beginning of the 16th century BC, the entire settlement was covered with volcanic ash that created an ideal environment for the frescoes (Vlachopoulos 2018).

Applications:
The paper will discuss the role of reconstruction drawing in the new environment offered by the use of new technologies. In more than a hundred years of research, this practice developed from using colored pencils and watercolors, to digital ways of drawing and more recently to 3D visual representations through photogrammetry and
3D scanning. Though, questions concerning the function of reconstruction drawings and the interpretation of the fragmented Bronze Age wall-paintings probably remain the same, even if the representation tools change:
- How is an interpretation legitimized to reconstruct the "initial" image of the fragmented archaeological evidence?
- How is it legitimized to reflect or to inspire our current collective image of the past?
- To what extent is a reconstruction drawing legitimized to stand for the fragmented original?

- Could new media provide dynamic images that would respond to the creation of a grid of possibilities between interpretation and visualizing?
- Could new media combine the archaeological data with possible versions of the fragmentary images, leaving the frame of representation open to new interpretations?

Questions that don't necessarily need a straight answer but encourage dialogue that can inspire contemporary practice.

The Author is an experienced visual artist (MA, MSc, PhD Candidate) involved in the study and reconstruction drawing of wall paintings. He has also participated in several archaeological excavations and has recorded in situ and made drawings of architectural remains, petroglyphs and other finds such as ceramics. He uses various methods, from pencil sketches and digital drawings to photogrammetry.

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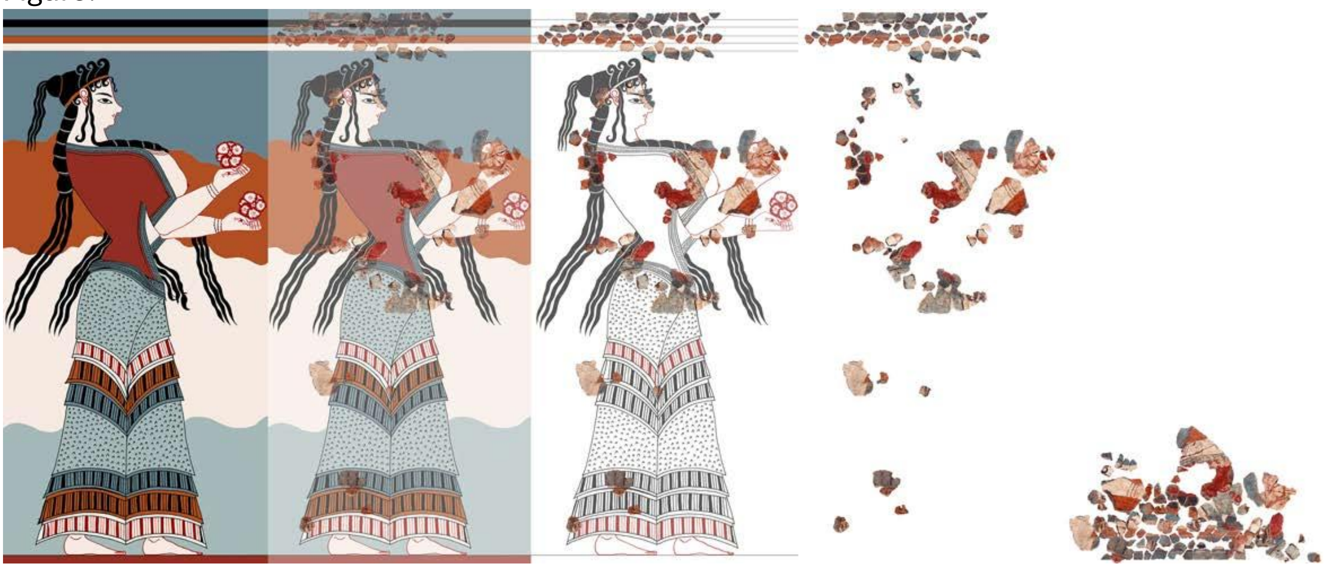
Figure:



435. Digital annotation and presentation of multimodal objects from Ancient Egypt

Rebecca Döhl (Humboldt University of Berlin)*

The digital recording (SFM, digital photogrammetry) of pictorial objects (such as rock art) or text/image objects (such as stelae, rock inscriptions, temple walls) makes it possible to document these objects quickly and accurately. However, when it comes to analyzing and presenting the data obtained in this way, the problem always arises, especially in the case of images, of the appropriate annotation and presentation method to do justice to the iconic nature of the images. When converted into text-based descriptions, many of the advantages and insights originally gained through digital recording methods are lost. In particular, images and their derivatives such as photographs etc. loose their specific semantic content in this transfer. Publications of 3D models via e.g. Sketchfab or of 2D data in data repositories have only very limited possibilities for annotation and linking with additional data.

In the context of creating a corpus of text/image objects from Ancient Egypt, we are trying to solve this problem by using a computer-based visual method to describe and present images and text/image objects. We use the open source software Yenda and Hyperimage (https://github.com/bitgilde) for this purpose, that allows for visual annotation and creation of hyperlinks between elements. In addition to this annotation and presentation method and thus further processing of the data, an annotation procedure is implemented, based on multimodal research in the fields of linguistics and semiotics, which integrates the multimodal aspect of the archaeological objects (text, image, space, etc.) into the analysis. The recognition of multimodal functions of archaeological objects is increasing. The inclusion of many relevant semantic modes of one object and its context, such as images, space, but also sound and gestures, means that new ways of annotating and presenting data are required. These are increasingly calling for digital processing, as text-based descriptions are reaching the limits of their capabilities in this instance.

In this talk, this method will be presented via three different types of objects from Ancient Egypt (rock art, rock inscriptions and offering slabs). The advantages of processing the objects in this way will be illustrated. At the same time, possible desiderata will be identified to enable further development of this approach. For example, the inclusion of audio or video files in the processing of archaeological data is being considered in order not to lose this semantically meaningful content. While this method has so far mainly been used for text/image objects, it has great potential for use with other archaeological objects that benefit from visual mediation with additional information entries.

51. DeepLearning methods and the identification of symbolic networks during European Upper Paleolíthic. A case of study

Natalia González Vázquez (Universidad Autónoma de Barcelona)*; Diego Garate Maidagan (Universidad de Cantabria); Joan Barcelo (UAB, Spain)

Prehistoric rock art is not only a unique World Heritage Site as recognized by UNESCO, but it is also a source of relevant information for the study of the societies that created it. This graphic expression is especially significant during the European Upper Paleolithic. The information available is restricted to the images themselves, or which we can discern from their relations to each other and to the landscape, or by relation to the archaeological context. The comparison between the representations has made it possible to relate some caves with others and thus, to establish connections between different regions. Initially, this comparison was carried out practically intuitively (e.g., Leroi-Gourhan 1971) and, more recently, based on the statistical analysis of certain graphic conventions (e.g., Sauvet and Rivero 2016). In this way, the existence of certain graphic territories is proposed, which evolve and transform throughout the Upper Paleolithic as a reflection of social dynamics.

In this paper we want to address how new technologies like artificial intelligence (AI) and machine learning (ML) could lead us to a more detailed identification of differences and similarities between the motifs, and to cluster them according to the obtained information(e.g., Horn et al. 2022). Convolutional Neural Network architecture could be designed and trained on a data set of rock-art symbols and figures, learning to recognize and classify various elements like:

- Artistic techniques (engraving, painting, etc.)
- Subject matter (animals, human figures, symbols, etc.)
- Stylistic attributes (line thickness, color usage, level of detail, etc.)

Our purpose is to argue why training CNN is an excellent methodology to identify stylistic similarities and differences across geographic areas:

1. Detecting potential “styles” or traditions of artistic practice
2. Mapping the distribution of specific motifs or techniques

By correlating the CNN's stylistic classifications with geographic data, we intend to potentially identify geographical areas with a different “cultural identity” and infer possible territorial boundaries between Paleolithic groups.

We have a constructive but a critical approach to using Machine learning tools for these purposes. It's important to note that while CNNs can be powerful analytical tools, interpreting Paleolithic art requires careful consideration of archaeological context, dating methods, and other factors beyond just visual analysis. Additionally, the limited and often altered nature of surviving Paleolithic art presents challenges for building a comprehensive dataset.

Our effort to achieve this, still in its preliminary phase, needs to be combined with traditional archaeological methods and expert knowledge to draw meaningful conclusions about Paleolithic territoriality and cultural boundaries.

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272. The contribution of areological and phylogenetic analyses to the study of the socio-cultural palaeogeography of LSA rock art sites in southern Africa - The example of the Matobo massif (Zimbabwe) and the Brandberg (Namibia).

Clémentine Bourbiaux (TRACES UMR5608)*

More than 1,400 km apart, and separated by two arid deserts (Kalahari and Namib), the Matobo massif in Zimbabwe and the Daureb/Brandberg massif in Namibia are major centres of Later Stone Age rock art in southern Africa, both listed as World Heritage. From the successive archaeological studies since the beginning of the 20th century, this rock painting activity has been dated to between 13 000 – 2 000 BP for the Matobo and 6 000 – 2 000 BP for the Daureb/Brandberg. Thematic, technical and formal similarities in the paintings have been noted. However, the two massifs were defined as belonging to different artistic regions in the 1980s. The aim of this PhD is to study the spatial variability of LSA rock art in southern Africa and to make a broader contribution to the issue of the socio-cultural geography of these societies, complementing ongoing research into other spheres of material culture. The research is structured around two questions: what are the stylistic connections (thematic, technical, formal and structural continuities and discontinuities) between the Matobo and the Daureb/Brandberg? How can they be interpreted in terms of social palaeogeography and settlement patterns?

To address these questions, this research is based on a comparative techno-stylistic analysis of the human depiction, thanks on the one hand to unpublished data in Matobo acquired during fieldwork in the framework of the MATOBART program (sup. C. Bourdier), and on the other hand to the database published on IANUS for the Brandberg, recorded by the Heinrich-Barth-Institute. In a classical way, the stylistic approach is based on a multi-criteria analytical grid combining motif type, technical features, forms, and composition (assemblage). These graphic elements will be analysed through multifactorial statistics (Correspondence Factorial Analyses, Hierarchical Ascending Classification) following a common trend in rock art research. We also decided to test on this corpus of data more innovative statistical approaches: areological and phylogenetic analyses. These two types of analysis have been used by archaeologists, particularly for lithic and ceramic studies, and have also been developed for the study of oral traditions and myths. However, they were only applied to rock art in the 2010s by J.L. Le Quellec on a corpus from the Sahara (2013, 2014). Areological analyses allow to map analytical criteria and investigate their geographical distribution and associations. Phylogenetic analyses will also be carried out as part of this study. Borrowed from geneticists, the aim of phylogenetic analysis is to highlight the similarities between entities according to their genetic code and to note whether this is due to kinship (phylogenesis) or to a phenomenon of borrowing, influence, exchange or innovation (ethnogenesis). Applies to archaeology, they provide phylogenetic trees which can be interpreted in socio-cultural terms : filiation/isolation, transmission/borrowing/innovation.

In a final step, in addition to the cultural spatial approach, this PhD will examine the organisation of the mobility of LSA hunter-gatherer groups between the Middle Holocene and the end of the Recent Holocene, drawing on models developed by the ethnography of the San-speaking populations of the Kalahari.

Through the combination of these methods, the expected outcome is to characterise the relationships between these two regions and to interpret them in terms of the internal socio-cultural geography of the LSA hunter-gatherer groups and to account for potential long-distance social networks between these two regions.

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109. How high is high? Using digital methods to trace land-use strategies of prehistoric hunter-gatherers in a mountainous region in Namibia in a period of increasing aridification

Oliver Vogels (University of Cologne)*

The Dâureb ("The burning one" in Damara language, which translates into Afrikaans as "Brandberg"), has the topographic characteristics of a 2000 m high turned-around granite bowl that has been heavily washed out by wind and water during the past 130 Mio years. Compared to the surrounding Namib and Kalahari biomes, the Dâureb hosts a special landscape. Its granite substrate and high altitudes cause less pronounced temperatures, water reservoirs, and a natural barrier for large mammals. 840 archaeologically well documented prehistoric rock art sites (as well as a few hundred undocumented ones) and 39.075 single paintings – the highest rock art intensity in southern Africa per km^2 – exhibit that this "inselberg"-landscape has been intensely inhabited by hunter-gatherers.

This paper presents new insights about when, how, and why the Dâureb was inhabited. While certain sites such as "the White Lady of the Brandberg" (which is actually the depiction of a man), or /Ui -//Ais (Twyfelfontein) are UNESCO world heritage sites today, the entire rock art of Namibia (and southern Africa) is deeply rooted as cultural heritage in the conception of many indigenous groups. However, in many areas rock art is endangered by increasing tourism and/or mining concessions. In this context scientific rock art documentation and analysis are important building blocks for raising awareness about rock art's cultural value.

A recent review of the calibrated radiocarbon record from archaeological horizons excavated at painted sites in the Dâureb shows that its habitation began 2000 years earlier than it was originally assumed – between ca. 6000 and 2000 BP. Around 2000 BP the habitation of the Dâureb by LSA hunter-gatherers stops immediately – the exact reasons for this are still unknown. A review of local climate records exhibits, however, that a process of increasing aridification took place between ca. 4000 and 2000 BP (Chase et al. 2010). According to the sheer number of calibrated dates, this particular period determines the main painting phase (Vogels 2023). Around the 4.2k event, which is characterized by pronounced rainfall in southern Africa, a hiatus exists in the radiocarbon record. Based on these observations it is argued here that the Dâureb was visited by LSA hunter-gatherers in periods of pronounced drought, whereas in periods of pronounced rainfall the surround Namib and Kalahari habitats provided enough water and food. But why did Later Stone Age hunter-gatherers visit this mountainous massif in a period of drought? And how relates the production and consumption of rock art, i.e. the social sphere, to this human-environment-interaction?

Percentiles of the topographic characteristics (elevation and slope) of locations selected by humans for painting allow to separate the Dâureb into three habitation zones: 'valley floors / intermediate plateaus' (areas between 650 and 1700 mamsl and slope <20°), 'slope' (areas between 650 and 2573 mamsl and steep slopes > 20°), and 'upper plateau' (areas between 1700 and 2400 mamsl and slopes < 20°). In the latter zone the number of painted sites (n = 507) and painted figures (n = 26709) is the highest, whereas at the 'valley floors / intermediate plateaus' the number of rock art sites (n = 138) and paintings (n = 8670) is rather low and similar to the number of sites (n = 194) and paintings (n = 10272) at the 'slope' zone. According to these numbers, the 'upper plateau' was the most frequently inhabited and most intensely painted zone (Vogels 2023).

The relevance of these three habitation zones was further tested using a pairwise statistical correlation (Kruskal-Wallis and Dunn tests) between painting intensity (number of painted figures

per site) and site characteristics such as water availability, space for group activities, view from site, rock-shelter size and quality, vegetation intensity (derived from a 30 year NDVI time series based on Landsat imagery). The results show that statistically significant differences exist across the three zones. Given that the Dâureb's 'upper plateau' was inhabited in a time of increasing drought, one of the most interesting results of this analysis is that this particular zone has the highest vegetation intensity (Vogels 2023).
Taking the radiocarbon and climate record as well as spatial characteristics of the 840 Dâureb rock art sites together, shows that LSA hunter-gatherers inhabited the Dâureb's upper plateau for its increased water-availability and plant food, whereas under good climatic conditions, the hunting-grounds surrounding the massif were preferred.
These new findings help to explain observations made previously in the themes depicted in the Dâureb rock art. For instance, depicted animals do not reflect the mountain landscapes with its specific small mammals, but the outer world. Springbucks (n = 731), giraffes (n = 503), oryx antelopes (n = 440), ostriches (n = 231), and zebras (n = 116) are the most frequently depicted species. Larger antelopes in contrast, which need to drink regularly, such as Kudu (n = 61) or Eland (n = 49) are rare. According to these numbers, the animal sphere reflects the world outside the Dâureb – in an idealized state –, not its interior. However, the most frequently depicted theme is the human social life (n = 22802). Moreover, in the social sphere a clear correlation exists between the number of paintings per site and the number of depicted humans (Vogels 2023). Given this, it is argued that activities beyond daily economic life, such as the production and consumption of rock art, was used to resolve conflicts, which are particularly high in larger hunter-gatherer groups (Lee 1972), and to express the strength of communal actions and rituals in times of drought, when groups of people had to aggregate in the Dâureb to share its 'hospitality'.

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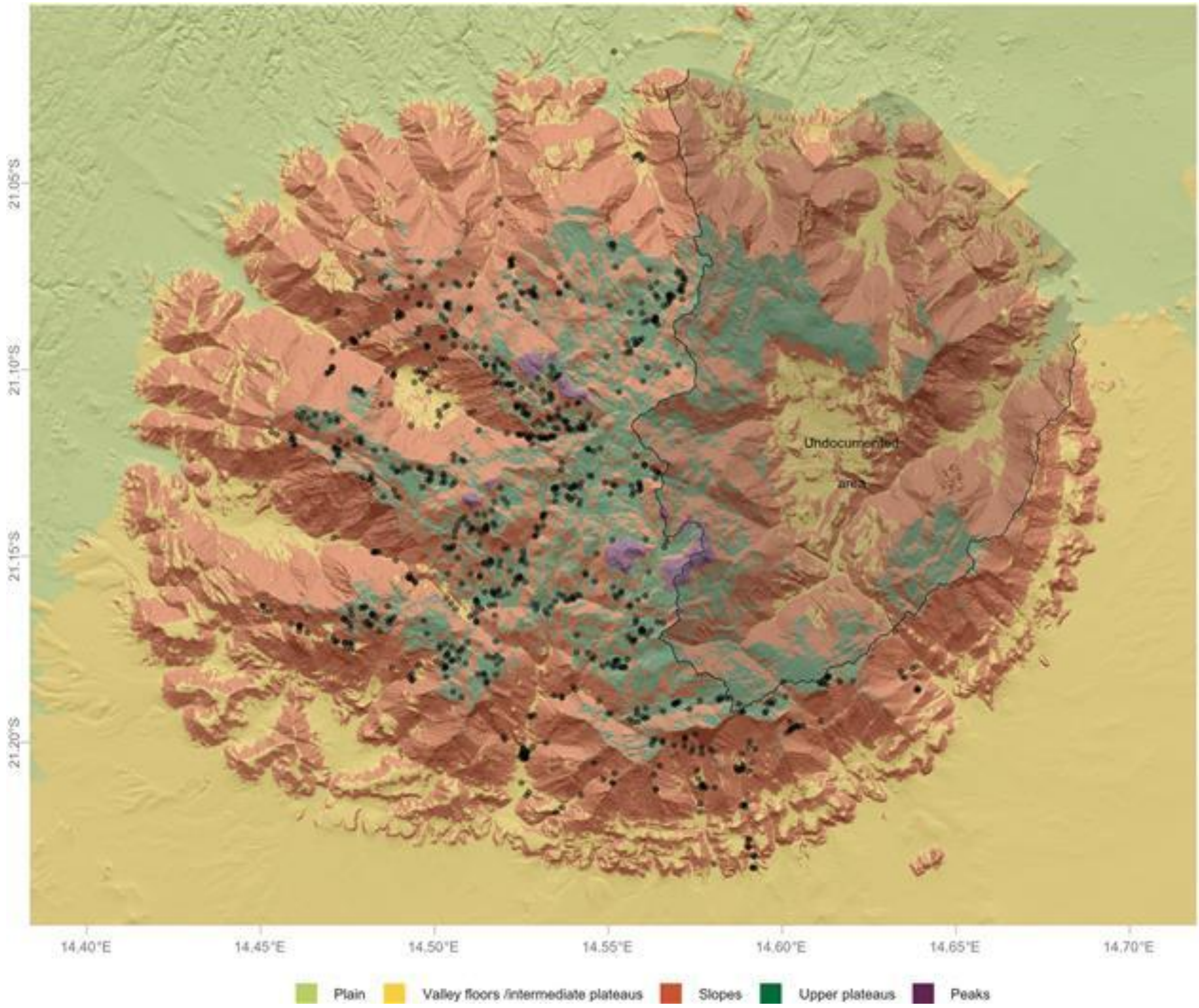
Undocumented area
21.05°S
21.10°S
21.15°S
21.20°S
14.40°E
14.45°E
14.50°E
14.55°E
14.60°E
14.65°E
14.70°E
Plain
Valley floors /intermediate plateaus
Slopes
Upper plateaus
Peaks

533. From Virtual access for Rock Art sites to Digital Rock Art Infrastructure

Trond Lodoen (University Museum of Bergen)*

Having explored and utilized a number of digital documentation methods and GIS structuring methods to provide virtual access to remote rock art, and as we are striving to establish a Norwegian Digital Rock Art Research Infrastructure, the paper will reflect on the achievement and the pros and cons of these digital approaches – and how these can enhance new knowledge and improved humanistic insight of the past. The presentation will amongst other use experience from traditional rock art documentation evaluated against photogrammetry, 3D scanning and other digital methods to discuss digital knowledge achievements. An obvious challenge with modern archaeological research is the fact that it to a major degree involves modern science-based methods that also suffuse archaeological methods with science concepts that challenge humanistic approaches. The latter is something we are gathering experience from through Infrastructure aims and humanistic AI methods.

40. Digitisation, Preservation, Interpretation: Online dissemination and AI in the Swedish Rock Art Research Archives

Christian Horn (Department of Historical Studies, University of Gothenburg); Ashely Green (Department of Historical Studies, University of Gothenburg)*; Rich Potter (Department of Historical Studies, University of Gothenburg)

Rock art documentation often generates large amounts of data, whether that be in digital storage or physical formats, which can impede data preservation, dissemination, and further research. The Swedish Rock Art Research Archives (SHFA – Svenskt Hällristningsforskningsariv), a research infrastructure at the University of Gothenburg, aims to implement workflows from data collection in the field to AI-assisted interpretation in Sweden and beyond. The SHFA has driven research and method development since it was founded in 2007. We not only support the digitisation of documentation from traditional methods, such as frottage, but we also collect and process high-resolution modern 3D documentations. To date, this has generated nearly 27,000 publicly available images from five countries. This paper presents current and future digital workflows in rock art research from a Scandinavian perspective.

In collaboration with Gothenburg Research Infrastructure in Digital Humanities (GRIDH), the SHFA has produced a new mobile-friendly website to display 2D and 3D rock art documentation (https://shfa.dh.gu.se, Green et al. 2024). The backend is GRIDH's Django-based database solution which uses Postgres/PostGIS for structured information and provides a public API. Images are converted to IIIF for high resolution display in the frontend. Each image and mesh are linked to a site. For Sweden, Norway, and Denmark, sites are from the national heritage databases, elsewhere a site is considered a placename and coordinates if not protected. Additional data recorded for each image includes: creator(s), institutions, creation year, collection, image type, visualisation subtype, and keywords to describe the image and rock art panel content. Similar data is recorded for each mesh, as well as the recording method, camera information for SfM models, weather conditions, and mesh dimensions.

The frontend has a three-panel layout using the Vue3 framework and split.js. The first panel contains the search methods, including a free-text search, suggested searches, a geographic search, and an advanced search menu. The middle panel displays a gallery of search results, with site information in a hover overlay on thumbnails. Clicking on a thumbnail opens the third panel which displays an Openseadragon IIIF image viewer, the data associated with an image, a button to open the mesh viewer if an associated mesh is available, a link to the site in the Swedish National Heritage Board for Swedish sites, and clickable keywords which allow users to find similar images. Each image is downloadable with a filename that retains attribution to the creator and can be shared via a unique URL. As all images are now provided under a CC-BY license, a suggested citation is below each image.

The 3D viewer is based on GRIDH's multi-modal viewer solution using 3DHOP and Openseadragon, with full capabilities additionally using Potree and OpenLIME (Jonathan Westin, Tristan Bridge, and Ashely Green [2024] 2024). Users can interact with the meshes, turn textures on/off, adjust lighting conditions, and share links to specific areas of a mesh. Each mesh has associated visualisations so users can compare the 2D representations to the original mesh. The mesh and visualisation data are displayed next to the mesh viewer, along with a suggested citation for the mesh. Many of the visualisations are generated with Topography Visualisation Toolbox (TVT; https://tvt.dh.gu.se) an open-source tool for enhancing carved surfaces which have also been used for image-based deep learning tasks.

Several deep learning approaches have been tested to automatically identify motifs in visualisations of the rock art panels. Initial object detection and segmentation models using TVT

visualisations demonstrated that there is potential for including deep learning in rock art recording workflows (Horn et al. 2024). These tests also highlighted the need to involve experts in both the generation of training data and review of model outputs, and the impact orientation can have on the useability of predictions. Recent preliminary tests aimed to use oriented bounding boxes (OBB) for improved the localisation of motifs. We tiled approximately 400 visualisations while attempting to minimise small crops along image edges, then resized images to 1024x1024 pixels during training. We fine-tuned YOLO11M-OBB models for binary and multi-class tasks with early stopping and used the best performing models for testing. These initial models have a mAP@50 of 0.64 for generic carving detection and perform well on boat and human classes for motif identification. Deep learning will not only be used in interpretive workflows, but also for further training data generation and image tagging in our web resources.
By openly sharing our data in an intuitive and interoperable framework, we can collaborate with a much wider audience and allow international researchers to share their material with us. Researchers and interested amateurs can freely access rock art documentation and compare and analyse multiple datasets directly on their screen, which in the past would have required visits to several museums and archives. This framework has also led us to improve our data collection methodologies and consider aspects of the process that might be of interest to other researchers, i.e. how data was collected and where things could be improved. The non-reductive 3D data we provide can be used as a control or directly as study material. The open access model makes it easy to use any rock art recording in scientific and popular publications, for exhibitions, or outreach tools like apps in future workflows.

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341. Afterlife of an excavation: Utilising excavation data for public engagement activities

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The season ends, the trench supervisor puts down their notebook, collects the photos they liked more and submits a final report. The notebook and the photos are then stored, often untouched, until a researcher decides to publish a specific context. Once this context is published, the materials are rarely revisited. This story is typical for primary excavation data, often maintained in archives for internal consumption This paper argues that excavation notes and photographs can have an 'afterlife'—repurposed as sources for stories that engage the public. Storytelling has already proven to be a powerful tool for archaeologists in both general and excavation-specific projects (Burlingame and Papmehl-Dufay 2022, Mickel 2012) a trend made easier with the expanding digital possibilities (Opitz 2018). As more archaeological materials become digital either through born-digital excavation data or the digitization of older projects, this paper seeks to inspire new avenues for our data.

Currently most most public engagement activities in archaeology are site-specific and are rarely more than an inspiration for other projects. Each site is perceived as unique, shaped by the a combination of different excavation methods, contemporary and archaeological contexts. This paper presents a methodology for using different types of source material and create an excavation story using the material in hand. This approach is not intended to be a one-size-fits-all solution but rather a framework for exploring different excavation materials and generating guidelines and suggestions that can be applied to any project looking to communicate the story of their excavation.

Building on these guidelines, the paper will explore their practical application in two distinct excavation projects: Plasi Marathon and Xombourgo Tinos. Both excavations are affiliated with the National and Kapodistrian University of Athens and have served as teaching grounds for the students of the department of Archaeology and History of Art. Plasi is an ongoing, digital born excavation, while Xombourgo is a digitized excavation currently in the publication process. They span different chronological horizons, archaeological contexts, and landscapes, providing a good baseline for testing the applicability of excavation storytelling guidelines.

Each case study acts as an independent project with deliverables of excavation stories.. The media used for these stories includes digital blogs hosted on a website, utilizing the spatial narrative tool ArcGIS StoryMaps. The presentation of the story material varies depending on the possibilities offered. While the stories follow specific narrative lines, the extent of the material used differs between the two case studies. In Plasi, the stories covers a specific area of the excavation over the spam of excavation activities, whereas in Xombourgo covers one excavation period and it expends on all the areas that were worked on this year.

This research highlights the potential for an 'afterlife' of excavation data beyond the traditional archaeological field. It is hoped that this proposal will inspire archaeologists to embrace public archaeology as a means of better communicating and preserving excavation data, regardless of the type of excavation or data involved.

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122. Reflecting on 10 Years at Kaymakçı: Institutional Memory and Bespoke Solutions in Archaeological Data Management

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The Kaymakçı Archaeological Project (KAP) began work in 2014 with the goal of being a totally born-digital excavation. While a few analog elements remain in the KAP recording system (e.g., hand-written artifact tags), almost all aspects of traditional documentation have been replaced with digital alternatives (see Roosevelt et al. 2015). The past ten years of this experiment have produced a huge assemblage of digital data, with several current projects engaged in cleaning, analyzing, and publishing this assemblage. The KAP recording system has also produced quite a bit of digital detritus: outdated protocols, unused database tables, digital assets that do not meet current standards for quality, etc. This digital detritus records how we have sought to adapt to the rapid development of digital archaeology as a field, to the needs of our born-digital recording system, and to specific problems we have encountered over the past decade. “Excavation” of this digital midden as part of recent work has also led to insights about how we approached this need for adaptation and how we could improve our approach in the future. Here, we take the opportunity to reflect on some of the challenges we have faced in managing and developing a born-digital recording system, and the protocols (successful and unsuccessful) we have implemented to address these challenges.

We focus particularly on the impact of personnel (and changes in personnel) on the management of spatial data for excavated contexts. This system consists of four intersecting workflows: excavation and data collection in the field; the processing of photogrammetric models and their products; the construction of “context volumes,” 3D digital surrogates of excavated contexts; and post-excavation stratigraphic analysis. Engagement with these workflows begins during active excavation and continues into subsequent years of data cleaning, post-excavation analysis, and publication. They also require effective collaboration among several project participants with differing types and levels of expertise, specifically excavation specialists and 3D modeling specialists. We have written elsewhere about the difficulties that arise when participants are siloed into different parts of these workflows by their expertise and by the structure of the project (Scott et al. 2021). Here, we consider how the natural movement of participants into and out of a project impacts the management of these workflows in the long term.

Two crucial issues are at the center of this topic. The first is the creation and preservation of institutional memory. The effort to preserve institutional memory generally focuses on proper documentation of concepts, rules, protocols, and standards, all of which are of vital importance and have been a significant focus of recent work at KAP. What is harder to capture is the full history of trial and error on a project and places where a failed method in the past might provide new insights in the present. A second crucial issue is the development of bespoke systems and software by digital specialists entering an existing project. The development of bespoke solutions to problems is incentivized by a specialist’s prior experience and preferences, by their lack of familiarity with the history of the project, and by the wider culture of academia. But how well do these bespoke solutions integrate with the project’s overall data management? And will such bespoke solutions survive the departure of a particular digital specialist from the project?

In this paper, we draw on ten years of work at Kaymakçı to explore these issues of institutional memory and bespoke solutions in the context of spatial recording, and to recommend how other projects might approach the development of similar born-digital recording systems in the future.

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291. From structured data to reuse and beyond: $(AIR)^2$? Artificial Intelligence to Reuse Data through the Archaeological Interactive Report

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Introduction

Over the years, the acquisition and management of digital archaeological data have been characterised by various practices that contributed to the definition of multiple “standards” in structuring data and the fragmentation of repositories.
The widespread adoption of 3D models in archaeological practice has introduced new elements to archaeological data management: on the one hand, the massive increase in the volume of data and information produced, and on the other, the need to access, manage, and share it.
The need for solutions spurred the development of national and international initiatives aimed at developing infrastructures for long-term data preservation, accessibility, and sharing (Richards et al., “Digital Archiving in Archaeology.”); the same needs also led to the development of digital systems to handle data produced within the framework of specific projects.
An example is the Archaeological Interactive Report (AIR), designed to manage data from archaeological excavations from the site documentation to data postprocessing.

Methods and materials

AIR is a web platform built on Omeka S, designed to document, manage, and share archaeological excavation data. It consolidates various forms of information, such as geographic data, 3D models, images, and videos, into comprehensive, interactive digital reports. It allows for exploring 3D data and 2D GIS maps enriched with text and multimedia. AIR can be used by researchers, educators, and the public and adheres to the FAIR and Open Science guidelines. The validation of AIR in multiple and diverse archaeological projects (Derudas and Foley, “Managing Data from Maritime Archaeology Investigations.”; Svensson and Derudas, “A View from the Hill.”), based on reflections and observations, has allowed it to be iteratively improved both for the field and for post-excavation use and dissemination.
Based on the experience gained during the fieldwork, we have developed a structured and robust data model compliant with the most widely used standards, enabling data interoperability. We also focused on the human interface to make the web platform accessible and usable by non-IT professionals, particularly during post-excavation activities.
The iterative process has been carried out within the long-term investigations at the Västra Vång site, where legacy data and data from five excavation campaigns have allowed us to process these data and thus validate, test and improve the system.
The vast amount of data from Västra Vång was exposed in json-ld through API, a format compliant with Linked Open Data. However, data interpretation, which always requires human review, is not straightforward through these interoperable formats, and it also requires human-oriented interfaces and conversion into narratives.
With the widespread use of large language models (LLMs) in 2022, we began to wonder how these models could facilitate the reading, transformation and interpretation of our excavation data.
To explore these new possibilities, we chose two well-known LLMs, the Open AI ChatGPT, following its evolution from version 3.5 up to 4.o, and Mistral Large 2 to analyse data from specific archaeological features and fed the two systems with structured data from a single context and its related finds. Both LLMs proved excellent in data conversion, especially in the restitution of

tabular data, which is a more readable format than the tree-structure database one. The ability to synthesise structured information into narrative and descriptive texts appeared to be the most relevant result. Proceeding with the experiment, the following step was to increase the amount of information, feeding the systems with the whole dataset from one trench, including all contexts and finds documented.
Based on such richer base knowledge, we requested the LLMs to interpret the trench's archaeological features.

Results
The results of these experimentations, which will be presented at the conference, proved the importance of having robustly structured data. It was clear that the LLMs based their responses on the pair of key values of each structured field.
Even if imperfect, the "produced" interpretations provided pertinent clues and, in some ways, facilitated the understanding of the mass of data. The experiments were not immune to the "hallucination" phenomena of the LLMs, and human intervention proved essential to bring the conversation back on track.
Another aspect to consider is that a considerable amount of data is impossible for the human brain to interpret unless it has undergone long synthesis and restorations.
The use of a considerable amount of data, which the human brain cannot interpret without lengthy synthesis and restoration, is another aspect to consider.

Discussion
In this new digital landscape, it seems that the position of an archaeological prompt engineer has begun to emerge.
Then the question is, what is its role? Based on the mass of data collected during our archaeological investigations, how can we take advantage of the APIs and the various LLMs?
The most difficult challenge in working with these relatively new models is essentially how to ensure the necessary scientific rigour and integrity. However, the ease of use and the gains in terms of 'on the fly' data analysis and synthesis time are indisputable.
Our reflections are in the preliminary stage, and we will present the results of our experiments to encourage and facilitate discussion.

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162. Automated Digitalization of Archaeological Field Documentation

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Introduction

Field drawing has long been an essential method for archaeological data recording, offering benefits such as focusing on detail, facilitating interpretation, and developing a deep understanding of the object, feature or site. Despite the growing number of projects adopting fully paperless recording, analog field drawing still persists for various reasons, from funding limitations and researchers' preferences to personnel's lack of expertise. In these cases, analog field drawing is digitalized during post-excavation management period, either by investigators themself or by external specialists or students and in addition to considerable time consumption, the outcomes may vary in quality, dependent on the performance of the digitizers and his/her perfectionism and experience of the software in use. This paper presents the approach to automate digitalization of analog field drawing, notably section drawings, through Python scripts utilizing open-access geospatial libraries and computer vision. The methodology was developed during the digitalization of nearly 1200 sections drawings of micro-sondages recorded during the pre-excavation survey in Dukovany, Czechia. The paper addresses questions: How effective is scripting for digitalizing analog records? What tools can automate digitalization? How can workflow be improved for better data acquisition and storage?

Methodology

The core premise of this methodology is to treat images as array of pixels, each with unique values (colour) and specific coordinates (x,y) which enable navigation and differentiation within the image. Using these techniques, algorithms were developed and implemented into reusable scripts that aim to streamline the entire digitalization process, transforming scanned forms to vectorized stratigraphic layers, operable in GIS platform.

In total, four scripts were developed. The first script automatically reads section and stratigraphic layer IDs using Tesseract OCR, involving image preprocessing in OpenCV to reduce noise, deskew, rotate, and define the area of interest (AOI) for the necessary data. Extracted data is then saved into a database using Geopandas. The second script rectifies section drawings with parameters scale factor (pixels to meters), CRS, and transformation type, using Rasterio and NumPy. The third script detects section drawings and converts them into polygons with Shapely and Geopandas. The fourth script merges databases of polygons (vectorized stratigraphic layers) with database with ID of stratigraphic layers gained by OCR. Due to the only sporadic occurrence of artifacts and other features within section drawings, these are vectorized manually during quality control. The scripts were tested on additional datasets, including more complex drawings, to verify robustness and adaptability.

Results

The OCR script was modified to semi-automated due to OCR's propensity for errors, particularly with handwritten texts. The rectification script achieved notable efficiency, processing 600 documents in 58.6 seconds, compared to one or two minutes per document manually. While the vectorization script efficiently vectorized all documents, some sections required refinement due to irregularities in hand-drawn elements. Supplementary script was developed to refine geometries based on the x and y vertex positions. Owing to the strict adherence of the ID sequence and sorting polygons by depth, the merging of stratigraphic layers by ID took several seconds with no errors.

Discussion

The scripts were further tested on more complex section drawings to demonstrate robustness. The OCR script depends on note readability and layout consistency, while vectorization may struggle with narrow layers and symbols, and may require manual adjustments. Additional scripts were developed and tested, including automatic refinement of manually created geometries, georeferencing of plans, bulk extraction of photos by automatically generated mask, bulk creation of mosaics. It has demonstrated that simple scripting can address diverse challenges in digitalization.

Scripts demonstrated not only reduction in the time necessary for digitalizing field documentation from days to hours but also increased precision owing to the defined positioning and vertices location, which is unattainable through manual digitalization. Minor adjustments make the scripts applicable to other datasets, supporting their use in various projects. Development of scripts needs to consider requirements of the project as well as the nature of the dataset to be processed and identifying the most efficient approach. Possible implementations may include Line Segment Detection, object matching, or object detection with Deep Learning.

Based on the application of scripts on different datasets of various complexity, it became apparent that to increase the effectivity of the scripts, methodology of field documentation may require some enhancement, including unity in section drawing appearance within the single project, defined symbology and layout of forms and increased readability of the notes. As these scripts work with rasters as array of pixels and differentiate colours, they are applicable on both analog and digital drawing drawn in the tables in specialized software. The latter case may be even easier as no noise removal derived from scanning is required.

Although scripts are designed to be as much easy to use as possible, for their utilisation and further enhancement to fulfil the desired outcome is still required at least the basic knowledge of coding in python. On the other hand, the adoption of scripting into data processing enables to work with geospatial data freely when only limitations can be the imagination and level of expertise. Development of new scripts may take some time but once scripts are ready, they can be easily adapted on the same or similar tasks in other projects and their effectivity rises with size and homogeneity of the dataset. With expertise with scripting, enhanced field documentation methodology and ability to decide which steps can be automated, the scripting can take advantages of detailed analog section drawing, i.e. deep understanding of the site/object/feature, and speed and accuracy of digital methods and can significantly reduce the time required for digitalisation significantly and as such enabling researchers to stay focused on the archaeological questions.

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142. The "fish bones galleries" of Lyon, France: combining archaeological and geological 3D modelling to understand a mysterious ancient underground structure

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Introduction

The network of ancient galleries located in the city of Lyon, France, known as the "fish bones galleries" (galeries en arêtes de poisson) were built under the Roman rule below the Croix-Rousse hill in between 40 BC and 20 AD. After their abandonment during the 2nd century AD, the 2 km long galleries were filled with sediments, and were rediscovered during the first half of the 20th century, when they were hastily emptied and reinforced by concrete for geotechnical reasons. No archaeological evidence thus remains inside the limestone clad galleries, leaving the researchers only able to speculate about the usage of this mysterious structure (Dessaint and Bernot 2009). Further questioning the researchers is the topology of the structure: its deepest part, in the south, is composed of a long central tunnel with a series of intersecting dead-ended galleries, whereas its northern part is made of two parallel tunnels and a series of larger rooms, just below the surface. Several hypotheses have been formulated about the possible uses, closely related to the construction methods and design choices of the ancient builders. To validate these hypotheses, a digital twin of the structure has been created. The reconstructed underground network has then been integrated in its geological context thanks to a 3D modelling of the stratigraphy of the Croix-Rousse hill based on a geostatistical interpolation of point data extracted from geotechnical boreholes.

Methods and materials

Several campaigns of LIDAR scanning have been undergone by the Archaeological Direction of the city of Lyon to obtain a 3D cloud point of what remains nowadays of the galleries. These data were post-processed to produce a mesh of the structure that has been used as a basis to create, in collaboration with the archaeologists, a virtual reconstruction of the galleries in their theoretical original configuration. Recreation of the damaged or disappeared parts of the structure was based exclusively on archaeological on-site observations, since no comparable structure exists in the Roman world. The unusual topology of the galleries prompted questions regarding the geological context of the Croix-Rousse hill: may the geology have had an influence on the choices made by the ancient builders? A 3D modelling of the stratigraphy, based on geotechnical boreholes, could provide insights and help researchers into validating some hypothesis regarding the usage of the network. The galleries are excavated in the different geological formations that make up the hill. These formations alternate permeable and impermeable layers (Pothier et al. 2020). Initially, geological boreholes were collected from various government databases and bibliographic sources. These databases are enhanced when new data become available, for example when modern infrastructures requiring geotechnical investigations are built in the fish bones galleries study area and within a 700 m perimeter around it. As of today, more than 600 georeferenced layer boundaries were obtained, most of them with indications of dips. The Python-based open-source library GemPy (De la Varga et al. 2019, 12) was used to create a 3D model of the stratigraphy of the hill. GemPy-Legacy allows the implicit creation of complex geological models from interface and orientation data. The core algorithm is based on a universal cokriging interpolation method. The obtained three-dimensional model shows the different layers of the part of Croix-Rousse hill around the Roman underground structure.

Results

Our work allowed us to reconstruct the network of ancient galleries and to integrate them in their natural context. We were able to ascertain that the southern part of the galleries was dug in a water impervious layer, in between two geological strata where aquifers are known to be present. This confirms the archaeological hints: the galleries are relatively dry even today, almost no carbonate concretions are visible on the cladding of the structure. The combination of the archaeological and geological data provides a strong argument in favour of one of the hypotheses regarding the possible reason for building of the fish bones galleries: usage as a storage, possibly for perishable goods. Concerning the northern part of the network, both the differences in the construction method, topology of the structure, and geological context make it obvious that the objectives were different. They remain unknown to date.

Discussion

Our work emphasizes the interest of combining various data sources to provide help in understanding the design choices made by the Roman builders of the fish bones galleries. Fieldwork, LIDAR scanning, 3D reconstruction and geological modelling provided data that were integrated in a unified visualization platform, allowing a combined study that contributed in the validation of research hypothesis. We are now able to extend our work by using the data and 3D models for new research topics: palaeoclimatic data and thermic and aeraulic computer modelling will be undergone to simulate the environmental conditions (temperature and humidity) in the galleries during ancient times. Additional geological field and lab work is also in progress to gather new data and validate and enrich the geological model. Furthermore, we plan to integrate all research data in a 3D online open source geovisualisation tool, open to the scientific community. Public valorisation of this unique heritage is also amongst our goals. Hence, a free online 3D virtual visit has already been created by taking advantage of the 3D models initially produced for scientific research and presents the general public with our most up to date hypothesis regarding the fish bones galleries of Lyon (aretesdepoisson.lyon.fr).

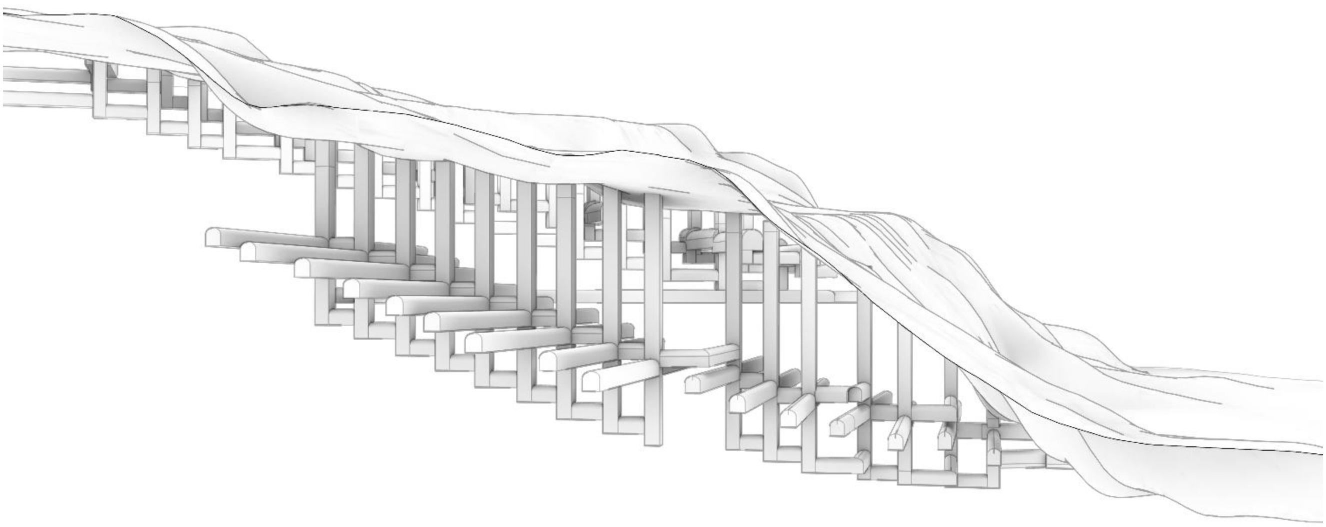

Fig. 1 : The fish bones galleries

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159. Re-engineering for Reuse: Is 'post excavation' analysis a "dark art", or can improved practices and processes using digital technologies help FAIRly share archaeological data from excavation to archived knowledge?

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Should archaeological analysis, commonly carried out as part of Post-eXcavation or "PX" processes, only be undertaken by a small group of highly skilled people? What opportunities are there for digital, and especially online, technologies to enable a more widely shared approach to how excavation data is recorded, analysed, published, shared and archived?

Despite well-known foundational works on stratigraphic laws and principles for recording archaeological stratigraphy (Harris), especially during archaeological excavation work (Roskams), there is still no commonly accepted consistent - FAIR & Open - practice for ensuring that such primary stratigraphic data from excavations is included in resulting digital archives. This problem is encountered in records of both the commercial archaeological work and research funded projects (Bradley). Although valuable initiatives, such as the CIfA "Dig Digital Toolkit" (https://www.archaeologists.net/digdigital), have begun to address what is included in the digital archive from excavations, the actual processes used in the post-excavation (PX) analysis stage of projects varies quite markedly and therefore the by-products from that stage of the archaeological process are far less consistent in any resulting digital archives (Moody et al). A big question remains: "To what extent are PX practices, techniques and documentation as well established as the methods for on-site recording" and what are the related opportunities and challenges, we still face?
Current practice for digital archiving of digital records of the stratigraphic data from excavations is still very variable internationally, particularly for commercially excavated sites. Experience in the UK, as reported through ARIADNE+ , shows "comparison of the number of archives deposited with the Archaeology Data Service (ADS) against an estimated number of projects found that, at best, 2-3% of all commercial projects have been digitally archived with the ADS" (Tsang 2021).
What improvements could be made to archaeological practice that would better encourage the sharing, linking, interoperability and "re-mixing" (Huggett) of archaeological data and information i.e., re-engineering which processes?

This paper will present the key outcomes from 'The Archaeologists Guide to Good Practice - Handbook' (AG2GP-Handbook) [AH/X006735/1] project which build upon published recommendations from The Matrix project [AH/T002093/1] which identified and addressed some of the current limitations in certain approaches to analysis and digital archives of archaeological stratigraphic and phasing data.
The AG2GP-Handbook project gathered the considerable collective expertise of the main archaeological contractors and associated researchers in the UK and, in consultation with other professional bodies and stakeholders from the sector (through FAME & CIfA), has undertaken the necessary feasibility work and collaborative activities to develop online tools and resources to support best working practice for these archaeological PX activities.
There are still considerable challenges ahead, not least how best to integrate guidance derived from best practice within one current geo-political system (country), to encompass a wider international (global) perspective, making sure to not over-ride ontological and cultural differences embodied in, amongst many things but not least, multiple languages. Since it was

published online in April 2024 the AG2GP-Handbook (English version) has already been viewed by users in over 68 different countries across the globe (figures derived from Google analytics), but how can the Handbook best reflect and incorporate, in a sustainable way, the many differing modern international political frameworks and archaeological funding streams (Taylor) that exist internationally? How far is it feasible to bridge across differing methodologies used to record and analyse different archaeologies, sometimes reflecting differing past geo-political systems and cultures that could be encountered in the piecemeal 4D ‘jigsaw’ of surviving archaeological remains?

The AG2GP-Handbook was specifically designed and composed to focus only on the specific area of stratigraphic analysis in PX. The argument for this was that such stratigraphic analysis forms the ‘backbone’ process by which much of the other information in the rest of the PX process is linked together using the core stratigraphic framework of a site and by which key phasing of major activities in the archaeological record are interrogated, collated, and verified for reporting and synthesis. There is therefore the potential to widen the AG2GP-Handbook approach to incorporate more elements and activities undertaken in finds analysis and dating, thereby distilling best practices in the broader PX and publication processes.
One recommendation from The Matrix project (May, et al) was to develop an online forum with a working group to build a sustainable pan-global international convention on archaeological stratigraphic methods. The said “international convention on archaeological stratigraphic information” should aim to provide more accurate and interoperable records of the “Boundary A” (Edgeworth) between human-made strata and naturally deposited strata for (re-)use in Anthropocene and ecological research such as Climate Change impacts analysis within and beyond the archaeological domain.

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517. Exploring the Utility of 3D Web Interfaces for Communicating 3D Paradata: The Case of the Late Roman Castellum of Maastricht in Voyager Explorer

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3D visualisations of archaeological remains are commonly viewed as outputs for public edutainment or site valorisation. While this is a valid outcome for 3D heritage, many advocate that these 3D presentations can also be curated in ways that appeal to a more expert, or scholarly audience. If done in a rigorous manner, the amount of research and knowledge that goes into making an accurate reconstruction of an ancient site can be significant, equating to a dossier on the known and unknown elements of a wide range of factors — from building construction, to the natural environment and experiences of daily life. Referred to as 3D paradata, this information that relates to the process of creating a 3D asset is defined by Snyder (2014) as a catch-all term that includes a variety of information about the scholarly workflow, technology devices and programs together with their settings and parameters, the subjective interpretive process with detailed explanation of decisions made, project realisation and the relationship of the 3D asset to other research in the field. While all agree that paradata needs to be well-documented and published together with the 3D asset, there are different options on how exactly to present 3D paradata — stored alongside the 3D models in a machine-readable format (Statham 2019) or directly integrated with the 3D models to manifest a 3D research environment (Schreibman and Papadopoulos 2019). Ultimately, audience is a key factor in deciding where and how data about a 3D asset is presented as well as the level of granularity of that data depending on the target audience(s). Thus, the challenge is how to effectively communicate 3D paradata to both scholarly and public audiences, thereby accommodating the widest spectrum of audiences without having to develop two or more 3D publications.

Following the concept of a 3D digital Scholarly edition, as laid out by Schreibman and Papadopoulos (2019), this project seeks to assess the capacity of robust public-oriented 3D web viewers, such as Smithsonian's Voyager Explorer, to dynamically communicate paradata for disciplinary experts without alienating a general public audience, and vice versa. This exploration of interface functionality for 3D paradata is done through a case study 3D reconstruction project of the Late Roman Castellum of Maastricht. Due to the heavy urban context of the site, only a few excavations have been able to generally sketch out the main structures of the fort. Therefore, a 3D reconstruction relies heavily on known Late Roman fort construction techniques and contemporary analogies from nearby sites, such as Tongeren, Amay, Deutz, and Aachen. The added value of conducting a 3D reconstruction is to bring together all the known sources of data on the fort in order to digitally map them to their relevant architectural feature. This accomplishes the call for more transparency in public-facing 3D presentations as well as providing a 3D reconstruction road-map for scholars to trace and access archaeological reports and data.

By compiling a 3D dossier of the Late Roman Castellum of Maastricht within the Voyager Explorer web viewer, this project seeks to dynamically problematise the 3D narrative and analytical affordances of common 3D CH interface features and conventions to communicate paradata-related information, such as level of certainty, alternative hypothesis, timelines and transparent communication of source data. As such, this paper explores and presents the opportunities for creative knowledge communication of 3D in 3D as well as the constraints presented by a given 3D web viewing interface.

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240. The digital workflow of the Cultural Heritage Response Unit (CHRU)

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The combination of natural hazards and anthropogenic land-use pressure has resulted in an increase in the frequency of destructive events, which have caused severe damage to archaeological and cultural heritage (ACH) sites. In response to this global challenge, the German Archaeological Institute (DAI) since 2020 collaborates in the project KulturGutRetter with its partners Leibniz-Zentrum für Archäologie (LEIZA) and the Federal Agency for Technical Relief (THW) in order to establish the Cultural Heritage Response Unit (CHRU) to facilitate heritage disaster recovery efforts world-wide. To fulfil its mission in an efficient manner, the KulturGutRetter team has developed standardised procedures utilising state of the art and open source technologies. Starting from assessing risks and damages using space-borne remote sensing and GIS, the digital workflow extends to 3D documentation of moveable and immovable objects on the ground by field crews.

In the initial phase of deployment, the KulturGutRetter remote sensing and GIS support team starts gathering information on (potentially) affected sites, using the most recent satellite imagery available and its own “KGR finder” tool for archaeological information augmentation. The team then produces GIS maps, integrates them with further data and uploads the complete information package, including a standardised data schema, to hand-held devices running mobile GIS for immediate on-site use. On the ground, the CHRU teams use UAV, laser scanning and other tools to further map and document the nature and extent of damages. Collection objects and artefacts on site are documented and assessed directly on mobile devices and for this purpose receive ID cards with QR codes as unique identifiers.

A key component for efficient and flexible on-site data collection is the use of a mobile server with a PostgreSQL DBMS, a network-attached storage solution, and further software for data synchronisation and management within an ad hoc, local network setup. This provides the CHRU teams with the capability of synchronising and securing data coming from a range of different devices, immediately and with great flexibility. Depending on a deployment’s individual circumstances and requirements, this mobile IT infrastructure provides reliable connectivity via its custom local wifi network or an available mobile phone network.

All remote and field data that is not subject to third party licensing restrictions will be handed over to the local antiquities authorities as a structured and documented package. The data will also be stored on the DAI's own servers, and, subject to agreement with said authorities, may be used for further research or publication. The data acquired in the field constitutes a valuable resource for ground-truthing of remotely sensed observations.

This contribution will provide insights into the open source technologies, data and workflows deployed on CHRU rapid response missions.

488. State of preservation analysis of human skeletal remains from Naqlun (Egypt) using new skeletal inventory recording software

Robert Mahler (Polish Centre of Mediterranean Archaeology, University of Warsaw)*; Maciej Krawczyk (University of Warsaw, Faculty of History)

Introduction
Human skeleton completeness assessment of remains under osteological analysis is one of the main factors directly influencing the credibility of results. Completeness also greatly limits the variety of potential analyses to be done, hence its importance for planning research. Presenting the completeness of skeletons from archaeological excavations with one standardized picture for each skeleton gives the reader easy-to-read information at a glance, essential for the illustration of the published results, see Mahler and Breidenstein (2021).
However, the real power of such an app stems from the automatic, on-the-fly transformation into numbers of visual data collected manually. As a bonus, the app provides new datasets that would be very costly to collect otherwise. This opens new research possibilities that can be explored using a computation environment of choice.
The current study aims to examine the potential of the new 'Bone Inventory' skeletal inventory recording software using actual data collected in the field to see if there is a sufficient number of skeletons available the completeness of which would allow the development a population-specific set of stature reconstruction formulae.

Methods and materials
The material for the study comes from a cemetery dated to the 11th–13th centuries CE located in the ruins of the late antique monastery at Naqlun in Fayum Oasis, Egypt. For the current study, 262 skeletons from the more than 500 excavated burials have been examined. The skeletons chosen for study were provisionally selected as sufficiently complete to enable an anatomic reconstruction of stature.
'Bone Inventory' is a digital skeleton inventory registration module developed within the frame of the project 'Muslim women in Fatimid Alexandria: Why did they die young? Biocultural factors in the change of living conditions for people buried at Kom el-Dikka in mediaeval Alexandria compared to the rural Christian population on the fringes of Fayum' (grant of the National Science Centre, Poland, SONATA-18, 2022/47/D/HS3/02162). The module was used to visually record all bone assemblages following the visual recording system proposed by Brickley and McKinley (2004: 6–7, 55–59). This computer application allows for a precise visual recording of intact and partly destroyed bones. Whole intact bones can be recorded also using other software but to date it was not possible to do so with partly preserved bones (Colleter et al. 2020).

Results
The computational completeness analysis performed using R indicated that no more than 228 of the adult skeletons from the sample could be used in an anatomic reconstruction of stature.

Discussion
The current analysis clearly shows the potential of the ‘Bone Inventory’ software for easy assessment of material in preparation for a variety of projects.
Moving from hand to digital drawing when recording skeletal inventories, beside considerably facilitating data presentation and publication, opens new avenues for data exploration and puts new life into the state of preservation analysis. Solving an old analogue problem the digital way

requires very much the same amount of work on the part of the researcher as when using paper and pencil. However, while certainly shortening the path leading from the field to the publication of results, it also gives the possibility of completely new insights into the material under study.

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181. 3D visualization of archaeological sites: state-of-the-art review of analytical applications

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From technical illustrations to physical models made from cork and wood, archaeologists have historically grappled with how to best visualize the three-dimensional nature of field contexts and material relationships for analysis (Opgenhaffen 2021). In the last 15 years, increasingly affordable and accessible 3D spatial recording technology and computer graphics software have opened new opportunities for visualizing archaeological sites. Photorealistic 3D models, point-clouds, and semi-transparent volumes regularly feature next to more conventional data representations such as drawings, photographs and Geographic Information Systems (GIS) maps in analytical discussions (Dell'Unto and Landeschi 2022).

Despite the widespread use of 3D visualizations in research, currently there is a lack of clarity regarding the characteristics of different 3D visualization techniques and their usefulness for interpreting different site contexts. "3D visualization" can at once refer to photogrammetric scans of excavation surfaces, to more creative reconfigurations of archival and digitally generated data into complex, multitemporal 3D composites. As such, 3D visualizations run the gamut from –to use the cliché– "a better photograph", to representing synthetic, digitally enabled viewpoints that one could not experience in the field at any single moment in time (Dawson et al. 2022). This review aims to characterize how archaeologists have created and applied 3D visualizations in their analyses over roughly a decade and identify emerging applications. By exploring how digital data is applied after fieldwork in analytical workflows, it seeks to contribute to the session "Moving Beyond Digital Fieldwork Documentation" (S21).

Focusing on the exploratory period of 2015 to 2024, this state-of-the-art review addresses: what techniques and data sources have been used to create 3D visualizations in archaeology? How has 3D visualization supported analysis, from data exploration to hypothesis testing, to answer different research questions? When and how has 3D visualization been combined with other analytical approaches?

The reviewed literature comprises systematically collected peer-reviewed journal articles and papers from the Computer Applications and Quantitative Methods in Archaeology (CAA) conference proceedings, spanning the years 2015 to 2024. Specifically, the review focuses on papers that used 3D visualization to understand archaeological finds-in-context, excluding those centered on reconstructing individual artifacts or architectural features. To be included in the review, papers needed to explicitly describe the process of creating the 3D visualization in their methodology and reference it in their analytical discussion.

Preliminary findings suggest 3D visualization in archaeology is characterized by methodological and theoretical diversity, embodying the unique decisions of archaeologists in curating field, archival, and other data sources. Frequently, visualizations are a data bricolage, combining data of different types and scales. 3D visualization can support a diversity of research goals, though recent work suggests it is particularly useful for the evaluation of site formation processes and skeletal taphonomy. Consistently, archaeologists emphasize that the additional visual degree of freedom afforded by 3D helps to identify material relationships that are obfuscated in 2D representations of excavations.

The range of approaches to 3D visualization emerging from this review highlights the need to actively consider the way visualization shapes how archaeologists think about archaeological sites. In particular, 3D visualizations that integrate different data sources (e.g., excavation archives, museum collections, laboratory analysis) from different points in time, raise questions about what kind of archaeological reality 3D visualizations purport to reflect. This is an important consideration given archaeologists "think through" visualizations to reconstruct site histories (Opgenhaffen 2021). The significance of this review lies in its in-depth examination of how and when 3D visualization is deployed for interpreting finds-in-context, its identification of emerging applications, and that it lays the groundwork for further epistemological reflection on this practice.

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368. Unhiding a WWII hiding place

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Introduction

Jits van Straten, the only child of Arnold and Lea van Straten-Mendelson, was born November 8th 1938. In March 1943, his family went into hiding due to increasing measures against Jews and the large scale raids in their hometown Amsterdam. Shortly after they went into hiding, the family split up and was hidden at three different locations. In February 1944, the hiding place of Jits was compromised, and the resistance transferred Jits to the hiding place of his father who lived with two members of the resistance in a hole in the ground in a forest. In April, the hiders could not combine their illegal activities with the care for a child anymore due to the lengthening of the days. Therefore, they built a small hiding place in the ground for Jits and his father Arnold. On December 19th 1944, Arnold, together with several members of the resistance, was caught during a raid of the forest by the Sicherheitzpolizei. Jits was found wandering in the woods the same day by a policeman, who brought him to a local vicar who cared for him throughout the rest of the war. Both his parents did not survive the war. Lea was killed in Auschwitz and Arnold died near Lübeck in a death march from the Neuengamme concentration camp.

All his adult life, Jits has been searching for this hiding place which he remembered from his childhood. Only in 1993, he tracked down one of the people involved in the hiding of his family. Together, they tried to find the hiding place but did not succeed. In successive years, Jits made several attempts to find the hiding place without success. In a last attempt in 2020, he asked the Archaeology department of our faculty for help. The hiding place was found by combining a high resolution LiDAR-scan, historical sources, and a soil map (Postma 2022). In 2022, the hiding place was partially excavated and turned out to be destroyed by a fire (Van Essen 2022).

The main question to be solved in the post-excavation was: “What did the hiding place look like at the time of World War II?”. After the excavation, the question: “What is the cause of the fire?” was added.

Methods and materials

To answer the first question, the finds were processed in a traditional way. In addition, all finds were photographed from two sides. Where possible, finds have been combined into objects. Historical sources have been analysed for descriptions of objects which were present in the hiding place. Three hiders who have visited the hiding place during WWII were tracked down and interviewed about their memories of this specific hiding place. For every identified object, a similar contemporary object was selected and used in a 3D-reconstruction.

The second question was answered by forensic research. The dimensions of the construction, the building material, the temperature of the fire, and the starting point of the fire had to be attested. In order to establish the starting point of the fire, all 1000+ finds from this 8 square metres excavation and the burning degree of each object were placed in a 3D-model. The temperature of the fire was reconstructed by two independent methods. First, a burning test of different types of glass was carried out in cooperation with the local fire department. Second, the fire progress was modelled using the software program OZone. The dimensions of the construction and the caloric value were derived from a combination of the 3D-photogrammetic model, historical sources, and dendrological analyses of the remains of the floor and walls.

Results

Almost 100 objects could be identified with varying certainty. A 3D-reconstruction has been drawn which shows the interior of the hiding place prior to the fire. As far as possible, the geographic position of the finds have been used to place the objects in the reconstruction. Each object in the reconstruction is clickable. It directly leads to a short description of the object and the sources which have been used for the 3D-reconstruction, such as historic information, photos of finds, and a photo of a comparable contemporary object. The reconstruction is colour coded in five certainty classes providing an easy overview of the accuracy of the reconstruction (Esselink 2024).

Based on the forensic research, the fire was probably caused by an accident with a self-made carbide lamp. Within 10 minutes after the start of the fire, it reached a temperature of approximately 600 degrees Celsius. Due to a lack of oxygen, possibly due to the collapse of the roof, the fire never developed into a blazing fire. The temperature stayed at approximately 600 degrees for at least two hours.

Discussion

This research project was meant to be a small project, namely the prospection of a hiding place followed by a small scale excavation of 8 square metres. Due to the small scale, it was possible to experiment with new and various digital techniques during the prospective phase and the excavation. We never expected such a high number of finds. During the excavation, we switched from documenting single finds to assembling material per square meter in layers of 5 cm. Despite this change in documentation, the excavation took nine days instead of the estimated three days. This change in strategy especially hampered the forensic analysis.

The 3D-reconstruction shows a well equipped hiding place. We think the chosen way of presenting the 3D-reconstruction helps in the creation of a reliable and, above all, reproducible image. A major problem, still to be solved, is storing the data in a sustainable way.

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376. The SUGAR project: Sweetening archaeological data management from fieldwork to digital domain

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Archaeological fieldwork and data collection are fundamental to the interpretation of past human behavior. However, the lack of standardized protocols for managing archaeological data poses significant challenges for information preservation, accessibility, and scientific collaboration. Current practices often rely on private physical or digital formats, limiting data availability and hindering the principles of open science. The persistence of traditional methods risks obsolescence as technological advances in digitization, automation, artificial intelligence, and cloud storage rapidly evolve. Systematic research requires the creation and management of large databases, which are the basis for an important number of analytical procedures (Roda Gilabert & Mora Torcal, eds. 2014).

The SUGAR project (Software Unificat per a la Gestió Arqueològica, Unified software for Archaeological Management) addresses the need for a standardized solution for managing archaeological data. This platform, which is currently at a high technology readiness level (TRL 9), has been specifically designed to streamline the organization and analysis of excavation and inventory data.

But why is this important? While general tools for document management or archives exist, software for archaeological data management is scarce and usually limited to solutions developed by other research groups. These software products, either proprietary or free, provide limited or partial solutions. SUGAR fills this critical gap by providing an integrated, user-friendly solution for the entire archaeological research workflow. From fieldwork to laboratory analysis, data storage and dissemination the software solution is designed specifically for the archaeological community.

Initially developed for internal use since 2004 as ArqueoUAB (Mora et al. 2010), the software has evolved significantly, integrating open access tagging technologies such as Datamatrix (Martínez-Moreno et al. 2011). Designed for the management of multi-layered archaeological sites, the application integrates the use of a total station, personal digital assistants, and the management of three-dimensional data of contexts and artifacts recorded during excavation.

In addition to database entry, the software offers archaeographic applications (horizontal and vertical plots, stratigraphic analysis, documentation of objects and structures, etc.). Thanks to its flexibility, it creates a dynamic interface between information retrieval and interpretation, stimulating a dialog between data and hypotheses, and the wide range of spatial analysis options available, this system facilitates the development of hypotheses that can be tested as fieldwork progresses.

After 20 years of field and laboratory testing, the software is now transitioning to a public open-source version that supports both Open Science and FAIR principles. We are currently making major updates to the source code with funding from the regional government (Generalitat de Catalunya, AGAUR). Based on the Microsoft.NET Framework, the new software stack includes

MySQL, PostgreSQL and Microsoft Access, along with DevExpress and other public domain components.

SUGAR 1.0 is scheduled for release in the fall of 2025. The go-to-market plan will include release under GPLv3 license and cloud distribution and a WebbApp visor with content under Creative Commons 4.0. In parallel, we are preparing an e-learning solution based on Massive Online Open Courses (MOOC) hosted by Coursera and the Universitat Autònoma de Barcelona.

The strength of the new release lies in a modern and scalable technical stack and innovative features, such as offline data collection and open-source collaboration, focused on maintaining a mature and extensively tested platform. Future roadmap modules include development of cross-platform utilities such as GIS (QGIS) and R integration. Ongoing benchmarking of our software against similar technological solutions shows that there is no other archaeological solution that integrates all of these features in a single platform. As we move forward, our primary challenges are ensuring user-centric design for, strengthening data security to protect sensitive archaeological information, and establishing a user community that includes both academic and professional sectors.

By streamlining the organization and analysis of excavation and inventory data, SUGAR ensures the preservation and accessibility of information essential to material culture interpretation and future studies. Like many other tools, it should be viewed as a

methodological tool for understanding the archaeological record. Bridging the gap between traditional methods and digital transformation represents an opportunity for social sciences and humanities to embrace digital transformation.

Keywords: software: methodology, data management; digital humanities; open science;

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152. Using GIS tools at multiple scales to restore the form and function of a unique Classic Maya mosaic Patolli game board

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Introduction

Ancient Mesoamericans practiced various race board games, now generally subsumed under the name of the best-known of them: Patolli, a Nahuatl word referring to the beans used as dice in this postclassic game. According to ethnohistoric and ethnographic accounts, enthusiasm and unbridled gambling characterized the games.

Dozens of patolli boards have been excavated from Maya archeological sites, from Mexico to Honduras (Swezey and Bittman 1983; Walden and Voorhies 2017), often, in elite contexts. All are etched into the plaster surface of floors or benches, except for a handful of them that were painted. This stratigraphic position leaves open the question of their placement in the sequence of buildings, and thus, of the conditions and significance of the game. Were they incised by the original users, or by later occupants (Fitzmaurice et al. 2021, 77)?

A Classic Period game board found in a high-status residential compound of the capital city of Naachtun, Guatemala, may prove useful in reconsidering the incorporation of the game in architectural sequences, and thus, part of its role in Maya society. It is a unique board, because it is not etched, but delineated in a plaster floor by small sherds, inlaid in the fresh mortar. This technique, recalling mosaics, is unique in Mesoamerica, where mosaics only adorned portable artefacts instead of floors.

This one-of-a-kind device demonstrates that a board could be included in the design of a place since its construction. However, to fully assess its contribution to the understanding of the practice of patolli among the Maya, we need to elucidate the board's context and exact process of creation. Reconstructing the original aspect of the mosaic (damaged by later architectural stages) is essential, as well as understanding its inclusion in the wider environment.

Methods and materials

To do so, our analysis bears on GIS, which provides us with exploration tools at multiple scales, a way to systematize the study of the relationship between the materiality, stratigraphy, and spatial context of the game area.

At the lowest level, the project aims to study the materiality of the board, investigate primary material, reconstruct its missing parts, and document its complete shape and size. Starting from the field record, we projected it on a reference model to estimate the whole area of the game. Then, we used QGIS to calculate the average distance between tesserae to compute their total number and understand raw material procurement.

At a slightly upper level, we need to rebuild the sequence of construction, to understand to which stages of the architectural history the board was linked, and which are less relevant to the analysis.

Once the exact stratigraphic position is known, it is necessary to change the level again, to contextualize the board inside the structure, and inside the group of structures, in relation to private and semi-open spaces.

Results

The model indicates that the board was made of dozens of sherds (more than 400) from many different vessels. Rather than pieces fabricated on purpose to create the board, they were probably obtained in a garbage dump. This leads to several implications and hypotheses concerning who built the game (workers or contractors), played this game (workers during the construction, dwellers of the group, attendants to the plaza), for how long (the time of construction or after), how (hidden, private or public) and why (entertainment during free time or a banquet, ritual, gambling). Also, the area resembles a ballcourt, which questions the possible link between patolli and the Mesoamerican ballgame, an association suggested by iconography.

Discussion

Naachtun's patolli board has a unique technique of construction, which gives it great potential for understanding the practice of this game among the Maya of the Classic period. How does space constrain our understanding of the game and the way we model it?

We started using GIS application to help us record a very unique artefact in an advanced state of decay, and reinsert it in its multiple scales of context. We were able to cross multiple hypotheses and model a standard board game that fits the material discovery. Through GIS, we investigated the relationship between materiality and space, and the entanglement between game and society.

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543. Coptic game board from Chersonesos Taurica and the experience of 3D reconstruction

Oksana Ruchynska *(V.N. Karazin Kharkiv National University/University of Fribourg); Walter Crist (Leiden University); Francesca Condorelli (Free University of Bozen)

Ancient game boards often cross cultural, chronological and geographical borders and are found at a considerable distance from the centres of their widespread use. The Coptic board game is one of the least studied and most controversial types of ancient board games. This type of game was first identified by Étienne Drioton (Drioton 1940, 179), and later Wolfgang Decker, Michael Herb, Roland May and Irving Finkel contributed to its study. Of particular interest is the unique discovery of fragments of a Coptic game board in Crimea, which until now had not been the subject of detailed scientific research.

In 1936, during the excavations in Chersonesos Taurica (modern Sevastopol), several ivory plates were found in the archaeological layer of Byzantine times: 2 thin bone plates and 5 rectangular plates – some decorated with concentric patterns and having through-holes in them. They were found in a layer of earth, charcoal and fragments of tiles. The plates are made of the same material and with the same technique. 4 round counters, each decorated with 5 circles, and 3 pegs were found next to the plates. A comparative-historical analysis using the method of historical reconstruction allowed to identify these bone plates as parts of a Coptic game board. The discovered fragments of a game board from Crimea typologically and structurally match game boards with holes for pegs, designated as a Coptic board game. Five examples of such game boards are known. Two of them are made of wood and ivory plates (Musée du Louvre). Three smaller examples are carved from solid bone (Egyptian Museum; Musées Royaux d'Art et d'Histoire, Brussels; Swiss Museum of Games, but this game board is now on loan to the Museum of World Culture in Sweden). These game boards share a stepped structure, divided into three parts. The lower part is the longest; it has two groups of twenty holes each. The intermediate part has ten holes on the outside and a varying number of positions in the centre. The upper part is the smallest. It has a central hole, which appears to have been the target, surrounded by other holes. Some perforations are not fully formed, they served as decoration for the game board (Crist, Dunn-Vaturi and de Voogt 2016, 123). These stepped game boards are utilized as a model for recreating the Crimean game board.

The aim of this paper is the experience of 3D reconstruction of a game board from Chersonesos Taurica. However, the complexity of this study lies in the fact that the reconstruction is conducted based on a single image. At the moment the artefacts are stored in the State Museum-Preserve «Tauric Chersonese» and access to them is impossible.

Reconstructing 3D scenes from a single image is a critical challenge in computer vision since obtaining complete 3D geometry and appearance from one viewpoint is inherently difficult, as traditional methods relying on geometric priors often fail to capture real-world complexities. Recent advancements in Artificial Intelligence, particularly Neural Radiance Fields (NeRF), have revolutionized 3D reconstruction by using deep learning to model volumetric scenes, synthesizing photorealistic views, and reconstructing detailed geometries from sparse inputs (Mildenhall 2020, 405-6). However, most NeRF-based approaches assume multi-view data, leaving single-image reconstruction an open problem.

Addressing this gap is vital for 3D modeling of cultural heritage, where datasets for digitization are often unavailable but essential for preservation efforts. In this research the Threestudio framework, Zero-1-to-3 and Zero123++ algorithm, a conditioned diffusion model that allows 3D images to be created from a single image, were implemented to test the feasibility of the 3D reconstruction of an ancient game using a dataset composed by only one image of the entire object. The Zero-1-to-3 model uses a conditional diffusion framework trained on synthetic data to control camera viewpoints and produce new perspectives. To make the best use of the already trained 2D models, new conditioning and training methods were developed, thus reducing the need for modification from standard models such as Stable Diffusion. Zero123++ is particularly effective in producing high-quality multi-view images, especially in relation to details. The first step in implementing the algorithm is to prepare the input data. Images should be prepared as RGBA or RGB images with white background. After the training phase, the live demo allows generating new views of an object within a single image.

The preliminary results indicate that the algorithm performs optimally when reconstructing the object. The fact that it is symmetrical of course helped the algorithm. This is because the similarity between side and front views simplifies the inference of missing perspectives, allowing the model to generate more accurate and coherent reconstructions.

3D reconstruction of the Coptic game board from Chersonesos Taurica will allow to recreate a rare example of a board game of this type. Being a part of the common game heritage of mankind, it will serve as a model for further research of this kind.

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372. Exploring Roman board games through AI-simulated play

Walter Crist (Leiden University)*; Eric Piette (UCLouvain)

Game boards have been found in the archaeological record since the early days of the discipline, but because research on play, until recently, has been deemed uninteresting for research, methodological and theoretical techniques for exploring this important type of artifact are largely behind that of other artifact types. This means that such identifications largely rely on analogy with known game boards from historical periods. In rare cases, identifications can be made based on the repetition of particular geometries that afford gameplay, sometimes in conjunction with archaeological contexts that point to a place where people were likely to have played. Artificial Intelligence offers a new avenue to explore how object could have been played as games in the past, and when combined with traditional archaeological methods, can aid in the identification of particular objects as (un)suitable for a particular kind of game.

This research explores two case studies where archaeological methods alone are insufficient to make claims about whether game rules belong to particular boards. In the first case, The Roman game Ludus Latrunculorum is a game for which most of the playing rules are known, as it is often used in Latin sources as a metaphor. They state that the game takes the form of a rectangular grid, and Roman-era boards with grids from 6x6 to 18x18 have been identified by archaeologists as belonging to this game. When the playing rules are applied to these boards, however, it was found that boards larger than 10x10 are not suitable for games with these rules, indicating that the large boards probably belong to a game with different rules suitable for such a large board. The geographical distribution of the findspots for these games—away from the urban core of the empire—further suggests that they do not belong to the game written about by authors in Rome.

The second example explores an object found in Roman Coriovallum, the Netherlands, which presents a pattern not found elsewhere. Nevertheless, use-wear is evident on the object that is consistent with the movement of Roman-era gaming pieces along the lines of the pattern. AI-simulated play of rules from comparable games known from European cultures was used to track the movement of pieces, and to identify rulesets that produce disproportionate movement on the lines with the most use-wear. This object is most likely a blockade game, which is rarely made into artifacts but more frequently made in an ad hoc fashion. AI-simulated play thus allows us to identify unique patterns that otherwise might be dismissed as too enigmatic or unusual to connect to a playful use.

230. AI-Powered Game Recognition: A Collaborative Dataset for Traditional Games

Eric Piette (UCLouvain)*; Achille Morenville (UCLouvain); Barbara Care (University of Fribourg); Dorina Moullou (Hellenic Ministry of Culture); Walter Crist (Leiden University)

The rapid advancement of artificial intelligence in the field of game studies has opened new pathways for analyzing and categorizing traditional games [1]. In this research, we propose the creation of a large, structured dataset of photographs of game boards, which will serve as the foundation for a supervised learning model capable of identifying and ranking potential corresponding games from the extensive Ludii game database [2,3]. The dataset will comprise images contributed by GameTable members and partners, capturing various game boards from a diverse range of cultural and historical contexts. By aggregating this rich visual information into a single dataset, we aim to facilitate comprehensive training for AI models, enabling them to recognize and categorize games with high accuracy.

Each image in the dataset will be annotated by experts, with contributors identifying the games depicted to serve as input data for supervised learning algorithms. This collaborative effort will ensure the dataset encompasses a wide variety of games, board configurations, and stylistic variations, creating a robust training set for model development. The labeled dataset will then be used to train machine learning models, such as convolutional neural networks (CNNs) and other supervised learning techniques, to recognize patterns in game board images and rank potential matches from the Ludii database. Through this process, we seek to build a model that can effectively learn the distinguishing characteristics of game boards, enabling accurate game identification from photographs.

The ultimate goal of this project is to develop a user-friendly application, accessible as a web app or Android app, that can automatically detect and rank the most probable games from images submitted by users. This tool would allow users to upload photos of any board game they encounter, from modern settings to historical artifacts, and receive ranked suggestions on potential matches in the Ludii game database. Its use will be particularly valuable for professional archaeologists working in excavations, offering a quick and reliable way to identify and contextualize gaming artifacts, thus enhancing on-site research and interpretation. Overall, this application has the potential to become an invaluable resource for game researchers, archaeologists, historians, and enthusiasts, providing immediate insights into unknown games and fostering a deeper understanding of the world's gaming heritage.

In conclusion, the integration of AI-driven image recognition within the realm of traditional games represents an exciting interdisciplinary intersection, combining computational power with cultural analysis. By leveraging the collective resources of GameTable members and partners, we can create a powerful tool that democratizes access to game knowledge, supports game preservation, and expands the Ludii game database's accessibility. This research not only aims to achieve practical functionality in game recognition, but also to contribute to the broader field of AI applications in cultural heritage.

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396. Engaging students to historical past through games: how to use preserved games in formal and informal settings.

Elias Stouraitis (Ionian University)*

The 21st century is characterized by the participation and active engagement of young people in their lives. The educational process must be transformed in the developments of this society giving significance to issues concerning experience, empathy, experiential relationship and interaction (Buckingham, 2021). The active participation of students and exploratory learning is at the heart of the educational changes right now. Teaching history the 21th century is a really challenge due to that fact that students receive information outside classrooms such as TV series, games, documentaries, TikTok, YouTube and so on. This has converted history didactics to new methods which include more attractive engagements for students and cultivate empathy and feelings from their everyday life (Retz, 2018). Historical past is everywhere in this digital era we live and educators cope with a very new educational condition.

The main argument of this paper is how can we use games in order to engage students to historical past in formal and informal settings. In doing so, the idea is to leverage reconstructed or preserved games from different time period and place. These games—ranging from ancient board games like Senet to medieval recreational activities—serve as tangible artifacts that embody cultural, social, and technological aspects of their respective eras. As Prensky (2001) has presented an idea of how to incorporate learning elements into a game, we can also use this idea on how we can discuss these elements with students after their gameplay. These elements are the gameplay (how), the rules (what), the strategy (why), the conditions (where) and the decisions/ethics (when/if). In addition to the previous elements, we can contextualize the games into the historical period that the game created and the meaning for the gamers of that time. This makes students come in touch with historical past more not only connected with west civilization, but they learn easily the worldwide human societies. This also helps the multicultural classrooms in order to trigger students to participate and connect with other classmates.

In this paper we will present examples of classroom activities and museum activities using games from the game platform “Ludii” (https://ludii.games/index.php) but also small hands on activities by boardgames. Integrating such games into the curriculum allows students to explore historical narratives, societal values, and the evolution of leisure activities through experiential learning. By actively engaging with game rules, materials, and strategies, learners can gain insights into topics like trade, societal hierarchies, and cross-cultural influences. Furthermore, these games provide a multisensory learning experience that appeals to diverse learning styles, fostering critical thinking and collaborative skills. Educators can use reconstructed games to connect abstract historical concepts to students' lived experiences, enhancing comprehension and retention. This paper finally discusses further methodologies for incorporating reconstructed games into home activities or campaigns with students outside classrooms.

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115. A Thin Line Between Learn And Play – Serbian Researchers' Perspective

Milica Tapavički-Ilić (Institute of Archaeology Belgrade)*; Marija Segan-Radonjic (Mathematical Institute SANU)

Over the past few decades, public interest in ancient games has slightly improved. This is mainly because there are several manifestations held by different public bodies, mostly those engaged in science and research, but also museums and archaeological parks. Prominent examples include "Roman festivals," like those held in Viminacium (Serbia), Salona (Croatia), and Ptuj (Slovenia), as well as "Maj mesec matematike" (May – the Month of Mathematics) in Serbia.

Roman festivals held at Viminacium, former Roman city and legionary fort, often include reenactments of ancient games and sports. They are organized both to educate and entertain, bringing ancient Roman customs to life in a setting authentic to the region's historical heritage. They serve as a bridge between Serbian and Roman history, drawing visitors from around the world to experience ancient Roman culture firsthand at Viminacium.

"Maj mesec matematike" is an annual public manifestation in Serbia that celebrates and promotes mathematics. Organized by the Center for the Promotion of Science (CPN) and the Mathematical Institute SANU, it's a month-long event dedicated to popularizing mathematics among all age groups, especially children and young people. It incorporates games as a central feature to make mathematics more engaging and accessible. Various math-based games and puzzles are designed to appeal to different age groups, encouraging hands-on learning and problem-solving in a playful environment.

This growing interest is reflected in the academic sphere, with an increasing number of articles on ancient games and sports published in international journals. These publications, grounded in historical and archaeological research, provide a scholarly framework for understanding the significance and mechanism of ancient games.

To enhance educational resources on this topic, the authors have reviewed Serbian scientific journals that occasionally publish on ancient games and sports. Focus is placed on periodicals issued by the Mathematical Institute SANU and the Institute of Archaeology, such as Arheologija i prirodne nauke (Archaeology and Science). Notably, some periodicals from the Mathematical Institute SANU, including Publications de l'Institut Mathématique and Theoretical and Applied Mechanics, feature articles on games from a mathematical and theoretical perspective, offering insights into the mechanics and strategies behind these activities.

Inspired by the COST Action CA22145 "Computational Techniques for Tabletop Games Heritage" (GameTable), this paper aims to provide an overview of relevant publications and public events in Serbia that focus on ancient games, assessing their cultural impact and educational value in contemporary society.

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385. Learning with the classic African board game Songo

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This study investigates the playing of Songo ¸ a classic African strategic board game in an informal setting in Yaoundé, Cameroon. The microanalysis of video-recorded interactions shows that Songo is a space where learning is embedded in the interactions between players and the audience. This paper highlights the complex learning that occurs during Songo board gameplay and highlights the importance of the audience in shaping learning in this informal environment.

Introduction

Songo is a nondigital competitive and strategic board game, mostly played in the central region of Africa (Bayeck, 2018; Meka Obam, 2008). The 70 seeds that make up the game, are shared equally between two players at the beginning of the game, who by turn, consecutively distributed these seeds one after the other in holes (14 holes in total) on the board game (Meka Obam, 2008). The game is played in a clockwise direction, and captures happen only when a player's last seed falls into a hole with one, two or three counters (Meka Obam, 2008). The player with the most seeds, 40, wins the game (Meka Obam, 2008). As shown in previous studies (Bayeck, 2018; Meka Obam, 2008), playing Songo also means engaging with the audience.

Though board game research is still emerging (Carter, Gibbs, & Harrop, 2014), studies indicate that these games are learning spaces (Bayeck, 2018; Berland & Lee, 2011). Board games facilitate computational thinking, collaboration, and argumentation (Bayeck, 2018; Berland & Lee, 2011). Board gameplay also supports different forms of interactions like drafting, and painting of board game characters (Carter et al., 2014; Peppler, Danish, & Phelps, 2013). Bayeck (2018) adds that gameplay includes collaborative and argumentation scaffolding. As video games, board games are spaces where learning is embedded in the gameplay. Yet, more research is needed to understand how learning is embedded in the classic African Songo board gameplay. This paper explores how interactions between players and the audience during Songo gameplay evidence learning.

Research question

Current studies reveal that board games are learning spaces (Berland & Lee, 2012). However, Songo has not yet been explored with regard to learning. This study examines how learning occurs in the interactions between players and the audience during Songo gameplay?

Methods

This microethnographic investigation of Songo gameplay of Songo in Yaoundé, Cameroon involved six French-speaking adult players, from different ethnic groups. Microethnography allows for detailed analysis of interactions through the microanalysis of naturally occurring activity ((Erickson, 2011). Videos of interactions were analyzed following Erickson's (2006) approach to interaction analysis. It is important to note that interactions in this study refers to gesture, body orientation, gaze, and speaking activities.

Preliminary Findings

Preliminary findings reveal peculiar forms of learning such as collaborative criticism and embodied cognition. Collaborative criticism is a collective criticism of a player that pushes him to reflect on his actions during the game, was recurrent in Songo play. Participants with more expertise in the game often criticized players with less understanding. This form of criticism often resulted in the player changing his move or action, which is evidence learning. The following except captures an interactions between players (Pierro and Anang), and the audience made of Caulet, Vince, and Ayos. The excerpt starts with the audience's reaction to Pierro's move, as he prepares to distribute seeds from the sixth hole on his right.

Excerpt 1.
Caulet: bouffe, bouffe, qu'est-ce que tu fais là?
[make a capture, make a capture, what are you doing there?]
Vince: = bouffe, bouffe (Vince draws closer to the board and looks over)
[make a capture, make a capture]
Caulet: = c'est quoi là?
[What is that?]
Vince: il faut bouffer encore ... il ne connait pas 4x4 .... c'est ca
[you should make another capture...he doesn't know 4x4... that is it]
Caulet: il te restait trois pions là-bas
[you had three seeds remaining]
Ayos : = tu ne lui donnais pas les pions
[you should not have given him seeds/pebbles]
Caulet : = tu ne lui donnais rien
[you should not have given him any seeds/pebbles]
Collective criticism caused Pierro to change his move, and instead of picking seeds from the sixth row as planned, he played seeds from the third hole on his right. This conceptual change in Pierro's actions at this moment reveals the form of learning that occurs as players interact with the audience.
Also recurrent in Songo board gameplay is embodied cognition. In this instance, learning and knowledge occur in the action and perception shown through the body in diverse environments (Azevedo & Mann, 2018). This excerpt shows learning as it is embodied by Pierro in his reaction to a move completed by Caulet in a game that opposes him to Jean.

Excerpt 2.
Caulet: (Plays the fourth hole on his right)
Jean: (plays the third hole on his right)
Caulet: [to Jean] non, prends ça [no, capture this] (points at a hole and moves the seeds in the third hole on his right)
Jean: [to Caulet] je prends les pions comme ça mon ami [I capture seeds like this my friend]
(leans toward Caulet side of the board, and captures seeds in two consecutive holes)
Caulet: 6, 7, 8, [six, seven, eight] (with his right hand counts the seeds in the third hole on his right)
Pierro: [to Caulet] comment tu peux donner tous les pions comme ça Caulet, il t'a gagné [How can you give your seeds this way Caulet, he won]
(Pierro leans over the board with left hand on Caulet's shoulder, and right hand fingers bent together)
Caulet: [to Pierro] je l'ai vu [I've seen it]

In this cultural context, the gesture of touching Caulet's shoulder signifies making known. Pierro through this gesture embodies his thinking, share knowledge with Caulet as he says: "comment tu peux donner tous les pions comme ça Caulet, il t'a gagné [How can you give all the seeds this way Caulet, he won]. Hence, Pierro uses his body as a means to share knowledge, while Caulet learn as shown in his reply "je l'ai vu [I've seen it] indicate learning.
Conclusion
Though analysis is still ongoing, these findings show that learning is embedded in Songo gameplay interactions. They also demonstrate the influence of the cultural context on the type of

interactions, thus learning players occurring during gameplay. These findings can inspire learning professionals in the design of learning environments that are inclusive and culturally sensitive.

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343. Ancient Board Games as Virtual Time Machines

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In this paper we will explore the development of video games based on ancient board games, as tools for research on traditional games, vehicles for the open and democratic sharing of knowledge about the past, and time-machines that can generate experiences of the past. We will present two video games produced by the authors in collaboration with students from the Utrecht School of the Arts (HKU).

The study of ancient board games has seen considerable growth and change over the last years. From material studies to the use of AI, ancient board games are appreciated as multifaceted, and critical objects for our understanding of past people. This project builds on and links two different types of research trajectories. Firstly, it builds on the Past-at-Play Lab project, conducted at Leiden University (2020-2021), by Aris Politopoulos, Angus Mol, and Sybille Lammes. The project took an experimental approach to the study of ancient board games, building an evaluative framework to explore how contemporary play of ancient games can inform our understanding of how people played in the past. This was achieved by a series of experiments in which citizens were asked to play the game known as The Royal Game of Ur, and the researchers recorded their experiences and ideas through digital recordings, surveys, and focus group discussions. A key result, amongst others, of the project was that ancient games are a particularly suitable medium for raising awareness about heritage, as they offer a unique and fun glimpse into ancient societies, and can act as springboards for the engagement of citizens with the past

Furthermore, this project builds on the extensive research of Walter Crist, who has conducted important work on the study of ancient games both in West Asia specifically, and around the world more broadly. This research has been critical in informing us about the social and cultural settings in which ancient games were played, and in exploring the potentially varied functions games had in past societies. His more recent work as a member of the LUDEME project, combining archaeological research with AI, has considerably enhanced our understanding of how ancient games were played, and different avenues researchers can take to study rules and rules variation.

These two different research trajectories to the study of ancient games led us to a common appreciation for the potential value of exploring the use of video games for reconstructing ancient games. Video games, being visual media, would allow us to reconstruct and explore a wide variety of social settings in which games were played, from palaces to ports, and from agricultural fields to markets. They would also enable us to actively and critically think about the social interactions that could occur when playing ancient games. At the same time, video games are an extremely popular medium, allowing us to potentially reach thousands of people and, through knowledge-driven design, expose them to archaeological knowledge in an informative, yet fun and engaging way.

For this purpose, we collaborated with game development and art students from the Utrecht School of the Arts to develop video game versions of The Royal Game of Ur, and Senet. In this presentation we will delve in the development process of these games, discuss how we conducted knowledge-driven design, and how we worked with the gaps in archaeological knowledge. We will also discuss how these games were developed with the player experience in mind, but also how they could be adjusted to fit museums and other public settings.

403. Neural networks vs tree-based algorithms: a comparative study and generative modeling for vegetation landscape reconstruction from pollen data

Elisa Paperini (University of Pisa)*; Nevio Dubbini (Miningful srls)

Introduction

Palaeoenvironmental reconstruction plays an important role in archaeology, helping to shed light on the interactions between human societies and their natural environments. The introduction of artificial intelligence (AI), particularly neural networks (NNs), offers a powerful tool to uncover patterns and insights that may have previously gone unnoticed. NNs have shown promise in diverse fields, and their application to archaeobotanical datasets, particularly pollen data, offers exciting opportunities for further exploration.

This study investigates the application of NNs in the analysis of pollen data for biome prediction and scenario modelling. To address this challenge, we compare two techniques based on fundamentally different mechanisms, i.e. NNs and tree-based methods, in order to evaluate how each approach performs in environmental archaeological reconstructions.

Methods and materials

The research focuses on pollen datasets spanning the last 100–150 years, sourced from open-access databases, including EMPD for modern data and Neotoma, SEAD, and BRAIN for historical data, covering European regions. For a preliminary study, pollen records from Germany, Sweden, and Switzerland were examined. The dataset comprises 782 records across eight classes, which are the target predictions: Alps conifer and mixed forests, Baltic mixed forests, Central European mixed forests, European Atlantic mixed forests, Sarmatic mixed forests, Scandinavian Montane Birch forests and grasslands, Scandinavian and Russian taiga, and Western European broadleaf forests. Data provides modern pollen counts essential for establishing baseline patterns for further analyses. The data were normalised, classified by species, chronological intervals and encoded to ensure compatibility with machine learning algorithms.

Predictive models were developed in Python, utilizing neural networks (NNs) implemented with the PyTorch framework and tree-based methods (i.e., random forests and Gradient Boosted Trees) built with the Scikit-learn library. The NNs are of feedforward type, with different architectures, where the input layer maps the feature space to a 64-dimensional hidden layer and the output layer has a dimension equal to the number of classes. The model is optimized using the Adam algorithm and trained with the CrossEntropyLoss function over 100 epochs. Input features are standardized via z-score normalization to enhance numerical stability.
The Random Forest models were configured with 50 to 150 decision trees, allowing different tree depths and samples required to split an internal node.
The Gradient Boosting Classifier uses a stage-wise approach for optimization and was trained with a random seed for reproducibility. Models evaluation includes metrics such as accuracy, precision, recall, and F1-score.
This phase of the research aims to evaluate which model is best suited to the dataset and how effectively these models replicate known ecological patterns from modern data. The models will be applied to ancient pollen data to assess their capability in reconstructing past landscapes.

Finally, the study touches on the potential of generative AI tools, such as MidJourney and ChatGPT-4, based on neural networks, for visualising reconstructed landscapes. For the generative component, examples of modern landscapes were produced by providing input solely from pollen diagrams. Further refinement was achieved through iterative interactions with the machine, enabling adjustments to align more closely with the actual environment.

Results

In the preliminary analysis, tree-based algorithms showed superior performance compared to neural networks in identifying patterns in modern pollen data. The accuracy metrics showed a performance of 76% for neural networks, 86% for random forests and 90% for gradient boosted trees. Confusion matrix analysis showed that the class most accurately identified by all methods was Western European deciduous forests, followed by Baltic mixed forests and Alpine coniferous and mixed forests, which also had the highest representation in the dataset.

Feature importance analysis for the tree-based algorithms highlighted Picea (spruce), Betula (birch) and Abies (fir) as the most important genera contributing to accurate predictions.

Throughout the study, the mechanics of both types of algorithm will be thoroughly investigated, including the underlying code structure and the Python environments used for implementation. This will provide insights into the computational frameworks supporting these models and identify opportunities for optimisation.

In terms of the generative component, the images produced by the AI tools showed a mixture of realism and creative deviation. Notable issues included overly vivid colours and the placement of species in implausible contexts (e.g. Abies alba depicted as growing on a riverbank). While such inconsistencies reflect the imaginative tendencies of generative AI, they can be addressed by incorporating more robust human-in-the-loop processes. These iterative interactions between human guidance and machine output are critical for refining results and ensuring greater ecological accuracy in visual reconstructions.

Discussion

Despite challenges, particularly the scarcity of comprehensive datasets, artificial intelligence - whether through neural networks or tree-based methods - shows great promise in assisting experts in environmental reconstruction. The application of these algorithms to ancient data appears feasible and is the focus of the next phases of research.

The generated images have potential for public dissemination, serving as engaging tools for outreach and education. With further refinement, these visual outputs could also be used in academic research, for example as didactic resources to support teaching and collaborative projects.

This study contributes to the wider discourse on the role of neural networks in archaeology by demonstrating how these models can reveal new perspectives on past landscapes. At the same time, it critically evaluates their performance in comparison with other algorithms, providing valuable insights into their practical application in environmental reconstruction.

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63. Improving classification models performance by using Explainable Artificial Intelligence (XAI) techniques

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Context

Straight after an archaeological excavation, the initial approach by an archaeologist involves the recording and quantifying the bulk finds to provide general data about the nature and size of assemblages. The identification of these category assemblages will guide and enable specialist expertise in the following stages of appraisal and analysis. The classification of pottery happens at this stage, addressing the need to sort the artifacts according primarily to shape and decorations.

While a morphological classification is based on profile measurements and general proportions, the classification of decorative patterns describes design, technique, and sometimes the symbolic meaning of the pattern itself, making the task difficult or even controversial.

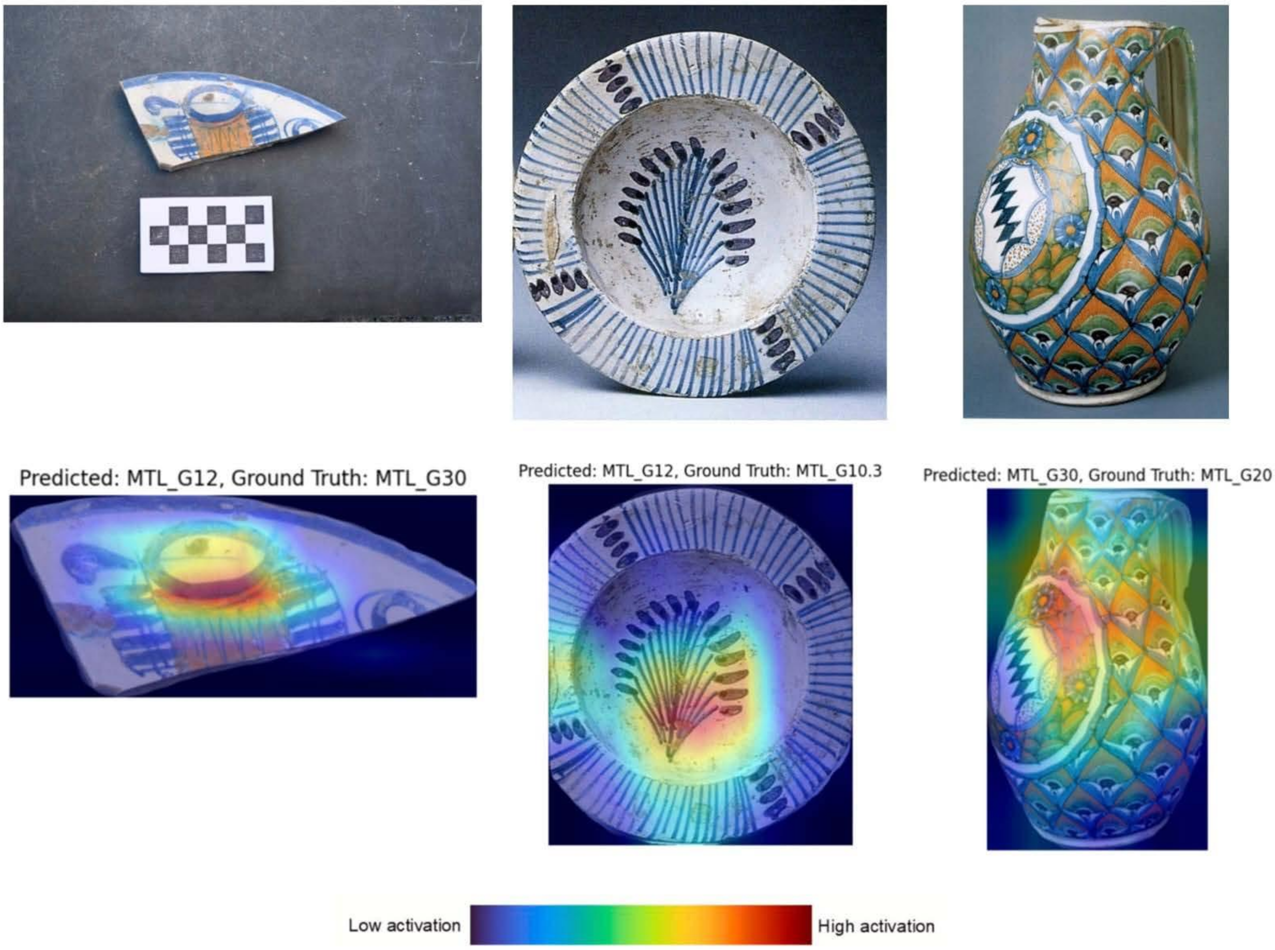
Most of the times, the expert archaeologist examining a vessel or a sherd knows where to focus to make an attribution: they select which elements to consider and which to deem less relevant. While a complete pot allows for a comprehensive analysis, focusing for example on the iconography, when faced with a fragment with minimal decoration, attention may shift to other details such as colors, brush strokes, quality of pigments, or varnishes.

The majolica from Montelupo Fiorentino, spanning from 1250 A.D. for about five centuries, is divided into 84 ceramic classes identified by expert archaeologists on the ground of their decorations [1]. The decorations are actually the most important element around which the study of these ceramics pivots. The extensive dataset, consisting of around 10,000 images, includes whole pieces, partial pots, and simple fragments. This variety in preservation has made appearance-based classification challenging for expert archaeologists, especially because minimally preserved decorations, when not distinctive, need to be imagined within a broader decorative pattern. Additionally, the identification of the correct class is further complicated by the combination of primary subjects and secondary decorative motifs. Specifically, traditional classification mainly relies on the non-trivial recurrence of these secondary elements.

Contribution

When fed into a classification model, like a convolutional neural network (CNN), a dataset undergoes several stages of analysis which are not visible to the user. Indeed, one of the biggest criticisms is that these architectures work as “black boxes”: the decision-making process is opaque. In other words, it is unclear where the network is looking at for its predictions. The use of Explainable Artificial Intelligence (XAI) tools can make this process more transparent by visualizing areas where the network responds with higher activations. The insights they provide into the model behavior demonstrate that the classifiers do not acknowledge the semantics behind the images and that their prediction is based solely on the pixel analysis.

When applied to decorations, entire elements or parts of them can end up being either overrated or overlooked, leading to confusion between classes (Figure 1). To give some examples, the same color combination, such as orange and blue, when recurring across multiple classes, is misleading for the network. Moreover, in a number of cases when the network is provided with a full vessel, it does not classify according to the predominant decoration, but instead shifts its attention to elements that are not useful for attributing the genre. It can also happen that the stylistic features of the elements, whether geometric or naturalistic, add to the network confusion. Furthermore, some specimens representing the transition between one genre and another have a high probability of being misclassified by the network because they may exhibit formal characteristics of both.



Two popular methods of explanations are Gradient-weighted Class Activation Mapping (Grad-CAM) and Local Interpretable Model-agnostic Explanations (LIME).
Grad-CAM [3], designed for CNNs, looks at the feature maps from the last convolutional layer and averages the backpropagated gradients to yields the importance of the feature maps for the target class. A heatmap shows which pixels regions positively contribute to the final decision. Grad-CAM provides a global explanation by showing how a model behaves with respect to a specific class.
LIME [2] offers local explanations for individual predictions. It breaks the image down into superpixels and randomly perturbs it by masking or modifying some portions. It then creates a simpler, interpretable model, such as a linear model, fed on the modified image and observes how those changes affect the prediction. By doing so, it helps identify which part contributes the most to a specific prediction.

Implications
The question to address is: how can classification techniques be improved in their core performance and trust when dealing with complex decorative patterns?
It becomes essential for XAI tools to facilitate a shift in image classification toward an efficient and reasoned analysis of the features (for example, in some cases, the outlines may be more important than the colors, or vice versa), such that they will be able to contribute differently to each prediction.
A comparison between GradCAM and LIME will be presented and discussed to see if they are able to explain different behaviors of the classifier. In addition, it will also be discussed and explored how explanation can be used to improve the classifier itself, and how this will lead to the

development of a preliminary classification system with human interaction, where domain-specific knowledge will be integrated during the training phase. For example, explanation can be leveraged to augment the used data structure or to mask and transform the features from the convolutions, or even to modify the components of the training process, such as the gradients.
In the context of this Human-AI collaboration, the specialist plays a dual role: on one side, they are responsible for selecting, adjusting, and inputting relevant information in a machine-readable format; on the other, they participate into the model evaluation by providing feedback on the outputs. Finally, this system will enhance the process of automatic classification of decorated pottery.

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92. Artificial Intelligence in Archaeology: The MAIA COST Action and its Transformative Potential

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Introduction
The Managing Artificial Intelligence in Archaeology (MAIA, 2024) COST Action (CA23141) emerges at a pivotal moment when AI technologies increasingly intersect with archaeological research. While AI applications in archaeology have gained traction over the past decade, the realisation of AI's transformative potential has yet to be fully explored. MAIA seeks to address this by fostering interdisciplinary collaboration among archaeologists, computer scientists, and heritage professionals to develop AI tools that improve archaeological data collection, analysis, and interpretation. This COST Action is structured around four Working Groups (WGs), each focused on a specific aspect of AI in archaeology. The aim is to tackle challenges such as data scarcity, ethical concerns, and technological integration while ensuring that AI's application in archaeology remains transparent and ethically sound. With the overarching goal of bridging the gap between AI innovation and archaeological practice, MAIA sets out to highlight best practices, share resources, and promote collaboration that will shape the future of archaeology in the AI age.

Overcoming Data Challenges
One of the key challenges in the application of AI in archaeology is the fragmented and incomplete nature of archaeological datasets (Huggett, 2020). Many digital technologies have become normalised and embedded in daily archaeological practice. However, AI introduces new complexities, especially when dealing with incomplete data or small datasets that are often difficult to process using conventional machine learning methods. The scarcity of well-labelled data presents a significant obstacle to the effective training of AI models, particularly in contexts such as artefact recognition and site detection. Techniques such as few-shot learning, zero-shot learning, and continual learning are critical for addressing these data challenges. These methods allow AI systems to progressively learn from smaller datasets, adapting as new data becomes available.
MAIA's second Working Group, dedicated to digital comparative collections and AI training datasets, aims to explore the possible standardisation of creating and managing these datasets. By promoting FAIR (Findable, Accessible, Interoperable, and Reusable) principles, MAIA seeks to ensure that archaeological data becomes more accessible and machine-actionable. This involves not only analysing the existing digitisation procedure but also developing protocols for gathering new data that can be integrated into AI systems. The Action emphasises the importance of domain expertise in guiding the creation of these datasets, as human input is essential for ensuring that AI-generated results are meaningful and contextually relevant. The MAIA initiative also draws on the work of previous projects, which successfully demonstrate the potential of human-AI collaboration to improve archaeological workflows.

Ethical Considerations and Technological Agency in AI Applications
As AI becomes more embedded in archaeological practice, there are growing concerns about transparency, bias, and the ethical use of autonomous digital tools. MAIA underscores the importance of Explainable AI (XAI) in addressing these challenges. XAI aims to develop methods that allow archaeologists to understand how AI models reach their conclusions, thereby ensuring that the results are interpretable and can be trusted. This is especially crucial in archaeology,

where AI algorithms may be used to make decisions about cultural heritage. Without transparency, there is a risk that AI-generated results could lead to misinterpretations or reinforce existing biases in the data.
MAIA's third Working Group focuses on these ethical issues, particularly concerning AI's technological agency (Gattiglia, 2022). By their very nature, AI systems introduce a level of autonomy that can obscure the human interpretive process. This raises concerns about the extent to which AI should be relied upon to make decisions in archaeology, a field deeply rooted in human experience and cultural understanding. The Working Group will explore strategies for mitigating these risks, such as incorporating human oversight into AI workflows and ensuring that archaeologists retain control over final interpretations. The ethical dimensions of AI in archaeology are not just about transparency but also about accountability—ensuring that AI tools are used responsibly and in ways that benefit both the archaeological community and the broader public.

Collaboration and Innovation through MAIA's Working Groups
MAIA's four Working Groups (WGs) are designed to address the complex and multifaceted challenges of applying AI in archaeology. Each WG focuses on a different aspect of AI integration, ensuring a holistic approach to the development of AI tools and methodologies. The first WG is dedicated to understanding the current state of AI applications in archaeology, mapping the existing knowledge gaps, and identifying the most promising directions for future research. The second WG, as mentioned earlier, focuses on creating and managing digital comparative collections and training datasets. The third WG addresses the ethical and epistemological concerns surrounding AI in archaeology, exploring how technological agency and interpretative autonomy can coexist within AI-driven workflows. The fourth WG is responsible for the overall management and dissemination of MAIA's outcomes, ensuring that the Action's work reaches a wide audience, including researchers, policymakers, and the general public.
By fostering collaboration across these Working Groups, MAIA aims to create a sustainable network that can continue to advance the field of AI in archaeology long after the COST Action concludes. The interdisciplinary nature of the Action allows for the cross-pollination of ideas between AI specialists and archaeologists, resulting in innovative solutions that address the unique challenges of archaeological data. As AI continues to evolve, MAIA is positioned to play a crucial role in shaping the future of archaeological research, ensuring that AI is applied in ways that are both scientifically rigorous and ethically responsible.

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437. Analysis of clustering algorithms and performance evaluation metrics applied to samples of the Tell El-Yahudiya ware typology

Guilherme D'Andrea Curra (Leiden University)*

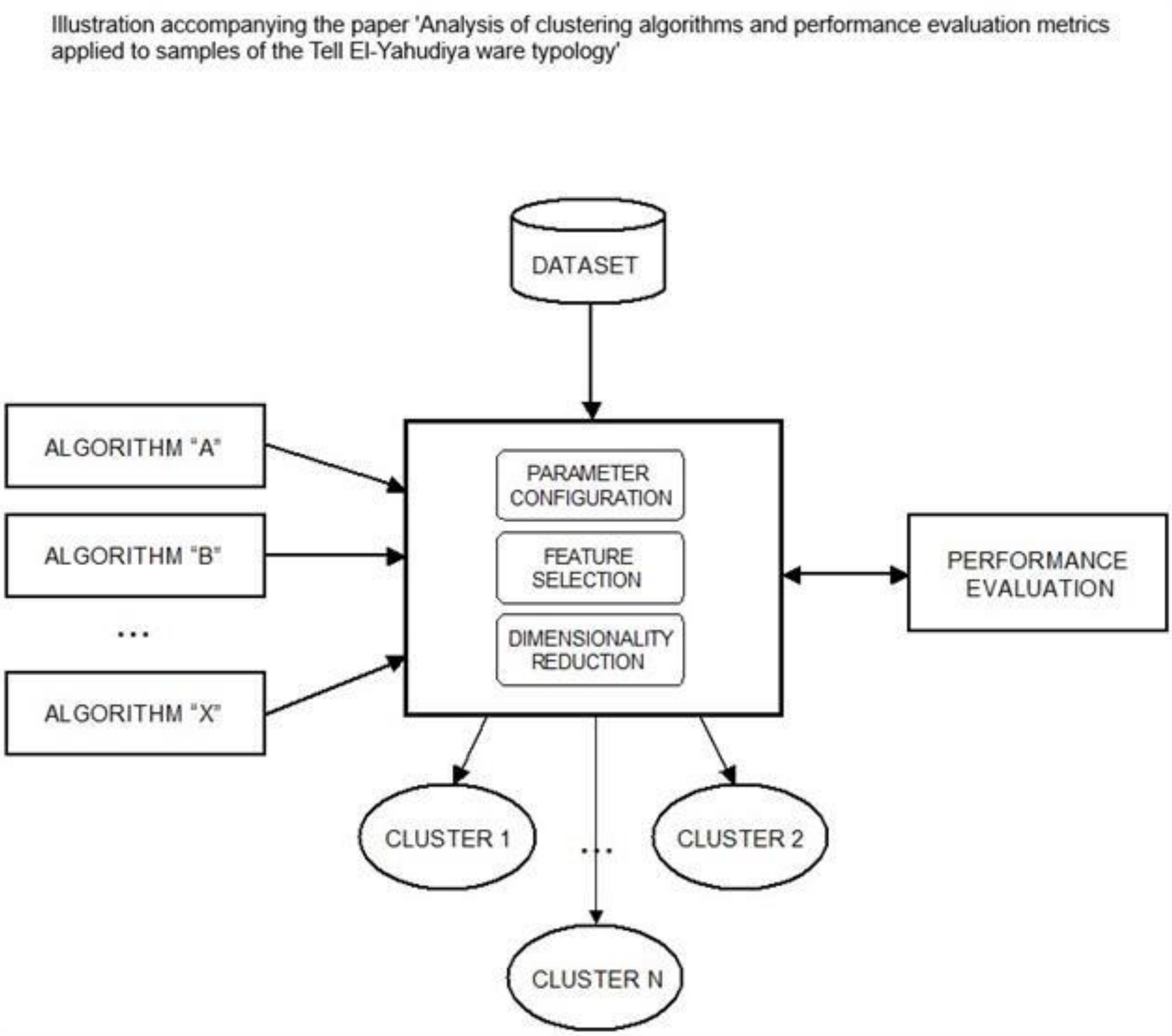
Introduction
This paper is related to a PhD research on pattern recognition methods, especially unsupervised learning, combined with analytical tools and interpretive approaches for constructing pottery typologies in archaeology.

Typology is one of the fundamental aspects of archaeology as a discipline and a basis for answering more complex research questions related to human activities in the past, such as interaction among cultural groups and the exchange of goods and ideas. This research aims to contribute to the understanding of how pottery typologies can be constructed, starting with already established typologies and then applying this knowledge to unclassified assemblages, or assemblages classified long ago and that have the potential to be reanalysed under new approaches and perspectives.

In the first stage of this research, different clustering algorithms are applied to pottery datasets with already defined chrono-cultural and shape-based typologies, to evaluate the potential that algorithms built with different concepts and several combinations of parameters have to replicate the original expert typology. Several combinations of features are taken into account. Clustering performance is being evaluated through both ground-truth based metrics and model-only based metrics.

Data and methods
The main dataset is based on the catalogue of Tell el-Yahudiya Middle Bronze Age pottery found in Tell el-Dab'a (Egypt), published by Aston and Bietak (2011). The jug or juglet is the principal category of this ware, which shows variations in certain attributes such as geometric shape, rim types and decoration. Other characteristics such as vessel measurements and features related to ceramic technology (e.g., type and quality of fabric, type of manufacture) are also included in the analysis. A complementary dataset used in this research is based on the 3rd and 2nd millennium BC pottery from Tell Brak (Northeastern Syria) made available by the Arcane (2016) project. In this dataset, nine different shape classes (bowls, jars, open pots, etc.) are represented, and vessel measurements and proportions are the main attributes used for their identification, complemented by information on rim and base types.

Six different clustering algorithms are currently being applied, provided by the scikit-learn machine learning library (Pedregosa et al. 2011): K-Means, Agglomerative Clustering, Birch, Affinity Propagation, DBSCAN and Mean-shift. Supporting methods for unsupervised dimensionality reduction, such as PCA, are also being considered. Initially, clustering performance is being evaluated using ground-truth based metrics (e.g., Homogeneity, Completeness, Adjusted Rand Index) and model-based metrics (Silhouette Coefficient, Calinski-Harabasz). Different ML models will be generated based on these input alternatives. The algorithms are executed in the Anaconda/Python software environment. Different variations of the datasets are considered, especially in relation to Tell el-Yahudiya pottery, which can be grouped in a chrono-cultural approach according to different levels of detail. The relevance of different sets of features in the identification of the predefined types is also being considered. A summary of the process is shown in Figure 1.



Expected results
The results of this research will be used to obtain an initial view of the different clusters of samples that can be generated and to what extent they broadly represent the typology under analysis. Additional steps will be necessary to identify how the samples are grouped using the types and subtypes represented in the assemblage as a reference.

Considering the number of variables included in the process (different algorithms, their main parameters, pre-processing methods, combinations of dataset features), a high amount of iterations (running the algorithms in different situations) is expected. Clustering performance metrics are the initial source of information at this stage of the research. Based on the most significant results a more detailed analysis of the clusters will be performed, taking into account the observation of vessel images and additional methods and variables not previously included in the process, for instance, the contextual information associated to the samples (stratigraphy, finds location).

The preliminary results indicate, as expected, a significant difference of performance among the algorithms, but this difference varies according to the various parameters considered for the ML model and this should be considered when evaluating the performance of the algorithms. The algorithms will be evaluated according to several criteria, including the flexibility in defining the number of resulting clusters (considering the positive and negative aspects of this alternative), the range of options and complexity of their parameters, and how they perform according to the different datasets characteristics.

Discussion

The definition of alternative typologies based on unsupervised pattern recognition methods can be related to different objectives such as exploring new methods that were not available when the typology was created, answering new questions or complementing existing data with information provided by new sources.

What it is expected from this research is a clearer view of the strongest and weakest aspects of the algorithms under analysis in relation to their potential application in the early phases of a process for constructing pottery typologies. Other aspects of the process will be included in this evaluation, among them the performance of pre-processing methods such as dimensionality reduction as well the dataset configuration, the choice of features included in the ML model.

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344. Clustering Analysis of Metallurgical Micro-remains Fiber-Optic Reflectance Spectra Using One-Dimensional Convolutional Variational Autoencoders

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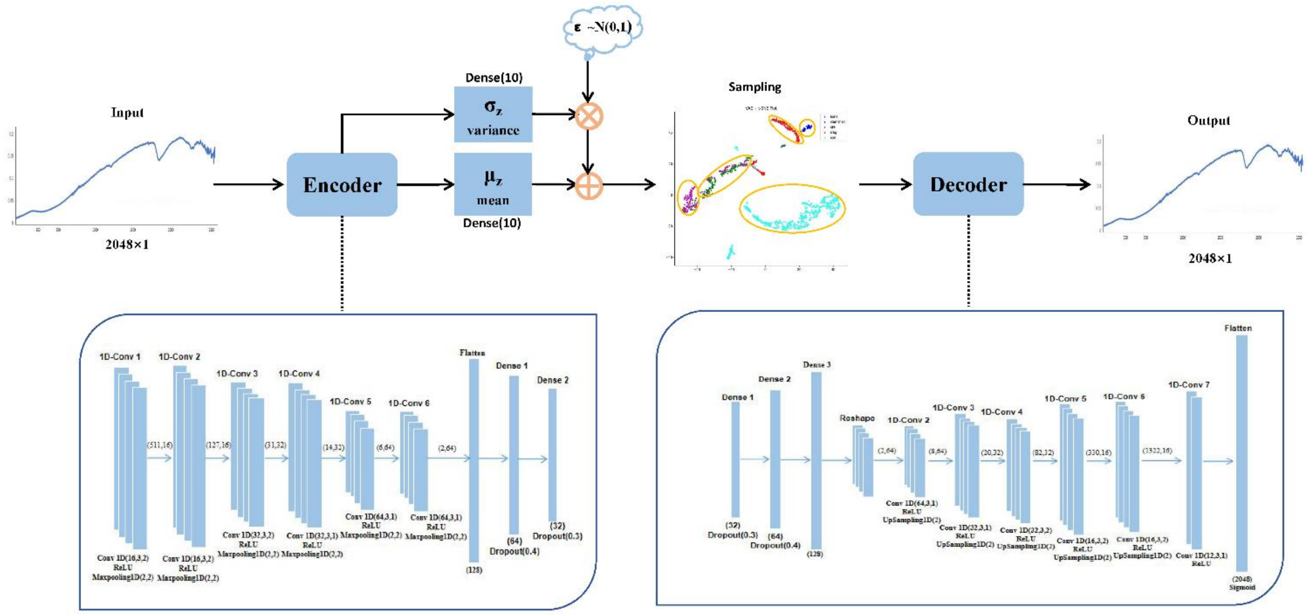
Metallurgical micro-remains refer to the minuscule remnants generated during ancient metallurgical activities, typically with diameters less than 1 centimeter, which are difficult to identify during regular archaeological excavations. Micro-remains are more widely distributed in metallurgical sites compared to macroscopic remains and are less susceptible to post-event disturbances, encompassing a considerable amount of information related to metallurgical activities. Numerous research cases have demonstrated that the study of metallurgical micro-remains can effectively supplement the crucial information often overlooked in macro-metallurgical remains, such as identifying technical processes like slag smelting and crude refining that were previously invisible. The micro-remains found at metallurgical sites usually encompass multiple types, including slag, ores, crucibles, pottery fragments, soil, charcoal, bones, lime, and other types. The main challenge in studying metallurgical micro-remains lies in how to efficiently and accurately identify and collect them among the numerous and diverse types of micro-remains. Although traditional methods such as microscopic observation, portable X-ray fluorescence (pXRF) analysis, and scanning electron microscopy energy dispersive spectroscopy (SEM-EDS) analysis can identify these relics, the operational procedures are complex and require significant economic and time costs. Therefore, there is a need for a low-cost, high-efficiency method to quickly screen and identify slag, ores, and technical ceramics related to ancient metallurgical activities from a large number of micro-remains.

Fiber-optic reflectance spectroscopy (FORS) analysis is a non-destructive detection technique known for its high sensitivity, rapid testing, and ease of data collection. Previously, in the identification of metallurgical micro-remains, supervised machine learning algorithms such as Support Vector Machine (SVM), Linear Discriminant Analysis (LDA), and Logistic Regression (LR) have been employed to quickly classify and identify spectral data from various metallurgical micro-remains. However, supervised machine learning methods require a large amount of labeled data for model training. When dealing with a large number of visually similar micro-remains whose specific categories are unknown, supervised machine learning methods are no longer applicable.Convolutional Variational Autoencoder (CVAE) can be utilized without the need for pre-labeled data (i.e., without explicit labels or answers). By employing convolutional operations, CVAE explores deep-layer features and structural relationships within the data, uncovering hidden patterns and associative rules, thereby facilitating better grouping of data.

In this study, we utilized 1885 FORS spectral data points from samples excavated at several Chinese sites, including the Zhengzhou Shang Dynasty Capital Site, Taijiasi site, Funan city, Anhui province, Yingshuisi site, Funan city,Anhui province, Juxinwu site,Anqing city,Anhui province, Guduiqiao site,Fengyang city,Anhui province, and Tongling site,Ruichang city,Jiangxi province. These samples comprised ores, slag, bones, soil, and lime. We then constructed a one-dimensional Convolutional Variational Autoencoder(Yun 2024,1606) with an encoder consisting of a 15-layer network structure,including six one-dimensional convolutional layers (each with kernels of 16, 16, 32, 32, 64 and 64), followed by max pooling layers after each convolutional layer. After being flattened, the data was connected to 2 fully connected layers (with 64 and 32 neurons, respectively), each followed by a dropout layer. Subsequently, the variance and mean were calculated, and the potential space was sampled through a reparameterization method. Finally, a decoder with the same network structure as the encoder was used to output the reconstructed spectra. Through CVAE, we reconstructed and reduced the dimensionality of the original 2048-dimensional FORS spectral data. The extracted 10-dimensional latent vectors were further clustered using t-SNE dimensionality reduction, revealing clear distinctions among various micro-remains. This confirmed the effectiveness of the CVAE method in the study of FORS spectra of micro-remains in metallurgical sites.



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416. Automating duck skeletal identification using convolutional neural networks

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Introduction

Artificial Intelligence (AI) is transforming academic research, including archaeology, by tackling complex, repetitive tasks and enabling exploration in otherwise inaccessible environments. Among AI methods, Convolutional Neural Networks (CNNs) have emerged as powerful tools for image-based analyses, contributing to site detection, artefact classification, and the interpretation of archaeological finds. While CNNs have demonstrated success in various applications, including human skeletal remains and archaeobotanical finds, their potential in zooarchaeology remains to be further explored.

This work represents the preliminary phase of a project funded by the European Research Council (ERC). This study aims to address this gap by implementing and testing CNNs for two key objectives: classifying avian skeletal elements and identifying taxa within a challenging group of duck species. By focusing on morphologically and ecologically distinct taxa, this research explores how AI can accelerate data processing, enhance paleoenvironmental interpretations, and overcome limitations posed by traditional methods reliant on manual expertise. Additionally, it highlights the potential of CNNs to assist in recognizing patterns that may be overlooked by human cognition, fostering more dynamic and accessible approaches to zooarchaeological research.

Critical preprocessing strategies, including data augmentation and background homogenization, are examined, with respect to their influence to model robustness and generalizability. Some aspects are considered for improvement, such as enabling the recognition of metric scales to facilitate morphometric analyses, enhancing the network's robustness by incorporating more specific layers and parameters tailored to the dataset's complexity and expanding the dataset to better represent underrepresented taxa. Other potential advancements include integrating multimodal data, such as texture and color patterns, to improve classification accuracy, and exploring transfer learning from larger biological datasets to overcome the limitations posed by small sample sizes.

Methods and Materials

The dataset consisted of 1833 images of five skeletal elements (carpometacarpus, coracoid, humerus, tarsometatarsus, tibiotarsus) from 25 duck species and five outlier bird species. Specimens originated from the Zoological Museum in Copenhagen (1057 elements) and the Natural History Museum in Tring (74 elements). Images were systematically labeled and organized by skeletal type and species, with preprocessing steps including removal of metric scales and background homogenization using OpenCV. Data augmentation was applied to enhance variability.

For species classification, the original 30 classes were reduced to 20 due to insufficient data for some species, ensuring adequate representation for training. Two CNNs were implemented: one for skeletal elements classification (five classes), based on a pre-trained VGG16 model with k-fold cross-validation (k=5), and another for species classification, using ResNet-101 with a customized fully connected layer. Optimized hyperparameters were determined through grid search. A Random Forest classifier was integrated with the species-classification CNN to refine performance. Both networks were trained and evaluated on appropriate computational platforms, leveraging their respective architectures for morphological and taxonomic tasks.

Results

The neural network achieved high performance in classifying avifaunal skeletal elements, with an accuracy of 61% in species identification and 98% for skeletal elements classification. Precision and recall values near 1 indicate the model's reliability in identifying correct instances and minimizing errors for bone type classification. However, species classification showed a notable drop in accuracy from 96% in the training set to 61% in the validation set, reflecting the challenges posed by a higher number of classes (20 species vs. 5 bone types) and limited training data. The better performance in skeletal element classification underscores the task's relative simplicity, driven by readily identifiable morphological differences, compared to species identification, which mirrors real-world challenges faced by zooarchaeologists. Improving taxonomic classification accuracy would require augmenting the dataset to provide more examples per species. Nonetheless, achieving 61% top-1 accuracy in species identification across 20 classes marks a promising foundation for future advancements in AI-assisted archaeozoological analyses.

Discussion

AI systems, such as the CNNs explored here, have the potential to assist in the classification of fragmented or morphologically challenging specimens, enhancing both research efficiency and accessibility to comparative data. Moreover, these tools can serve as valuable teaching aids, fostering critical thinking and exploration among students.

However, the adoption of AI in archaeology requires addressing challenges such as data accessibility, ethical considerations, and algorithmic transparency. Developing FAIR-compliant datasets and leveraging interdisciplinary collaboration will be key to overcoming these barriers. By integrating AI with expert oversight, as shown in related fields, archaeologists can ensure accuracy while maintaining the essential role of human expertise in interpreting historical narratives.

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154. Rerouting Connection: Hybrid Computer Vision Analysis Reveals Visual Similarity Between Indus and Tibetan-Yi Corridor Writing Systems

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This thesis employs a hybrid CNN-Transformer architecture, in conjunction with a detailed anthropological framework, to investigate potential historical connections between the visual morphology of the Indus Valley script and pictographic systems of the Tibetan-Yi Corridor. Through an ensemble methodology of three target scripts across 15 independently trained models, we demonstrate that Tibetan-Yi Corridor scripts exhibit approximately six-fold higher visual similarity to the Indus script (0.635) than to the Bronze Age Proto-Cuneiform (0.102) or Proto-Elamite (0.078) systems.

Additionally and contrarily to our current understanding of the networks of the Indus Valley Civilization, when measured through direct script-to-script embedding comparisons, the Indus script unexpectedly maps closer to Tibetan-Yi Corridor scripts with a mean cosine similarity of 0.930 (CI: [0.917, 0.942]) than to contemporaneous west Asian signaries mentioned above, which recorded mean cosine similarities of 0.887 (CI: [0.863, 0.911]) and 0.855 (CI: [0.818, 0.891]) despite their close geographic proximity and evident trade relations. Across various dimensionality reduction practices and clustering methodologies, the Indus script consistently clusters closest to Tibetan-Yi Corridor scripts.

Our computational results align with qualitative observations of specific pictorial parallels in numeral systems, gender markers, and key iconographic elements; this is further supported by archaeological evidence of sustained contact networks along the ancient Shu-Shendu road in tandem with the Indus Valley Civilization's decline, providing a plausible transmission pathway. While alternative explanations cannot be ruled out, the specificity and consistency of observed similarities challenge conventional narratives of isolated script development and suggest more complex ancient cultural transmission networks between South and East Asia than previously recognized.

407. All along the watchtower: studying historical masonry using AI

Quirino Saraceni (ISTI-CNR)*; Gaia Pavoni (ISTI-CNR); Massimiliano Corsini (ISTI-CNR); Filippo Sala (University of Pisa); Anna De Falco (University of Pisa); Marco Callieri (ISTI-CNR)

The study of historical masonry, both for archeological and historical investigation and structural assessment and conservation, heavily relies on the annotation of areas, elements and structures. The OPUS project (financed by Italian PRIN programme “Research Project of National Interest) aims at developing tools and workflows to support these tasks, speeding-up and increasing the accuracy and effectiveness of the annotation process.

As a primary instrument, the project uses TagLab, an AI-powered segmentation software designed to support the analysis of large orthographic images. TagLab provides an assisted annotation workflow, integrating AI and computer vision algorithms for the interactive pixel-wise region segmentation, and a fully automatic learning pipeline that assists the users in developing automatic semantic segmentation models.
TagLab, despite having been firstly designed and developed for marine biology research, namely, for monitoring coral reefs, can be adapted to other fields, as most of its functionalities are agnostics (i.e., will work on any subject).
The use of TagLab on historical walls has already been tested in Pavoni et al. 2022 with excellent results, however, to go beyond the test phase, it was still necessary to make the TagLab tools more suited for the segmentation of a different sort of subject.
All the existing tools and instruments have been tested on the cultural heritage context, tweaking their functionalities to better cope with the characteristics of these datasets. The software can now adapt its tools and toolbars according to the specific research field (marine biology or cultural heritage), to streamline the user experience. The export capabilities of Taglab have also been expanded to support vectorial formats normally used by archeologists, such as DXF or SHP (Bogdani 2009).

In the OPUS project, TagLab has been firstly applied to annotate the mural stratigraphy, i.e., the various construction / intervention phases on a historical structure. To this aim, it is necessary to segment large areas of coherent characteristics. A scribble-based annotation tool that uses the OpenCV watershed algorithm, firstly tested in Pavoni et al. 2022, has been further improved and included in the official TagLab distribution. With this tool, in conjunction with the other segmentation and region- editing tools already available in the software, experts can quickly and precisely segment the various areas of coherent material/technique, mesh and so on.

During the segmentation process, the experts can reason on the stratigraphy, associating specific classes that define the temporal and logical relationship between the construction and intervention phases. At any time, following the ongoing reasoning process, the areas can be edited, corrected, split, and merged. This interactive, circular process is also supported by the possibility to add to each of the segmented areas textual notes or custom properties. enriches the annotated map with an additional information and discussion layer, geo-referenced to the data.
This integrated workflow of segmenting, annotating and interpreting enables a more cohesive reasoning, as it happens directly on the data, keeps the mapping editable the entire time, and provides a contextual space for documenting the interpretation.

All the notes and other custom properties associated within each segmented area in TagLab maps can be exported in the different formats (ShapeFile, DXF, CSV, SVG), to transfer this data into other tools.

Beside the mural stratigraphy task, another application is the study of the structural characteristics of the masonry by working at the level of the single constitutive element (stone/brick). We added a new segmentation tool based on the powerful Segment Anything model (SAM) by Meta. This model is perfect to segment the individual components of the wall, such as the single stones/bricks. The tool can be used in a fully automatic way (segment every entity in an area) or interactively (click to segment a specific entity).
By analyzing the geometrical features of the segmented stones/bricks, it is then possible to extract statistical and metric information (e.g., dimensions, aspect ratio, outline sharpness) as well as the structure of the wall mesh (number of rows, interruptions, decrease/increase, slanting). All this information can be used to assess the structural strength of the wall, and to find irregularities. Thanks to the Taglab tools it is possible to segment a large number of elements, and carry out precise metric computation, making this process of structural evaluation more accurate and sound.

At the moment, the project is just using the “assisted annotation” workflow of TagLab, i.e., where a human uses the tools to directly annotate the input image maps. This provides a more direct approach, it is more similar to the current manual workflow used by experts, and can be easily customized to specific cases.
In other situations, where the amount of maps to be annotated grows and the similarity between their structure is higher, it will also make sense to apply a fully automatic segmentation process. This could be possible thanks to the network training functionalities of TagLab: after segmenting a sufficient number of examples, it is possible to train a semantic segmentation network to automatically perform the annotation of areas or individual elements on new maps.

Given the preliminary results we believe TagLab, with the enhancements implemented in the OPUS project, can be used to improve the annotations and interpretation process when studying historical masonry, and at the same time, it can provide quantitative geometrical information useful for the conservation of the structures.
Furthermore TagLab might be a valuable tool in other Cultural Heritage fields, in particular in tasks where the annotation of an image by segmenting areas of interest is crucial: for example, in archeology excavations (tracing findings / bones in an excavation), or conservation-restoration (mapping degradations and problematic areas).

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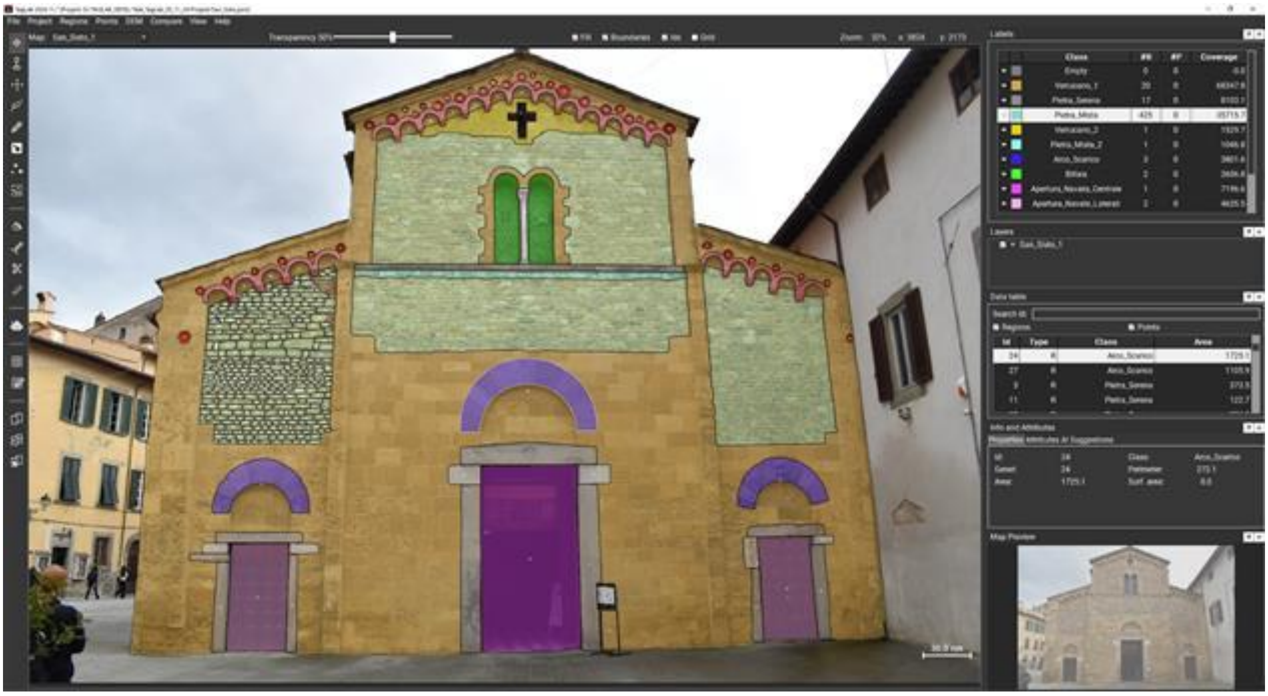

278. The ArchAIDE Picker: AI and robotics for efficient potsherds classification and sorting

Quirino Saraceni (ISTI-CNR)*; Nevio Dubbini (Miningful SRLS)

Introduction

The work introduces an innovative system that integrates robotics and artificial intelligence (AI) to streamline the classification and sorting of archaeological ceramic fragments, specifically potsherds. This research builds on advancements made by the ArchAIDE project, which utilised convolutional neural networks (CNN) for the automated recognition of ceramic sherds. By addressing the time- consuming nature of artefact classification, the work seeks to speed up post-excavation activities. The use of a robotic arm, coupled with an enhanced deep learning model, automates the process, reducing the need for manual intervention from archaeologists and enabling faster and more efficient sorting of fragmented pottery. In the last decade, the intersection between technological tools and the humanities, especially within the field of archaeology, has become increasingly pronounced, leading to significant advancements in data collection and analysis. Recent technological advances, such as unmanned aerial (UAVs) and underwater vehicles (UUVs), have facilitated the collection of vast amounts of archaeological data, particularly in areas that were previously challenging to explore. Despite these advances in data collection, the application of robotics in artefact analysis has remained limited (Wang et al. 2021), although the classification and cataloguing of archaeological finds, particularly pottery sherds, are traditionally labour-intensive processes requiring considerable human effort. Robotics, therefore, presents a promising avenue to improve and automate this task (Automata 2024).

Methods and materials

This work aims to bridge the gap in archaeological artefact handling by leveraging AI and robotics to automate key aspects of artefact sorting and classification: the system's primary function is, in fact, to classify and sort ceramic fragments scattered across a working surface; this is achieved through a combination of machine learning algorithms and robotic manipulation. The system developed for this purpose is based on the ArchAIDE deep learning network (Gualandi, Gattiglia and Anichini 2021), enhanced and updated to a PyTorch-based framework for improved performance and maintainability. A key feature of the current system is its improved top-1 classification accuracy, which allows the robotic system to function autonomously without the need for human intervention. After capturing images of the fragments, the system processes them using state-of-the-art deep learning techniques to identify individual potsherds, measure their dimensions, and classify them based on their appearance, assigning each fragment to a class and providing a confidence level for the classification. The robotic arm then executes a pick-and-place task, sorting the potsherds into pre-assigned containers according to their class. The hardware setup includes a 6-degree-of-freedom robotic arm and a D-RGB camera.The arm is capable of 360-degree rotation at its base and can handle a maximum payload of 400 grams, which is more than sufficient for most archaeological ceramic fragments. The D-RGB camera plays a crucial role in capturing both RGB images and depth data, which are necessary for fragment recognition and determining the appropriate grasp pose for the robotic arm. The depth sensor ensures that the system can accurately detect and handle fragments of varying sizes and shapes. The software framework used in the system integrates several advanced technologies. The Robot Operating System (ROS) is used in conjunction with the MoveIt! motion planning framework to control the robotic arm's movements. The simulation environment is created using

Gazebo, which provides a realistic and physics-based platform for testing the system's capabilities before deploying it in real-world scenarios. The use of ROS, MoveIt!, and Gazebo ensures that the system's operations are both reliable and highly transferable from simulated environments to physical settings. The decision-making process for sorting involves evaluating the confidence level of each classification, the standard deviation within each class, and the number of fragments belonging to each class. A confidence threshold is set to discard any fragments for which the classification is uncertain, thereby ensuring a high level of accuracy in the sorting process.

Results

In terms of performance, the system underwent extensive testing to evaluate the success rates of its grasping and sorting operations. Two different grasp pose configurations were tested: one involving a 90-degree rotation of the grasp pose relative to the world axes and another using a 45-degree rotation. The 45-degree configuration demonstrated greater reliability, with success rates ranging from 66% to 80%. In contrast, the 90-degree configuration resulted in lower success rates, with some tests yielding success rates as low as 33%. This variation in performance was attributed to the complexity of the fragments' shapes and the level of clutter in the working environment, which made grasping more challenging in some cases.

Discussion

By automating the classification and sorting of ceramic fragments, this system can significantly reduce the time archaeologists spend on repetitive tasks, freeing them to focus on more critical aspects of their research. Additionally, the system addresses the issue of unclassified artefacts, which often accumulate in storage due to the lack of time and resources for manual classification. By physically sorting these artefacts and providing classification data, the system offers a dual benefit, contributing both to the preservation and analysis of archaeological findings.

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382. Classifying the Actor of Bone Breakage: A New Deep Learning Architecture Learning Directly from the Fragment Surface

Riley O'Neill (University of Minnesota)*; Katrina Yezzi-Woodley (University of Minnesota); Jeff Calder (University of Minnesota); Peter Olver (University of Minnesota)

Zooarchaeological collections can offer valuable insights pertinent to the study of human evolution, including environmental reconstruction, human-carnivore interactions, and exploitation of animal food resources. A key milestone in human evolution was the emergence of the human predatory pattern (HPP) (Thompson et al., 2019) — the exploitation of animals larger than themselves for food, a behavior unique to humans amongst primates. The mechanisms by which the HPP emerged remain debated: whether humans began by hunting small animals, scavenging from large carcasses, or a mix of both. These methods imply different behavioral and social developments with manifold ramifications for human evolution. Scavenging poses additional questions surrounding primary or secondary access to carcasses, passive or confrontational scavenging, and most crucially: whether for in-bone nutrients or other meats. Thompson et al., 2019 hypothesizes the HPP emerged from scavenging in-bone nutrients (i.e. percussing bones with rocks).

To test this hypothesis, marrow exploitation in the fossil record must be identified — this requires bone fracture pattern analysis. While more success has been had with surface mark analysis, this is not feasible when surface preservation is poor. Furthermore, fragments produced by radiating fractures instead of direct impact are not admissible in surface mark analysis, but these are used in fracture pattern analysis. Additionally, many collections have tens of thousands of fragmentary bones: manual approaches can be daunting, demanding tremendous time and expense. These considerations incentivize new, automated digital methods for fracture pattern analysis on 3D models of fragments.

In a large experimental study, the University of Minnesota's AMAAZE Consortium (Anthropological and Mathematical Analysis of Archaeological and Zooarchaeological Evidence) has broken hundreds of faunal bones by different means: some were fed to hyenas, others were broken experimentally by humans with stone tools, and the rest were broken by falling rocks to emulate cave collapses. This has produced 7,000+ bone fragments with known break actors, most of which have been processed into 3D models using CT, micro-CT, and other scanning technologies. The challenge is then to develop methods (e.g. deep learning) to identify what broke each fragment that generalize to the analysis of fossilized fragments.

Previously, Yezzi-Woodley et al., 2024 examined the connection between a fragment's break edge geometry and the actor of breakage via deep learning. They employed user-selected fragment features on a subset of the AMAAZE dataset to classify the actor of breakage for entire bone fragments and individual break edges via deep learning. The features include summary statistics (e.g. mean, STD) from fracture angles measured using the virtual goniometer (Yezzi-Woodley, Calder, et al., 2021), break edge length, total mesh surface area and volume, and other user-identified break edge Boolean quantities (e.g. bordering the endosteal surface, intersecting other breaks, notch or not). While they achieved a mean fragment-level classification accuracy of 77%, suggesting break edge angles are promising predictors of the break actor, the user-selection of features biases the classifier and confines it to only use what the user believes important; other features may yield a higher classification accuracy. Further, break edges may also erode over millions of years, which warrant the use of even more global geomorphometric features (e.g. break-face features). Finally, the user measurement of all the break-level statistics is still variable, time consuming, and an intensive process for collections of thousands of fragments.

Rather than manually select local surface features to use for training classification models, we introduce a novel machine learning architecture — the implicit-shape convolutional neural network (ISCNN) — that operates directly on the fragment 3D models. This leverages local surface geometry to perform several layers of feature extraction, which feed directly into the classification loss to learn the most meaningful surface features for break actor identification. Unlike conventional 3D CNN's (for volumetric images), the ISCNN is not limited to a fixed input resolution or maximum object size. Compared to the acclaimed PointNet, which requires a fixed number of input points and uses no connectivity information, the ISCNN allows any number of points in the surface and leverages connectivity to extract meaningful geometric features. In contrast to both these methods, the ISCNN is designed to exploit high resolution surfaces, but also works on lower resolution scans via several scales of filters. This makes it ideal for a mixed resolution 3D model collection such as ours. The learned ISCNN features for fragment classification merit further study for other analyses and applications including identifying specific break actor methodology (e.g. stone tool type, butchering method), animal taxa, and skeletal element.

We compare our results with conventional 3D object classification models, including Point-Net and 3D image convolutional models. We also examine simple modifications to our model to remove the need for data augmentation (randomly rotating the meshes) in training, which is typically done to increase the testing accuracy. However, our model is easily modified to be rotation invariant, which removes the need for data augmentation in training, which removes a degree of freedom and accelerates training. We discuss the implementation details in Pytorch, challenges and potential solutions, and further applications of our network in and beyond archaeology. These include use in high-resolution 3D vision transformers (an active area of neural network architecture research), surface in-painting to fill in corrupted or missing parts of objects, initial match configuration for reassembling broken objects (i.e. propose one patch matches to another on another object), terrain segmentation, and beyond. Given the incompleteness of the fossil record, these are highly desirable developments. Finally, we use our ISCNN model to establish a benchmark on our soon to be released open-access bone fragment model dataset (anticipated by January of 2025), which will enable others to develop, test, and compare 3D archaeological classification models.

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179. From local mobility to dispersing population: bottom-up modelling approach to study the earliest populations of Western Europe

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Hominin populations are complex adaptative systems. They are composed of nested groups, and there are dynamic interactions between these groups. Therefore, when studying a population dispersal process on a continental scale, it is necessary to study all levels of the population and how elements at one level affect the other.
In particular, we are interested in studying the populations involved in the earliest dispersals towards Western Europe. The relevance of this subject lies in the spatiotemporal pattern observed in the archaeological record. The earliest evidence of hominins outside Africa is dated to more than 2 Ma and is located in China, and possibly the Levant. The record also tells us that hominins were present at the gateways of Europe, southern Caucasus, at around 1.8 Ma. Nevertheless, according to the current data on the first “Out of Africa”, Western Europe remained unoccupied for almost 1 Ma. The early evidence of hominin presence is documented so far in southern Mediterranean Europe, dated ca. 1.4-1.2 Ma. We propose three hypotheses to explain this spatiotemporal pattern: i) it may be the result of taphonomic bias, ii) climatic, geographical or environmental conditions in Europe may have hindered dispersal in large enough proportion to be archaeologically visible, and iii) specific cognitive capabilities may have been necessary for hominins to successfully occupy this mid-latitude area.
The study of this process poses multiple challenges. The first one is the limited amount of data available. The archaeological data of the Early and Middle Pleistocene is relatively sparse, fragmented and has low temporal resolution. For the period between 1. 4 and 0.5 Ma, there are a total of 73 sites. However, 34% of them do not provide sufficiently reliable data to be included in any analysis. Second, the idiosyncrasy of the archaeological record undermines our understanding of processes at all levels of the human system. For example, it limits our understanding of how climatic oscillation affected population distribution, or how local groups managed to secure the resources they needed to sustain themselves. The third challenge relates to the lack of knowledge and/or understanding of how dynamics interacted across scales.
To assess the plausibility of all three hypotheses while addressing these challenges, the Lateurope modelling team has chosen agent-based modelling as its main tool. Specifically, we have designed a multiple-models bottom-up approach to study the first dispersion of hominins into Western Europe. Starting with local groups, a model that studies the consequences (i.e., home-range size and survivability) of hominins foraging behaviour in the different regions of Europe (Southern, Central France, Northern Europe) during glacial and interglacial periods. The results of this model can also inform us about the possible consequences of local mobility on intergroup interactions. On a regional scale, we will study the plausibility of continuous occupation during the Early and early Middle Pleistocene on the Iberian Peninsula. First, we will observe the evolution of populations whose behaviour does not change or adapt to climatic

oscillations. Subsequently, these populations may develop behavioural plasticity and thus change their behaviour in response to climatic oscillations. Finally, the continental population dispersal will first be studied via a cellular automaton in which populations advance depending on a dynamic environment. Later, a large-scale agent-based model in which the hominin-environment feedback will be refined by the observations done in the local and regional models. Following the simulations, a series of sensitivity analyses will be carried out with the aim of identifying the relevant dynamics/variables to explain the current spatiotemporal pattern of the occupation of Western Europe.

The architecture of our approach, although aimed at building a large-scale model is composed of small-scale models independent from each other. All models address their own study cases which will increase our understanding of early hominin behaviors at different spatial and temporal scales. More importantly, the outcomes of the smaller-scale models will help us fill the gap in the archaeological record. Following our approach, they will serve to observe the range of possible behaviours and emergent phenomena they produce and to reconstruct the nested structure of the system from the bottom up. Our approach studies hominin movement at different scales, and how the levels interplay with each other. We are using a single tool, complemented by various techniques and disciplines, to better understand the movement of hominins when they first set foot in Europe.

268. Where to hunt? When to forage? Modelling human past behaviour in Bunuba Country using a Landscape based GIS approach for the West Kimberley, Western Australia

Josue Gomez (UWA)*

Introduction

Bunuba Country, located in the Kimberley region of Western Australia has been an epicentre for ecological and archaeological investigations exploring questions on the arrival of the first Australians. Archaeological sites are discrete spaces of accumulated material remains providing clues of past behaviours. However, activities taking place off-site or in-between sites like hunting, collecting and processing plants, transportation of fuel and other materials, and exchange of goods and knowledge while moving through space have been often overlooked, creating fragmented views of human behaviour at the landscape scale.

These activities crucial in hunter-gatherers' decision-making processes influence how landscape is perceived and conceptually constructed through experiencing it. Consequently, for looking into aspects of human life as located in space through time a landscape approach is used in this work challenging the traditional view in archaeology considering the 'site' as minimum unit of study. Instead, I theorise landscape as a complex network of places interconnected by social meaning; a web of loci of human-land interactions where all human behaviour is contained including 'spaces' between 'places' as whole (Zedeño and Anderson 2015)

Since hunter-gatherers carry out most subsistence activities off-site, they do not always leave material traces rendering them almost invisible to archaeological enquiry. One way to unveil those behaviours archaeologically and how they occur is by looking at balances of energy in terms of subsistence as energy is stored across the landscape in the form of edible resources (Whitley 2016) The Metabolic Theory of Ecology (MTE) offers a heuristic framework for macro-ecological approaches using mathematical equations for analysing processes at various scales from single individuals to complete ecosystems. Thus, the rate of matter and energy exchange between a human population and its surrounding environment turns out a function of the combined metabolic rates of all individuals comprising said population.

In this paper a macroecological model of hunter-gatherer subsistence behaviour (rate of resource supply) is presented as a function of the available energy present in the environment is developed for Bunuba Country under Late–Holocene climatic conditions. This model conceives landscape as minimum unit of study for human behaviour located in geographic space. Thus conceived, it is deployed in this work with the tools and methods of GIS for exploring the following three questions:

1. - How do human subsistence behaviours correlate with resource distribution across the landscape?
2. - How does resource distribution influence individual movement and group mobility in the dry and wet seasons in Bunuba Country?
3. - How do different combinations of subsistence behaviours influence individual movement and group mobility in the dry and wet seasons in Bunuba Country? Following from this question are three nested subsidiary questions:

a. Are unevenly distributed human subsistence behaviours a result of unevenly distributed resources in the landscape or a result of specific human decisions?

b. How were resources distributed at different times during the year in Bunuba Country in the Late Holocene around the time of European contact?

c. Which subsistence behaviours (hunting/fishing VS gathering) are more efficient given resource distribution and occurrence modelled for the dry and wet seasons in Bunuba Country?

Methods and materials

Archaeological and ethnographic data from Bunuba Country is compiled in a geodatabase for simulating spatial distribution of resources. Individual patterns of resource distribution were modelled from the weighted sum of eleven variables accounting for the complex interplay of physical aspects of landscape, climatic and environmental conditions, and behavioural characteristics of each species.

The model identifies subsistence behaviours (hunting/fishing, gathering) entailing significant and immediate exchanges of metabolic energy. Seven combinations in various proportions were evaluated for their efficiency in extracting caloric energy from resources. Total 344 recorded sites from various datasets were organized in two classes; residential/logistic and Other attractors. An assessment of connectivity in a terrain of energetic potential was made incorporating information about site location and function, calculating foraging radii and connectivity corridors between sites using least-cost-path tools (Verhagen 2013)

Results

Figure 1 show calories distributed unevenly across the landscape, thus uneven distribution of human occupation and subsistence behaviours should be expected in correlation. Modelled seasonal energy availability datasets show more calories are available for extracting in the dry season, while energy available is lower during the wet season.

Results from the least-cost-path analysis show two different patterns of resource acquisition. The calculated foraging radii for various combinations of subsistence behaviours during the dry and wet seasons shown in figure 1 delineate most efficient spaces, or catchment areas where enough calories can be obtained by an individual around residential/logistic sites. Given the spatial distribution of calories vary seasonally, it is expected catchment areas will vary, demonstrating that area size increase with higher proportions of hunting/fishing contributing the diet.

Discussion

Human subsistence behaviours are directly correlated with resource distribution across the landscape since these are resource specific. And every resource requires a particular set of tools, information, and knowledge for harvesting efficiently.

Resource quantities and distribution will impact decisions on how long to stay in one place, when, and where to move. Physical aspects of landscape will determine the cycles and provide the conditions for plants and animals to grow and reproduce; and these can be observed and structured into a codified system of knowledge.

Patterns of movement across the landscape are influenced by resource availability and preference. Resources obtained will vary from one day to the next, while the quantity and variety of resources will decrease the more time is spent in an area, therefore mixed strategies must be employed for maximizing the probability of meeting macronutrient and metabolic requirements with the minimum effort. In turn, some strategies will be prioritized given the resources available and where they are located.

The results show that regardless of the season, the number of calories available will increase with higher emphasis in hunting and fishing. This distribution of available energy influencing subsistence behaviours impacts directly in the patterns of mobility, logistic acquisition of resources, and a range of other behaviours which should be observable archaeologically at the Landscape scale through settlement-subsistence patterns, site location and connectivity.

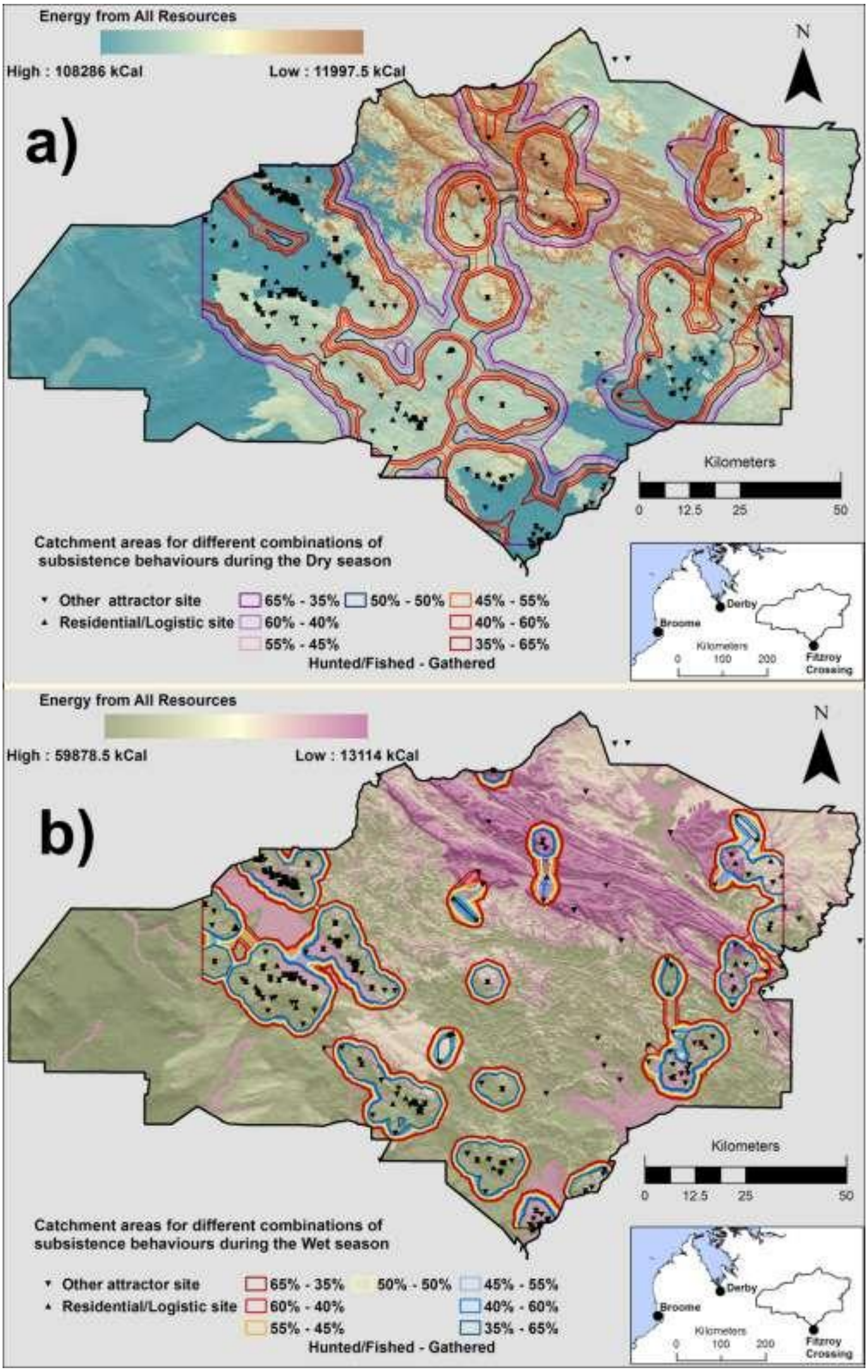

Figure 1: Energy availability surfaces and catchment areas for various combinations of subsistence behaviours in Bunuba Country for a) Dry season, and b) Wet season

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310. Cellular Automata modelling of hunter-gatherer mobility: a case study of Palaeolithic Iberia

Richard Hewitt (CSIC)*; Manuel Alcaraz-Castaño (UAH); Mike Morley (Flinders University)

1. Introduction and Methods

Understanding the mobility of hunter-gatherer populations in and around the landscapes they occupied is an enduring challenge (e.g. Perreault & Bratingham 2011). However, few studies employ dynamic approaches to model the movement of hunter-gatherer agents as they cross the landscape. In this paper we apply the DISPERSCA model (Hewitt 2022), a simple agent-based model grounded in cellular automata theory, as a tool to help to address this research gap.

In the DISPERSCA model, an agent, representing a hunter-gather group, is located randomly in geographical space. A neighbourhood is defined around the agent, and thereafter a walk is commenced to the least-cost cell of the neighbourhood, around which a new neighbourhood is defined. The process is repeated for n iterations or until some constraint is reached. Previously visited locations are excluded from each neighbourhood. When the simulation ends, the points visited by the agent, and the path taken from the beginning to end of the trajectory can be plotted on screen or exported to file.

The agent's neighbourhood can be defined in two different ways. 1) A Moore neighbourhood of 8 square cells surrounding a central candidate cell; 2) A hexagonal neighbourhood of 6 cells surrounding a central cell (Figure 1). The chosen study area was the whole of the Central Iberian Mountain range, an area of approximately 48000 km2. The model was programmed in the R environment, and in its simplest form takes just one input, a GIS raster layer representing a cost or friction surface. While the friction surface could be a suitability layer of various composite variables affecting diffusion through the landscape (vegetation, water, etc), in the present case demonstration we use just a simple slope map (in degrees) obtained from the NASA Shuttle Radar Topography Mission (SRTM) digital terrain model, resampled to 100m x 100m cell resolution.

The size of the neighbourhood, which represents the agents' decision-making catchment, is determined by the width of the cells, and can be easily adjusted. The ideal or typical size of this space is not likely to be fixed and would vary widely between individuals and different types of terrain. To account for this uncertainty, the model was executed 6 times, with nsize values corresponding to the agents' least cost decision catchment of 1km, 500m and 100m respectively, and with both square and hexagonal cell neighbourhoods.

2. Results

Many walks stayed to one side of the Central Iberian Mountain range and did not cross it, repeatedly exploring low-cost troughs corresponding to localized plateaus surrounded by higher ground, or low-lying land beyond the mountain slopes. Other walks found paths that led along the ranges for many kilometres, hugging the shallower slopes of the foothills without moving to steeper ground at all. While the 100m neighbourhood walks in the Central Iberia case study were not typically long enough to cross the range completely, the 500m and 1000m walks were able to do so. Of these 400 total walks, only 5 clearly crossed the range in its entirety (from the southern to northern Meseta or vice-versa) through there were several partial crossings and many incursions into the slopes from lower ground. Though the routes taken were often circuitous, they corresponded to well-known mountain passes, like the valley of the river Alberche, in between the Guadarrama and Gredos ranges, or the rivers Lozoya and Jarama, in the northern Guadarrama range.

At first glance, walks undertaken with hexagonal neighbourhoods (HN) seemed very different to those with square neighbourhoods (SN). Overall, in model runs with the same neighbourhood size, SN configurations tended to produce longer total distances. Logically, large neighbourhoods also led to longer total walk distances. However, in aggregate, the most-visited locations were similar (Figure 2), suggesting that the flexibility of the HN in optimizing for least cost did not completely overcome the constraints of the terrain. In particular, the river corridors of the Jarama and Henares, to the south of the mountain chain, were particularly favoured dispersion corridors, with many walks concentrated in these areas both in HN and SN modes (Figure 2).

3. Discussion

There is a notable scarcity of Late Pleistocene archaeological sites in central Iberia, especially for the Early Upper Palaeolithic (see e.g. Sala et al. 2024). One possible explanation for this apparent lacuna is that the Central Iberian mountains, probably combined with the Iberian System range, presented a significant barrier to hunter-gatherer groups moving south, especially during harsh environmental conditions. Though our study can hardly be considered to provide conclusive evidence, application of the DISPERSCA model does suggest that natural topographic corridors facilitating movement across the mountains would not necessarily have been easy to find. If the crossing points were ice-covered, and the easiest valley routes less accessible than today (prior to later river valley incisions), crossings might have been limited to a few travellers with specific local knowledge.

The DISPERSCA model permits the exploration of plausible routes across a generalized suitability surface when the starting or destination points (or both) are unknown. The size of the decision catchment for a hunter-gather group crossing a particular landscape is context dependent. However, running the model for multiple cell neighbourhood sizes and comparing the results may highlight patterns, such as repeatedly visited areas, that are common to all catchment sizes, allowing this uncertainty to be partly addressed.

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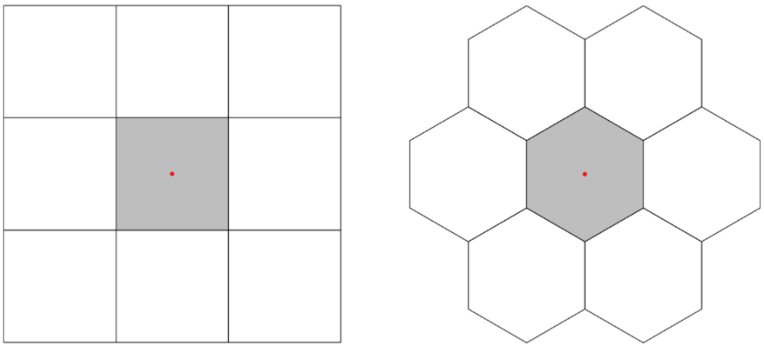

Figure 1 (left). A square “Moore” neighbourhood, with an agent (red dot) located at its centre (grey cell); (right). The same situation, represented by a hexagonal neighbourhood.

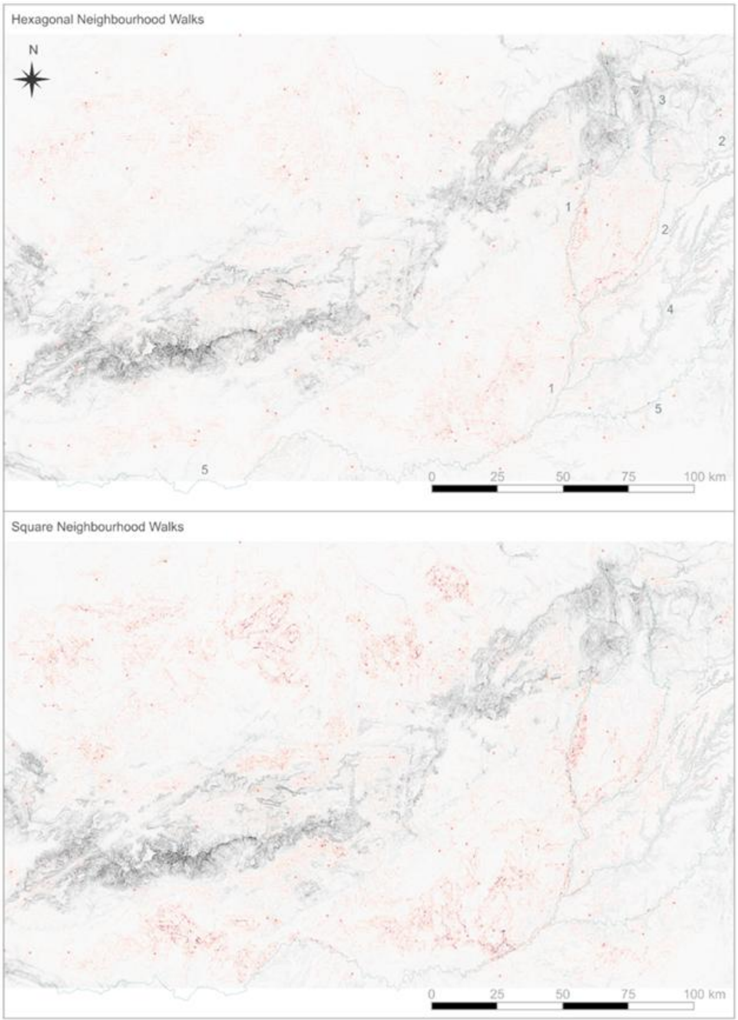

Figure 2: Aggregate results of 100 least cost walks for 1000m, 500m and 100m neighbourhood sizes (cost decision catchments) from randomly determined starting locations (red points) in the Central Iberian Mountain region. Walks coloured from pink to purple, the more walks cross each cell, the stronger the colour. The background map shows terrain slope with darker greys representing more steeply sloping terrain. Numbers indicate major rivers: 1: Jarama; 2: Henares; 3: Sorbe; 4: Tajuña; 5: Tajo.

78. Siligîtes: a QGIS extension to create and analyze straight lines and LCP networks in archaeology. Modules presentation and application on a Magdalenian culture in south-west France

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For about fifteen years, Collective Research Projects (PCR) and research groups (GDR) have significantly advanced research on the origin and processing of silicites (commonly referred to as "flint") during Prehistory. The method of inventory and characterization of these lithic resources, described from a dynamic perspective using the concept of the evolutionary chain (Fernandes and Raynal 2006), is now applied during systematic prospecting as well as in the inventory of reference collections known as lithothèques. All this data is freely available through a dedicated mapping platform: www.cartosilex.fr. The wealth of available data acquired in this context allows us today to fundamentally question the geography of Paleolithic "cultures" in Western Europe from a landscape archaeology perspective.

Among these research areas, those related to lithic transfer networks play a central role in better understanding the spatial occupation by prehistoric populations (Delvigne et al. 2021). Until recently, the preparatory data required to conduct these studies, as well as the analysis of the network's components, represented very time-consuming and repetitive stages. Moreover, the possibilities offered by Least Cost Path (LCP) analysis were underused, despite it becoming an essential tool for such studies by enabling the integration of topographical constraints into models of prehistoric population movements. This underuse is due to the complexity and low visibility of some of these tools, even though they are available in several GIS software packages (such as QGIS). To simplify the analysis process, we have developed a QGIS extension and propose appropriate modules and tools for prehistoric archaeology to: 1) assist in the acquisition and preparation of data for the creation of transfer networks; 2) facilitate the use of various LCP analyses by guiding users through the specific choices available; and 3) offer tools to simplify network analysis. For this purpose, we utilized the Python language, along with the tools provided by QGIS and PyQt, complemented by R scripts to access functions in the Movecost library (Alberti 2019). This library enables LCP-based analyses and offers a wide range of models, along with detailed explanations to help avoid errors during use.

Three modules were developed to perform the analysis steps within the QGIS extension, named Siligîtes. The first module, Silextracteur, allows users to create a vector layer representing specific parts of geological formations from a WFS. This tool reduces the data preparation time for archaeologists by a factor of six. The second module, SilLCP, focuses on preparing the previous data to create networks, particularly those based on LCP. It enables the use of the resources provided by the R library Movecost, including tools for creating LCP networks, isolines, Least Cost Corridor analyses, and more. A wide variety of LCP models based on time and energy costs are also included. The third module, Silanalyses, is designed to assist users in analyzing the networks they have created, whether by simplifying the network to include only links with a specific distance, time, or energy cost; studying the centrality of nodes (degree and betweenness); or determining the shortest path between two nodes (with or without intermediate steps).

To test these tools, we used the example of the “Magdalénien inférieur à Lamelles à Dos Dextre Marginal (LDDM),” a prehistoric “culture” dated between 21.5 and 20.5 ka calBP. This “culture” includes 13 prehistoric sites, including Lascaux, and features lithic objects that can be linked to nearly fifty geological sources. The area covered by these locations stretches in a big southwest of France from the Loire to the Pyrenees, and from the Atlantic Ocean to the eastern Massif Central. Using the tools developed with different datasets, we compared the results obtained by studying networks, whether using straight-line connections between locations or LCP-based networks. The two types of networks are quite similar in terms of the surfaces covered, with a margin of error of five to ten kilometers. Their nodes also display a similar level of connectivity, particularly in terms of betweenness. However, LCP-based networks offer new hypotheses, especially in topographic contrasted lands.

This presentation will focus on the efficiency of the GIS tools compared to manual execution of the various stages of analysis, as well as exploring the limitations, whether related to the tools themselves or more globally in the application of LCP to prehistoric archaeology.

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253. Connectivity between Harappan settlements

Salil Sayed (Deccan College PGRI)*; Prabodh Shirvalkar (Deccan College PGRI)

The vast region over which the great number of Harappan settlements are found is made difficult to access by deserts, salt marshes and perilous international borders in our time. During the mature period of Harappan civilisation their cities, towns and outposts were busy with trade in grains and valuables. The intricate networks of transportation between these sites remain to be understood.

There are several challenges in the study of the connectivity in the Harappan realm. A large portion of the region is covered by desert with shifting sand dunes allowing only seasonal access. The Rann of Kutcch, a great salt marsh today was then a shallow water body allowing transportation dependent on great tides typical of the region. The paleo-shorelines (here the word 'paleo' indicates during the Harappan period) differed significantly from today's, and are yet to be determined with some accuracy. The elevation of the terrain too has varied during the time-span of four millennia due to geological activity. The rivers that existed during Harappan times dried out and lost in the current arid environment. Methods like least cost path which depend on environmental obstacles and terrain models are challenging to implement. The data that will help in determining the paleo-climate is patchy in the same way as the exploration of the inaccessible area. The great floods of Indus and other rivers have washed away archaeological remains in their flood plains. A research project investigating the connectivity of the Harappan settlements needs a strategy to work with this nature of available of data.

The research presented here takes an exploratory approach to least cost path analysis using an iteratively developed agent based model. The use of an ABM to implement such a strategy using the partly consolidated and evolving datasets about the complexity the urban/rural mix of Harappan society is demonstrated by Angourakis et al. (2020) in their modelling of an Harappan village. Our strategy is to model the traveling agent on the connecting paths of the Harappan civilisation. Based on the inferences drawn in available literature about Harappan trade based on the archaeological remains of trading outposts, we a define a set of agents such as on-foot travelers, carts carrying grain and other materials and possible configurations of caravans. Researches involving the movement of various goods and possible modes of carriage (Petrie et al. 2024) provide deep insights into the configurations of such traveling agents. These agents then traverse the terrain model created from digital elevation models and land surveys enriched with datasets of palaeo-environment. Each simulation run reveals the limitations of the state of the model which is then improved upon and the simulation is run again. These iterative simulations also highlight the lacuna in the data and in some cases allow us to make postulations about the paleo-environment and terrain. For the first phase of implementation we chose to limit the study-area to modern day Gujrat state which exhibits most of the variations in climate zones and has 485 documented sites in our database.

While the primary aim of this research is to investigate the transport connections between Harappan settlements, the continued work is expected to provide insights for further field exploration by suggesting locations for yet unidentified sites. The diffusion of Harappan civilisation has been established through analysis of ceramics and ethnoarchaeology of current practices related to ceramics in ethnic communities. The same communities still use modes of transport in the arid zones that are relatable to Harappan period. As the Harappan civilisation expanded from its cradle to outposts and ports further away into distinct climate zones the gradual evolution of the modes of transport must have been necessary for this diffusion. We hope to shed some light on this phenomena.

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292. Computational Challenges and Improvements in Modelling Past Human Mobility

Giacomo Bilotti (Kiel University)*

Understanding past human mobility is a key aspect of archaeology, as it helps address many research questions central to the field. For example, it can be used to explore patterns and routes of movement for foraging or migration, as well as to investigate polity size, boundaries, and the organisation of farmsteads and farmland in early state societies (Byrd et al. 2016; Bevan 2010).

Least Cost Path (LCP) analysis has been employed by archaeologists for a long time, even before the advent of computational methods. A notable example is Pendlebury's work on Crete, where walking times between several important prehistoric sites were measured and compared with historical accounts (Pendlebury 1963). The introduction of computational models has made these calculations easier, but their conceptual foundations remain largely unchanged, as seen in the case of Crete, where computational estimates overlapped significantly with non-computational findings (Bevan 2010).

Recently, significant improvements have been proposed to advance LCP studies, particularly in refining methodologies and addressing methodological issues. One key area of focus has been map resolution, aimed at reducing computational times through coarser resolutions while avoiding modern artefacts such as highways that could distort the analysis (Verhagen & Jeneson 2012). Other important factors, such as the impact of temperature, elevation, aspect, and other environmental variables on travel speed, have also been discussed methodologically, although these are often not considered in case-specific applications (Herzog 2014).

Over the last decade, two major developments have pushed forward LCP analysis: circuit theory (CT) and the "from-everywhere-to-everywhere" (FETE) approach (White & Barber 2012). Both methods shift focus from individual sites—which often present challenges—to the properties of the landscape itself. Despite these advancements, several methodological issues remain unresolved.

Another issue is the consideration of costs of traversing different landscapes and the integration of different means of movement. Computationally, this involves incorporating different friction maps and movement algorithms. Water features, such as rivers, lakes, and seas, pose particular difficulties as they require specific handling and are often modelled separately, leading to disjointed narratives of movement that likely did not exist in the past (nor in the present).

In this paper, I examine the impact of various methodological settings on the outcomes of LCP analysis. Specifically, I compare the outputs of CT and FETE, investigate the effect of the number of sampled points—particularly in the FETE approach—and evaluate the influence of friction and other constraints on each run. Attention is also given to the computational effort required for each model tested and the interoperability of different tools (e.g., R, GRASS GIS). Additionally, I demonstrate how changes in prior assumptions, such as the means of transport and friction, can significantly affect research outcomes.

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254. The Integration of Connectivity Analyses to the Study of Palaeolithic Mobility in the Pyrenees

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When attempting to approach the mobility of prehistoric groups that inhabited a specific territory, we have to search for proxies than could provide us information about this movement. Within prehistoric research, chert has proven to be one of the best elements to infer this mobility, as it is the material remain most commonly found in the Palaeolithic assemblages of the archaeological sites.

Thanks to archaepetrology and geochemical analyses, the provenance of archaeological cherts identified at the sites can be determined. These types of analyses allow the correlation of chert types with specific geological formations, and even with specific outcrops. In this way, the possible procurement sites of these Palaeolithic hunter-gatherer societies can be determined.

In the ongoing research, the chosen study context is the Pyrenees during the Upper Palaeolithic. Analyses of the provenance of chert from various Pyrenean sites have suggested that in this Pyrenean environment, there would have been frequent contacts between the two sides of the mountain range, as chert that outcrops at the northern slope has been identified in archaeological sites located in the south.

This situation insinuates that despite encountering very harsh climatic conditions during certain periods of the Upper Palaeolithic, such as the LGM, there would have been specific paths to cross the Pyrenees that were accessible at certain times, allowing transit between the two sides.

However, studying the mobility of past Palaeolithic groups in mountainous areas can be quite a challenge, considering the various topographical elements that may influence or impede movement. Previous studies have approached mobility using Least Cost Path (LCP) to analyse the mobility in the Pyrenean region. In those analyses, the cost was only modelized from the slope using the function (cost (s) = 1+(s/S)2) (Llobera and Sluckin 2007 in Rubio-Campillo et al. 2022) and a raster resolution of 250 m. The objective of applying LCP was to attempt to identify the optimal routes that would have allowed contact between the two sides. As a result, the LCP was drawn through river valleys. However, some studies suggest that moving along mountain crests could be more efficient than through valleys.

The main goals of this work are (1) to explore how routes might change if we attempt to incorporate movement along mountain crests, and (2) to determine the most suitable resolution for the cost surface raster to work across the entire Pyrenees without resulting in an excessively large computational cost, given the vastness of the study region.

Nevertheless, the main limitation of LCP is that it only shows a single route between two given points. However, we must consider that prehistoric societies inhabiting this extensive territory may have utilized alternative routes that were not optimal for reasons unknown to us.

In this regard, connectivity analyses provide us with the opportunity to approach these suboptimal routes. This connectivity can be modelled using Circuitscape (Anantharaman et al. 2020). To run this algorithm, we only have to input a cost surface plus the origins and destinations, which can be either points or areas.

The result of applying Circuitscape is a raster that displays all well-connected zones between the origin and destination, which may or may not coincide with the LCP. In this way, another goal (3) is to obtain a broader view of the various passageways in the Pyrenees, rather than limiting ourselves to only the optimal paths.

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90. From Valleys to Desert: A Combined Approach to Mobility, Visibility, and Landscape Interaction to Reconstruct the Wari Road System in Northern Peru

Julia Chyla (Faculty of Archaeology, University of Warsaw)*; Miłosz Giersz (Faculty of Archaeology, University of Warsaw)

The Wari road network in northern Peru, while less known compared to the Inka Qhapaq Ñan, holds great significance in understanding the mobility and control mechanisms of pre-Columbian empires. My research aimed to address this gap by investigating the road systems around the Castillo de Huarmey, a Middle Horizon/Wari Empire site, and examining its connectivity with adjacent valleys, such as Culebras. This study combines Least Cost Path (LCP) analysis, ortho-photo interpretation, visibility analysis, and field reconnaissance to present a comprehensive look at possible Wari road networks in the Huarmey region.

A significant aspect of this research involved generating multiple LCP scenarios to propose different pathways that might have connected sites during the Middle Horizon. These models were then tested in the field, with positive outcomes in several instances. For example, the watchpoints found above the quebrada next to Castillo de Huarmey align with the model, suggesting their role in monitoring access to the valley. Additionally, near the ocean, a feature previously identified by Duccio Bonavia as an “ancient wall” was reinterpreted, through modeling and comparison with Chimu road typologies, as a probable road linking desert settlements to the fertile delta.

Visibility analysis further supported the hypothesis that the Mausoleum at Castillo de Huarmey served as a marker visible from the valley's entry point, reinforcing the concept of its role as both a border marker and a significant cultural symbol. This analysis indicated that the mausoleum was visible only when one entered the green delta from the desert, suggesting its intentional placement as a landscape feature to mark territory.

The combination of remote sensing, GIS-based modeling, and targeted field verification proved to be an efficient approach, significantly focusing the fieldwork on areas likely to yield results, rather than surveying blindly. While some regions, like agricultural fields near the quebrada, hindered direct verification, the integration of these methods provided insights into the connectivity and landscape use during the Wari Empire. The natural landscape, including valleys, quebradas, and desert areas, played a crucial role in shaping movement routes, acting both as facilitators and barriers to connectivity.

The results suggest a potential road network between the Huarmey and Culebras valleys, indicating that these regions may have been more interconnected than previously thought. Although further research is needed to confirm these broader connections and their implications, this study provides a foundational understanding of the Wari road system and its influence on regional interactions. This approach can serve as a methodological framework for future studies on ancient road systems in under-researched regions such as the northern Peruvian deserts.

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98. From paths to mobility landscapes : modelling landscape accessibility for the Iron Age Dolenjska, Slovenia.

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Well known in archaeology since at least the 1990s, the least-cost path (LCP) analysis has nevertheless seen quite unequal success across the discipline. Rather counterintuitively, it has proven to be particularly useful for the study of highly sedentary societies, such as urbanised ancient states, while the movements of hunter-gatherers, pastoralists and other types of mobile societies seem to have remained beyond the reach. Common approaches rely on connections between specific points of origin and destination, which may be problematic for a number of mobility practices that are not oriented towards a fixed destination (hunting, gathering, pastoral herding etc.). What is more, archaeological methods often cannot determine with accuracy the location of potential destination points even when there is clear evidence of regular movement, such as the exchange of raw materials and artefacts.

A number of solutions to the problem of breaking away from the point-to-point mobility paradigm has been proposed, known under abbreviations such as MADO (Fábrega-Álvarez, 2006), FETE (White & Barber, 2012) or CCP (Verhagen et al., 2013). Cellular automata and agent based modelling (ABM) also provide very useful insights for the prehistoric period in particular (Mlekuž, 2013a; Gravel-Miguel & Wren, 2018). Nevertheless, these approaches share several common issues. Most have been developed for the study of specific questions and cannot be applied to other research problems without significant methodological adjustments. The technicalities of such adjustments, involving coding and in-depth familiarity with sophisticated software, including the ABM, effectively keep at bay much of the archaeological community. Furthermore, the implementations of “homemade” LCP algorithms, or solutions relying on out-of-box GIS modules have proven to be of poor computational efficiency and, for that reason, often impractical for general use.

For these reasons, we have developed a series of computational modules for both, classical point-to-point LCP analysis and general landscape accessibility analysis. The modules rely on highly optimised Python libraries, scikit-image in particular, which is otherwise widely used for scientific and industrial purposes (Van Der Walt et al., 2014). Thousands of optimal paths can thus be calculated in a matter of minutes, if not seconds. The computational library is still under development, but the beta version is already available as a plugin for QGIS software at https://github.com/zoran-cuckovic/QGIS-movement-analysis. The plugin was developed with the ease of use as one of primary objectives, in line with the general philosophy of the QGIS project.

The Dolenjska region of the south-eastern Slovenia, which will be our case study for the analysis of general landscape accessibility, is relatively well known among the Early Iron Age specialists as a part of the Hallstatt cultural province of the Central Europe (8th – 5th c. BCE). Most likely due to the strategic position between the Northern Italy and the Danube basin, the groups of the Dolenjska region were able to gather significant wealth, part of which ended in sumptuous burials. Decorated buckets and other bronze objects are perhaps the highlight of the Dolenjska Iron Age material culture, namely the depictions of courtly and everyday life in the so-called situla art style.

Concerning the problem of mobility landscapes, the Dolenjska presents a configuration common to large swaths of the Iron Age Europe: hilltop settlements, normally equipped with fortifications, dispersed smaller settlements which remain relatively poorly known, and necropoles of tumuli, often but not always in proximity of larger habitats. None of these can be considered as determinant nodes of a potential communication network, even if accessibility must have played an important role in the evolution of the settlement pattern. We have thus modelled the overall landscape accessibility on the basis of so-called focal mobility (Llobera et al., 2011). Technically, this involved generating a regular grid of theoretical destination points, and modelling the optimal paths from each pixel to all neighbouring destination points.

The resulting model consists of thousands, if not millions of potential paths. The talk will thus focus on basic understanding of such models, on parameters used for their creation, and on the extraction of theoretical pathway networks for further analysis. Some common issues will be revisited, such as the existence of water barriers and the effect of terrain roughness. We will also consider the issue of simplification and unbundling of often unruly model outputs.

In order to understand the landscape setting of the modelled pathways network, a visibility analysis was also performed. It appears that certain sites, in particular burial grounds, tend to be visually exposed to theoretical travellers. The visual setting of prehistoric burial monuments has been studied extensively in Europe, but relatively rarely in the context of the mobility landscapes (e.g. Murietta-Flores, 2014). We will thus discuss the visibility as an experiential parameter for mobility models.

Finally, an unexpected result of our experiments with general landscape accessibility models appeared when these were compared with historical and modern-day pathways. Holloways in particular, which tend to form spontaneously on strong to moderate slopes, seem to be picked-up with relative consistency using our method. Such paths form through the compound effect of movement and soil erosion, normally without significant planning and construction effort (Mlekuž, 2013b). This may shed the light on mobility practices which may be studied through our approach, as well as its limits, namely the lower success in modelling planned and constructed roads.

In conclusion, the analysis of mobility landscapes, in contrast to point-to-point optimal path networks, is an important research problem in landscape archaeology, but unfortunately suffering from significant technical and methodological hurdles. We aim to provide both, a simple algorithmic solution and a general methodology for modelling landscape accessibility. This methodology will be discussed and critically evaluated on the case study of the Iron Age record for the Dolenjska region, Slovenia.

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294. From roads to landscape and back: Using Roman road data to understand past movement

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Reconstruction of past routes is traditionally done through least-cost path analysis (LCP) calculated over a surface that represent cost of movement through landscape. Both time- and energy-based LCP algorithms are based on the notion that slope is the main limiting factor of human movement. Besides slope, additional variables, both environmental (such as land cover, hydrology, etc.) and socio-cultural (such as taboo areas, monument visibility, etc.), are often included to refine the LCP analysis. These variables are typically added or removed iteratively during the analysis in order to provide best fit to the available archaeological evidence in a postdictive-predictive framework and so to arrive at explanation of the past movement patterns (Herzog 2022). However, this explanation is often provided only for a small region or a single road that works in the particular setting and no attempt is made to generalize the findings. In this contribution, it is attempted to utilize Roman road data to identify main topographic constraints of past mobility and to evaluate their influence on the movement patterns in the Roman provinces of Syria, Judaea, and Arabia, represented by the Roman road network.

Roman roads are one the best documented remains of pre-modern transport infrastructure reflecting past human movement. However, utilization of Roman road data to analyse patterns of human movement in the landscape on a large scale was not possible due to lack of high-resolution spatially accurate representation of that data. This much desired dataset of Roman roads has been collected in course of the projects MINERVA (PI Tom Brughmans) and Viator-e (PI Pau de Soto) and is published as Itiner-e: The Digital Atlas of Ancient Roads (Brughmans et al. 2024). The research presented here focuses on the Roman road data from the Levant (Syria, Lebanon, Jordan, Israel, Palestinian territories, and south-eastern Turkey).

The principal aim of this contribution is to provide a general mobility model for the Levant based on the notion of ‘natural corridors of movement’ and compare it against the surviving evidence of the Roman roads. In doing so, it is attempted to evaluate the weight of topographic variables on road construction and mobility in the Roman Levant.

This is done through analysis of topographic constraints of the road locations (layouts), focusing on a) maximum slope, b) topographic position index (TPI), and c) local vector ruggedness measure (VRML). These variables are in turn used to model natural corridors of movement in the study region through ‘FETE’ approach (‘from everywhere to everywhere’, White and Barber 2012) using isotropic least-cost algorithm. Several iterations using random seed of 100 generated points in the study area is used to calculate the final model. The weighted density of the ‘natural corridors of movement’ is then compared to the known layout of the Roman road network and a dataset of archaeological sites.

With this research it is hoped to gain informed results on a) utility of the historical road data and topographic variables derived from them for analysing past movement in general, and b) the weight of selected topographic variables in explaining the past movement patterns specifically in the Roman Levant.

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442. Empirical insights on the modelling of movement behaviour in mountainous regions

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In many desert and mountain areas, movement traces and infrastructure tend to accumulate over the long term. Archaeologically, this process often produces a cumulative palimpsest of roads and paths that have belong to movement systems of different epochs, functions and scales. These palimpsests constitute rich archaeological datasets, enabling the empirical study of the rationales behind specific movement systems and of their evolution over time. Such empirical data also provide an opportunity to concretely assess the outcomes of terrain-based movement simulations, such as least-cost paths (LCP) and focused cumulated movement potential (MADO). A case study in a highland region of Chile, featuring 600Km of linear features connected to 120 settlements, allows us to do it, by comparing different modelling results with empirical road data. This experiment reveals certain biases in theoretical movement modelling for mountainous terrain, particularly the tendency to prioritize ridges and valleys over mid-slope routes (those following contour lines). It also demonstrates significant differences between the results of LCP and MADO models in the same area. Beyond methodological insights, the case study also illustrates how theoretical modelling can reciprocally (and more classically) be employed to better understand the rationales behind specific road patterns.

509. Calibrating Least Cost Path Models through Evolutionary Algorithms: A Methodological Exploration Using 17th Century Pre-Industrial Estonian Regional Road Networks

KAAREL SIKK (Kaarel Sikk)*

Least Cost Path (LCP) modelling has been used in archaeological research to predict pathways used by past societies. These models typically rely on cost functions, often derived from energetic assumptions—such as minimizing energy expenditure—and social considerations like proximity to significant locations (e.g., settlements, resources). By weighting environmental variables based on these factors, LCP analysis aims to reconstruct the most efficient or likely routes ancient peoples might have traversed.

In this study, we propose a reverse approach to LCP modelling. Instead of using environmental characteristics to predict pathways, we utilize known historical road networks to identify which environmental factors were most influential in their development. Focusing on regional transportation maps from 17th-century Estonia, we examine an interconnected road network. This network not only connected major centres beyond the immediate map area but also linked local hubs such as churches and villages.

The case study is from a period marked by an agrarian, pre-industrial society with a relatively low population density, with the Estonian landscape having relatively homogeneous elevation and terrain ruggedness, contrasted by the complexity introduced by wetlands and diverse soil types.

To explore the potential meaning and effectiveness of LCP modelling, we employ evolutionary algorithms to optimize both the cost weights and function parameters used in LCP analysis. By calibrating these functions against the empirical road network, we aim to minimize the spatial discrepancies between the modelled paths and historical routes.

This reverse-engineering methodology not only has the potential to enhance the accuracy of LCP models in archaeological contexts but also provides a framework for exploring how environmental and social factors intertwine to shape transportation networks.

166. A new method of validation for least-cost analyses using historical sources

Friederike Juercke (University of Cambridge)*; Joseph Lewis (University of Cambridge); Enrico Crema (University of Cambridge); Cameron Petrie (University of Cambridge)

Introduction

Least-cost analyses are now a well-established suite of techniques for investigating the rationale behind routes created and used in the past. These models simulate the routes individuals may have taken, assuming they aimed to minimise travel costs across the landscape. Model outputs represented as a singular path of lowest cost (i.e. the least-cost path [LCP]) or gradients of low-cost across larger areas (i.e. the cost corridor) are then validated against known historical routes to assess their ability to accurately reconstruct past choices and routes. This validation process, incorporating field observations, indigenous knowledge, and/or archaeological and historical data, is crucial for assessing model accuracy and its implications for understanding past routes. Approaches for this validation step, however, remain limited. Informal approaches rely on visual comparisons, but these lack a quantifiable measure of how well the model outcomes compare to the known routes, limiting their comparability across different models. Formal approaches assess route overlap with least-cost paths within specific buffer zones or calculate deviation between the LCP and the known route. While these provide greater precision over informal approaches, the distance required for the modelled outcome to sufficiently explain the past route remains subjective.

This paper introduces a quantitative approach to better assess the accuracy of least-cost analyses in explaining historical travel routes. We introduce a goodness-of-fit test designed to assess how closely least-cost models align with known routes from the past. This approach offers a structured, objective way to determine whether these models effectively reflect the travel patterns and choices of historical travellers.

Methods and Materials

In this study, we test our approach using a case study focused on two historical routes in southeast Iran, followed by British explorers Sir M. Aurel Stein and Sir Frederic John Goldsmid during the nineteenth and early twentieth centuries. To reconstruct their journeys, we combined historical maps, published data, and diary entries, identifying and matching historical place names with current ones using tools such as Google Maps, Google Earth, and GeoNames (www.geonames.org). From their diaries, we identified key environmental factors that influenced their travel choices, which were then used to inform the choice of parameters included in the corridor model described below. Our validation approach enabled us to evaluate how accurately our chosen proxies could replicate the actual paths taken by these travellers.

The corridors were generated using the Multi-factor, Probabilistic Route Modelling algorithm (MPRM, Petrie et al., submitted; Orengo et al. in prep). This cost surface model integrates slope, snow, altitude, surface water, and potable water availability, using data derived from multi-spectral satellite imagery processed via Google Earth Engine (GEE). For validation purposes, each environmental factor was represented as an independent cost surface and combinations of cost factors were also tested, with corridor widths set to the least costly 10% for consistency in interpretability.

In our approach, corridor representations of least-cost gradients are validated against historical routes by assessing the percentage of the historical path that falls within each quantile of the least-cost corridor. Quantile standardisation across corridors enables a consistent comparison, and higher route inclusion within lower-cost quantiles suggests a better fit. The cumulative percentage sum of each historical route across quantiles is visualised in line graphs, and the area under the curve (AUC) serves as a quantitative goodness-of-fit measure. AUC values closer to 1 indicate ideal fit, quantifying the route's alignment with the modelled corridor.

Results

The analysis yielded cumulative sum graphs representing the historical routes within quantiles of the least-cost corridors for each environmental factor and combinations of factors. Variations in these graphs indicate how closely route sections align with model parameters, distinguishing factors that fit better than others.

The cumulative graphs reveal differences in fit accuracy, clearly identifying routes that fall fully or partially within modelled corridors and quantifying the distance at which each route aligns. Routes aligned with the first quantile signify closer model conformity, while other sections reveal deviations that inform on the suitability of different factors.

Discussion

This study presents a quantitative method to validate least-cost analyses against historical routes, offering a reliable measure of fit for different factor configurations. By producing a single goodness-of-fit measure, the approach facilitates the evaluation of individual cost factors and supports sensitivity testing for multi-parameter models. This method broadens the scope of least-cost analysis validation, providing a standardised framework to improve model accuracy across diverse geographical and historical contexts.

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412. OpenArchaeo : A semantic web portal applied to archeological datasets

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With the rise of Open Science practices, numerous heterogeneous datasets have been published by researchers to support these initiatives. In Europe, such datasets can now be found on platforms like Nakala in France, e-Archeo in Italy, and ADS in the United Kingdom. The aim of Open Science is to make these datasets available to other researchers for reuse in scientific endeavours, and accessible to the public as findable data reflecting recent knowledge.

While many Open Science platforms publish data in standardised ways, the published datasets can still still vary in terms of structures, formats, and scientific expressions of the data producer. These involvements still make the data heterogeneous and difficult to cross-referenced. These variations contribute to the heterogeneity of the data, making cross-referencing and integration difficult. Although mandatory metadata required by publishers provides some level of cross-referencing, it remains generic and linked to entire datasets rather than specific data.

Based on this observation, the Huma-Num Consortium MASAplus, dedicated to the French archeological community's data, developed a solution based on semantic web technology, and linked open data elements: the OpenArchaeo portal.

A model for a common structure and a common expression

To facilitate the cross-referencing of the multiple heterogeneous datasets, a common data structure had to be created. The datasets can be found as encoded documents, relational databases or tabular files, each its own structure defined by the researcher or the project that produced them. While the main subjects of these datasets might be similar, the heterogeneity of their formats, structures, and models hindered the ability to cross-reference them.

During the conceptualization of the OpenArchaeo platform, a solution was provided, through a generic CIDOC-CRM model. This model represents key entities within the archaeological domain, such as archaeological sites, discoveries/excavations, artefacts, stratigraphic units, buildings, archaeological features (e.g., walls, burials, post-holes), and archaeological documentation (e.g., record sheets, photographs, drawings).

Although the content of a dataset may be more specific than the entities in the CIDOC-CRM model, it can still be described using one of these entities. In this way, the CIDOC-CRM model can aggregate objects that are deeply differentiated in their original source materials.

The specific details of each object, or its expressed type in the source dataset, are retained through controlled vocabularies like PACTOLS and the Getty AAT. This approach not only cleans and enriches the data but also ensures that the datasets are interoperable within the semantic web, through a common structure provided by the CIDOC-CRM generic model, and through a common expression provided by the use of the controlled vocabularies and other standard. The object types are not the only entities aligned or referenced with controlled vocabularies. Indeed, entities such as places, periods, persons or organisations use resources from gazetteers like

GeoNames, PeriodO, IdRef, VIAF or ORCID, ensuring that each dataset contains disambiguated information and common scientific expressions in these fields.

With these two methods of modelling data, each dataset can be cross-referenced conceptually through the fundamental questions: Who, What, How, When, Where and Why. To apply them, a whole workflow has been produced which transforms these heterogeneous dataset into a homogeneous knowledge graph.

This workflow allowed us to express in the same structure and with the same expression, field recording such as ArSol, excavations inventory like Archaeology in Greece Online and french aggregators like ArkeoGIS.

And a web platform to enable interoperability

Querying a triplestore can be a complex process, as it involves using the SPARQL language, which many researchers are not familiar with. Additionally, some ontologies, like CIDOC-CRM, can enhance the data model to such an extent that it becomes difficult for researchers to navigate, due to complex class and property names or the intricacies of the model itself. Simple information, often accessible through a single property or attribute, may require two or three properties in the CIDOC-CRM model. To address this challenge, many existing solutions provide user-friendly interfaces that use simpler models, querying only a few key concepts of the graph to solve this difficulty. While these solutions are more accessible, they offer a superficial view of the data and provide limited interoperability.

OpenArchaeo provided a solution, now called Sparnatural, inspired by ResearchSpace, which was developed as a semantic visual querying system for end-users. Sparnatural allows users to interact with the triplestore without needing specific knowledge of the ontology, the underlying model, or the SPARQL language. In fact, the concepts used in the CIDOC-CRM generic model, such as classes like Human-Made Feature, Human-Made Object, or Encounter Event, can be difficult to relate to common domain expressions. By using Sparnatural, each CIDOC-CRM class and their relationships can be interpreted using familiar domain terminology. For example, an object associated with the Human-Made Object class in CIDOC-CRM generic model, is interpreted as an artefact in the OpenArchaeo portal. Sparnatural translates the user-selected Artefact into the corresponding Human-Made Object class and sends the SPARQL query directly to the triplestore. The same approach is applied to relations, allowing users to select connections like “an artefact found in an excavation,” which is then translated using the appropriate classes and properties from the CIDOC-CRM model. Through this method, shortcuts can even be realised, dodging the complexity of the model for user-end accessibility.

Sparnatural is a highly powerful open-source application that enables data on the Semantic Web to be used not only by machines, but also by researchers. It enhances the value of research data by making it easily findable and accessible, in line with the first FAIR principles. Also, by using semantic technologies, standard domain ontologies, and linked open data standards, the data presented in OpenArchaeo is accessible through a single endpoint, interoperable through the CIDOC-CRM ontology and controlled vocabularies, and reusable via the triplestore's endpoint.

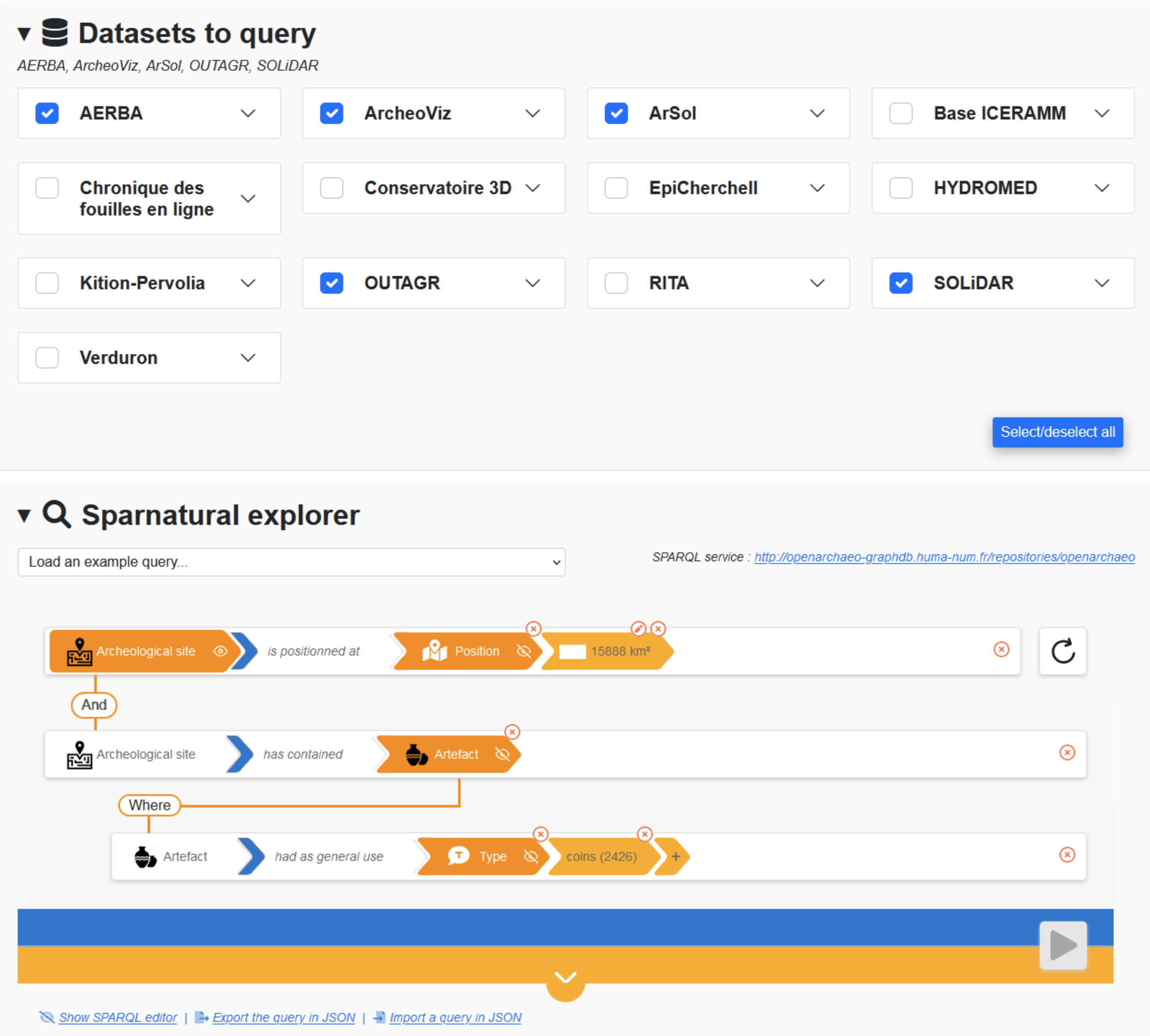

Fig. 1 - The OpenArchaeo explorer, where datasets can be selected to be queried through Sparnatural.

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476. Modelling diverse African archaeological heritage information: perspectives from the MAEASaM project

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One of the main challenges of constructing digital repositories for data coming from disparate geographical locations with great archaeological diversity and heritage management systems is the presence of diverse and at times conflicting conceptual structures for data organisation. The modelling of heritage information - which often can be characterised as partial, structure, unstructured, or semi-unstructured, and at times incomparable - into a single standardised framework is a difficult task (Huggett, 2012) and requires several interventions in order to make the data findable, replicable and reusable. This paper considers the hands-on practicalities of standardising and integrating such information from the perspective of Mapping Africa's Endangered Archaeological Sites and Monuments (MAEASaM) project and the processes of remediation and mediation required to make these data more in line with FAIR principles whilst also maintaining CARE principles.

Since September 2020, the MAEASaM project has worked in collaboration with national museums and heritage authorities across eight countries in Africa to establish a secure and accessible digital geospatial repository of sites and monument records using the Arches Project Open Source Data Management Platform as a tool for the management of archaeological data by heritage authorities and other stakeholders whilst facilitating transnational research. Data derives from several different sources including archaeological site registers (mostly in Excel format), paper-based museum excavation sheets and site index-cards, digital and analog topographic maps, aerial photographs and digital satellite imagery, and is stored using different file formats. Each project collaborator brings different types of data workflows and archaeological site documentation requirements as well as terminologies for describing archaeological entities. These are integrated within a single, semantic framework, using Arches. Arches supports the management, discovery and visualisation of heritage data, using semantic graph data structures known as 'resource models' and employs CIDOC-CRM (CIDOC CRM, 2024) ontology for the modelling and linking of heritage data. The schema has been built to be comprehensive enough to accommodate for variations and integration for diverse data, whilst remaining flexible to cater for these variations mainly through vocabularies.

The integration of multiple and diverse information into a standardised format is often resource intensive and requires hands-on, practical, work from the outset. In this paper, we present the project's ongoing work in the development of a comprehensive Arches Site Resource Model using CIDOC-CRM ontology. Using case studies from southern and eastern Africa, we illustrate the type of interventions that we used for structuring and standardising heritage information. We also present on the development of a non-exhaustive collection of vocabularies to facilitate the diversity and comparability of concepts relating to heritage management across regions in Africa.

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43. A collaborative approach to data integration: development of a web-application for an effortless, but reliable relational databases management

Nicolas Antunes (DAI)*; Maria Rocio Koloffon Arias (DAI); Rosalind Gillis (DAI)

Due to the wide diversity of research questions, contexts, methodologies and expertise among researchers in computational data, every archaeological projects differ considerably in their data collection and management. Therefore datasets are frequently heterogeneous and their merging in order to reuse them in subsequent researches might become extremely challenging. The biggest obstacles for aggregating existing datasets are either they present structural differences or they don't adhere to standardized data management practices. The above is particularly relevant for data derived from multidisciplinary research or gathered from a large number of sources. Consequently, poor integration implies that a vast volume of potentially useful data remains unused or uncombined, making studies less scalable.

In this paper, we present a user-friendly application developed with R-Shiny, to help users seamlessly insert spreadsheets from different sources into a relational database (PostgreSQL). This web-application is designed to facilitate the ingestion and the management of data from a large number of files, while guaranteeing integrity and conformity with the norms and standards generally used by the archaeological community. An intuitive tool that helps to solve the inherent problem of data variation, enabling researchers to process datasets efficiently and store them in a durable and consistent way.

The data injection process is simplified by an interface featuring drop-down menus, buttons and text fields, enabling users to map columns from different spreadsheet formats to a standard SQL database schema. The application can run online or on a local network, and is designed to be easy to use, even for non-technical users. In this manner, data insertion is guided and supervised, imposing constraints on the required formats and filtering out duplicates.

One of the key benefits of this tool is that it records every modification made to the raw data sets. This change-tracking function is notably important when several users are working more or less simultaneously on the same data set. Tracking produces a complete history, guaranteeing traceability and control of data handling. In this way roll back where necessary is possible, and duplicate processing avoided, ensuring that each study is based on clean, up-to-date versions of their working database.

The efficient and collaborative process of integrating data at large scale saves time and effort by bringing together disparate datasets with minimal risk of error during operation. In addition, the application is suitable for use in cooperation between a group of researchers working on a single database, to ensure uniform processing of the various datasets.

This tool aims to solve typical issues in archaeology, but its concept is highly flexible and can be adapted to other areas of humanities, natural or social science, and even beyond. The Shiny-based application is a robust, scalable and user-friendly remedy to the complex problem of merging heterogeneous archaeological datasets. The tool permits simple data manipulation, workload distribution among several users, and ensures consistency and traceability of raw data. Such an application would be a valuable asset, particularly in the context of collaborative studies where researchers with different backgrounds contribute to a common data repository. The use of this application could in the near term lead to quick access to high-quality datasets and data storage which would benefit the entire archaeological community, as well as other disciplines.

414. Harmonizing People, Styles, and Places: A Database Application for Integrating Heterogeneous Epigraphic Data

Maciej Krawczyk (University of Warsaw, Faculty of History)*

Introduction

The transformation of Roman epigraphic traditions from the third to the fifth century C.E. represents a pivotal yet underexplored phenomenon in the study of collective memory and commemorative practices. Within the framework of the STONE-MASTERS project (ERC StG 101040152), a key focus is the role of stonecutter and mosaicist workshops as intermediaries in this cultural evolution. This paper introduces a database application designed to integrate, harmonize, and analyze heterogeneous data related to these workshops across the Mediterranean. The challenges posed by managing diverse data sources, which differ in scale, scope, and standards, reflect broader issues faced in archaeological research. The developed tool tackles these challenges by enhancing data interoperability and facilitating advanced analyses to reveal patterns in the spread of epigraphic practices.

Methods and materials

The database was designed to integrate diverse data sources while ensuring data integrity and comparability. It incorporates inscriptions from across the Mediterranean dating from the 3rd to 5th centuries C.E., and literary sources, capturing metadata such as workshop signatures, stylistic features, textual formulae, and material provenance. A standardized schema was developed to harmonize diverse data models into a unified framework, preserving compatibility without losing information. Advanced digital tools are employed to facilitate the annotation, visualization, and analysis of data, enabling spatial mapping, stylistic comparisons, and textual analysis. The system also adheres to FAIR principles—Findable, Accessible, Interoperable, and Reusable—ensuring integration with existing databases and scalability for future use.

Results

The database application has proven highly effective in consolidating and harmonizing epigraphic data from diverse sources, offering new insights into Roman commemorative practices. This comprehensive aggregation would uncover significant patterns and trends that illuminate the activities of ancient workshops and the evolution of stylistic elements in inscriptions over time. By analyzing recurring textual formulae and stylistic patterns, researchers have reconstructed portions of model textbooks likely used by stonecutters to create standardized inscriptions. These reconstructed guidelines provide insights into workshop practices and their role in standardizing and disseminating epigraphic culture.

Through these in-depth analyses, the database would advance our understanding of the cultural transformations of the Late Antique period. It serves as a robust foundation for interdisciplinary research into the influence of artisans on collective memory and the evolution of public commemoration. By focusing on workshops and artisans, it uncovers the mechanisms of cultural dissemination and adaptation during a period of profound change. Furthermore, it demonstrates the potential of digital tools in managing heterogeneous archaeological and historical data, offering a model for similar projects.

Discussion

The project contributes to broader discussions on the role of artisans in shaping collective memory and the evolution of commemorative practices. Its methodology aligns with current

efforts to establish minimal information standards and promote interoperability in archaeological research.
The STONE-MASTERS database significantly advances the understanding of Late Antique epigraphy by bridging historiographical gaps, showcasing methodological innovations, and informing contemporary commemorative practices. By addressing the decline of classical epigraphic traditions and the rise of Late Antique practices, the database elucidates historical patterns of cultural memory and material reuse. Its methodological framework highlights the transformative potential of digital tools in epigraphy and archaeology, emphasizing the importance of data modeling for synthesizing diverse datasets. By fostering interoperability and adhering to FAIR principles, the database sets a benchmark for future digital humanities projects, demonstrating the value of collaborative, data-driven approaches to historical inquiry.

256. Refactoring and modulating archaeological data: a case study from Alagoas, Brazil

Grégoire van Havre (UFPI)*; Rute Barbosa (IPHAN); Kleython Monteiro (IGDEMA/UFAL); Lais Gois (IGDEMA/UFAL)

Disaggregating data is a common practice in some research areas, such as gender studies and critical race theory, when entities are collected and saved through classes so large they are unable to make light on specific matters. We argue here that archaeological data as a whole can be subject to the same problem. Addressing this allows us to consider the importance of data structure and design in archaeological research. In computer science, the terms modularity and refactoring both refer to solutions or measures available to fix antipattern. Antipatterns are design solutions initially thought to be convenient that, with time, turn out to create more problems than they solves. One of these antipatterns, common in archaeological databases, is known as a god class, or god object – an expression broadly linked to typological thinking. First defined by Arthur Riel in 1996, this antipattern is characterized by the concentration of all or most of the data in a single class or object. It often evolves from older databases migrated without change to new platforms. In Archaeology, database design seldom deals with that kind of problem, as most databases remain relatively small sized and managed by their own authors, for their own research. Yet, we entered the age of big datasets and many institutions now hold very large global databases that can and should be interconnected. The many debates about what is exactly an archaeological site bring us an interesting starting point. In this communication we will address that question. We will also bring details as how modularity and refactoring can be relevant, not only to database management, but also to research as a whole. We propose to drop the concept of archaeological sites as entities and to consider them as assemblages containers. They are n-dimensions hypervolumes, ranging from "simple" lithic or rock art occurrences to complex polities and their regional ties. This allows us to give more relevance, as well as a key role in databases, to features and assemblages. We can thus refactor whole databases around objects (as well as non-objects). In order to illustrate this proposal, we bring examples from the state of Alagoas in North-East Brazil. We refactored the class "archaeological site" from two Brazilian public archaeological databases (CNSA and SICG) into a series of new multiple entities. This first allowed us to identify problems within these databases structures. Multiple scales then allowed us to propose a more detailed mapping and to avoid information bias when specific contexts have been more studied than others, as is the case of rock art in Brazil. Second, by modulating landscape into smaller units, we also analyzed these dimensions through more appropriate filters. Finally, disaggregating archaeological data through refactoring and modulating is also an appropriate measure for finer-grained modeling.

331. Inspecting, categorising, digitising... analysing data from the multi-layered structured painted Volp caves (Tuc d'Audoubert, Trois-Frères, Enlène). The long process of successfully integrating data from different sources

Andreas Pastoors (FAU Erlangen-Nürnberg)*; Thorsten Uthmeier (FAU Erlangen-Nürnberg); Eric Bégouën (Association Louis Bégouën); Robert Bégouën (Association Louis Bégouën)

Introduction

The Volp caves in south-western France (Tuc d'Audoubert, Trois-Frères, Enlène), discovered more than 110 years ago and one of the most important multi-layered structured painted caves in the world, containing unique cultural evidence dating back some 17,000 years BP (Bégouën et al. 2009; Bégouën et al. 2014; Bégouën et al. 2019), are the subject of a new research project based in Germany (Erlangen) and France (Montesquieu-Avantès). The aim of this project is to restore the dynamics of static archaeological finds through spatial analyses in multi-layered, structured painted caves dating from the end of the last ice age. Painted caves such as the Volp caves are ideal for this purpose, not only because original footprints have been preserved in the untouched cave floor, connecting some of the activity zones, but also because the central question of the social context of their use and their significance for the reconstruction of Late Glacial rituals and beliefs has remained completely unanswered. Among the painted caves with internal archaeological context information, the Volp caves are unique in terms of variety and quantity.

A new research project, which started in 2024 and will continue for a period of 12 years, has two principal objectives: (1) in the Volp caves, the identification of activity zones, their spatial location and the reconstruction of the connections between the individual activity zones (on-site) and (2) within the Magdalenian of the Pyrenees, the integration of the Volp caves as multi-layered structured painted caves into the regional subsistence system (off-site).

It is expected that the comprehensive analyses of the three multi-layered structured caves of Tuc d'Audoubert, Trois-Frères and Enlène will provide high resolution data that will allow insights into their use concepts. The approach of integrating the Volp caves into the regional subsistence system will be combined with the methodological-theoretical study of the high diversity of painted caves as a whole, which is expected to stimulate the debate on the significance of painted caves.

Material and methods

The Volp caves have not only been known for over 110 years. Moreover, the caves have been the focus of extensive research, as evidenced by the considerable number of publications, approaching 250. The consistent implementation of clear rules in dealing with archaeological remains has facilitated the integration of all analogue and digital data into a single repository, that is, the Volp caves archive. The data set is notably heterogeneous. The archaeological finds are diverse, encompassing a wide range of materials and forms. These include imprints in clay, clay sculptures, rock paintings, artefacts fixed in fissures in the cave walls, fireplaces, pits and stone settings. Additionally, there are concentrations of finds with rich archaeozoological and lithic material. Furthermore, the archive contains analogue cave plans and lists of survey results, drawings of rock paintings and mobile art objects, artefact drawings, photographs and a plethora of additional materials.

A number of years ago, an attempt was made to initiate the process of organising the heterogeneous analogue data that had been digitised, sorted and made accessible through the

creation of structures created through content indexing and thematic classification. The primary digital data was entered into these structures and will form the basis for the research project described above.
In this process, all mobile data carriers are subjected to inspection, as are all analogue data. All excavation reports and documents are digitised, and all available analysis results from external and internal researchers are collected and stored in a hierarchical folder structure. Furthermore, all vector-based graphic plans are transferred to the Volp-GIS project that is being developed in QGIS. A digital inventory book is used in which every single finding and find of individual significance is listed. The process is not yet concluded, and we are still seeking to identify practical solutions. In addition to existing data, the current methods of documentation such as Structure from Motion or 3D scanning have already been applied and will be important in the coming years, as well as state-of-the-art analyses of sediments, finds and features.

Results
It is not yet possible to present definitive results in the form of finished products. Nevertheless, we can show examples of heterogeneous analogue and digital data obtained from the Volp caves and provide insights into the ongoing process of structuring and indexing them as a case study which demonstrates the successful integration of data gathered from different sources.

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Bégouën, Robert, Jean Clottes, Valérie Feruglio, and Andreas Pastoors. 2014. La caverne des Trois-Frères: Anthologie d'un exceptionnel sanctuaire préhistorique. Somogy.

415. Combining archaeological, environmental and other kind of digital spatial data on chosen case studies from Pomerania, Northern Poland

Kamil Niedziółka (Instutite of Archaeology, University of Gdańsk)*

Context: The implementation of the widespread use of GIS tools into archaeological research was undoubtedly a huge step forward in the study of the human past (Conolly and Lake 2006). The digital data format has opened up completely new possibilities for archaeologists. The ability to seamlessly analyse large amounts of spatial information has greatly facilitated the diverse analysis of available archaeological resources. Many issues that had been known for decades could now be looked at from a new and much broader perspectives (e.g. these related with the utilisation of spatial analyses). What is more, archaeologists, seeing the potential offered by these tools, also began to pay attention to the integrative potential of geographical databases. It is now difficult to imagine research involving the analysis of available geographical space through geophysical prospecting, the use of lidar or aerial photography, without the use of GIS tools.

Main argument: Still, a number of other studies that are very useful from an archaeological point of view, such as the results of pollen analysis, are still difficult to integrate meaningfully and, importantly, synergistically with archaeological data using GIS tools. Different perceptions of space by archaeologists and palynologists (e.g., how an archaeological site relates to a palynological site, or what is the spatial “extent” of a given pollen profile and many other “details”) is certainly a significant obstacle to coherent interpretations of an interdisciplinary nature. This also involves a different approach to the use of GIS tools, as well as sheer awareness of what such differences look like and how this translates into interpretations of the research material created with their help within these disciplines. It seems that there is still too little interdisciplinary cooperation between archaeologists and natural scientists from the point of view of utilisation of geospatial tools. However, it appears that things are going in the good direction (e.g. Kozáková et al. 2015).

Many problems arise from the simultaneous analysis of spatial data of a typically archaeological character, but collected in a different way. How, for example – can data sets resulting from standard surface surveys, where the chronology of surface finds is usually determined with a very wide margin of error – be compared with archival data relating to excavated archaeological sites? The chronology for such sites is (in most of the cases) precise, but their location, due to inaccurate maps in old publications, can in many examples currently be determined only to the exact boundaries of the locality within which such a site was discovered. In such cases, selected spatial analyses implemented in a GIS environment can be very helpful

Next, the extensive possibilities that GIS tools now provide us with allow us to look at the available resources of strictly archaeological information from a new, somewhat critical perspective. For example, it seems that still many archaeologists consider maps of dispersion of archaeological sites as a strict representation of the past settlement structures, not taking under consideration of various aspects of post depositional processes, related quite frequently with numerous contemporary factors, e.g. current forest cover (Banaszek 2019). And this can be proven with the proper combination of archaeological information available for the area of interest, as well as quite contemporary digital data on land cover (which determines the availability of land for surface surveys), or economic land use, which is showing, e.g. the course of major investments and related archaeological rescue excavations.

Applications or implications: Having in mined above facts, this presentation will focus on chosen examples of the integration or/and comparison of heterogeneous data from the field of settlement archaeology, (palaeo)environmental studies as well as the utilisation of digital datasets related with contemporary land cover, land use and spatial planning. All of the digital spatial data, that will be presented during this paper were collected within various parts of Pomerania, a region located in Northern Poland. The state of archaeological research is quite varied in this area, making it an interesting testing ground for mentioned researches.

The main objective of this presentation will be to highlight the synergetic potential resulting in the creation of a new data resources through the juxtaposition of information of a different nature. No less important will also be the analysis of methodological and perceptual (i.e., representatives of different scientific disciplines perceive their research in their own peculiar way) risks that are associated with the integration of these diverse datasets.

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330. The Minimal Meta Data Set for Archaeological Fieldwork within the N40 Objects Ontology

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Within the NFDI, the NFDI4Objects consortium is particularly focused on issues relating to research data infrastructure in the research area of the material remains of human history. Archaeological findings that survived in the ground form an important basis for context-related cultural scientific research and classification and add to the known material cultures of the past. Within its mission, the provision of services for sustainable RDM is a core task of NFDI4Objects.

The majority of the primary information described above is obtained in the course of archaeological activities and from there fed into the research data life cycle. Archaeological documentation activities cover a range of different methods and procedures (prospections, sondages, excavations, surveys, etc.), each of which generates different data sets according to their individual conditions and circumstances (research question, location, man-power, etc.). In Germany, the majority of archaeological activities fall under the responsibility of the federally organised heritage and monument preservation authorities, which are active both at existing monuments and at new sites. The processed documentation data generated by the various types of documentation are then archived and a selected overview is usually published in various publication formats, predominantly in the form of short preliminary reports[1]. As a rule, there are neither enough resources for in-depth re-search into the documented findings nor research is a core task of heritage and monument preservation authorities. However, this can take place within the framework of cooperations with research institutions, especially for in the form of theses or third party funded research projects.

To open effectively the path to cooperation, the provision of existing datasets in alignment with the FAIR principles is essential for the successful conception and subsequent realisation of further research projects. In this specific case, making datasets findable means making qualified, machine-readable metadata publicly available, which not only allows the technical categorisation of the dataset in question, but also enables an assessment of its content without making the dataset available in principle.

Such minimal datasets and corresponding exchange formats have already been developed for example for museum collection objects[2], and set the basis of various working groups in NFDI4Objects. However, the applicability of the existing schemas to the broad field of archaeological field research is not readily possible and requires a targeted expansion of the semantic schemas. Meeting this need is the motivation behind the efforts of Task Areas 1: Documentation and 5: Archiving of NFDI4Objects to develop a Minimal Meta Data Set for Archaeological Fieldwork. This is in line with the joint efforts to create the NFDI4Objects Ontology as part of the NFDI Core Ontology. The activities are therefore structured in the following work steps: 1. evaluation of existing metadata schemas 2. iden-tification of core attributes 3. creation of an ontological framework. The ontological framework is based on CIDOC CRM and the relevant extensions. The identified core attributes will be mapped to CIDOC CRM and, if the use of controlled vocabularies is recommended in the application, additional mappings are offered.

The presentation will emphasise the following points in particular:

- Discussion of the current status with regard to applied or mandatory technical and con-tent-related metadata labelling in German archaeology
- Presentation and discussion of the current state of work on the Minimal Meta Da-ta Set for Archaeological Fieldwork
- Insight into the technical integration process and provision via NFDI4Objects services

This presentation enriches Session 17: Comparing the Incomparable: Managing and Analysing Data from Heterogeneous Sources in Archaeological Research with an example of the development of a minimum information standard and the accompanying ontological framework. The broad discussion of our work results in the context of the session serves in particular the goal of the global applicability of the Minimal Meta Data Set for Archaeological Fieldwork and represents an essential step towards ensuring the sustainable findability of archaeological data sets in accordance with the FAIR principles.

References:

[1] e.g. https://journals.ub.uni-heidelberg.de/index.php/fbbw/index

[2] https://cidoc.mini.icom.museum/working-groups/lido/lido-overview/lido-schema/, https://wiki.deutsche-digitale-bibliothek.de/pages/viewpage.action?pageId=120422678

87. The Sudan Heritage Register and the Heritage @ Risk Database: Digital Tools for Protecting Endangered Heritage in Conflict Zones in Sudan

Pawel Wolf (none)*; Sami Elamin (NCAM); Mohamed Ahmed Abbas (NCAM); Niama Sabel (NCAM); Rehab Ismail (NCAM); Cornelia Kleinitz (DAI)

Due to the ongoing illegal gold mining activities in northern Sudan for many years, and especially since the outbreak of the military conflict in April 2023, there are significant threats to Sudan's tangible and intangible cultural heritage, which is subject to destruction and looting by the military, paramilitary groups, and criminal gangs. As digital tools to address these threats and provide better protection for cultural heritage, the Sudan Heritage Register and the Heritage @ Risk Database were developed. This paper outlines the steps that led to the creation of these digital resources and emphasizes their role in managing endangered heritage in real-time conflict scenarios and beyond.

Building on Friedrich W. Hinkel's extensive life's work, the “Archaeological Map of Sudan,” the Sudan Digital Project (2017-2020), developed in close collaboration between the Sudanese National Corporation for Antiquities and Museums (NCAM) and the German Archaeological Institute (DAI) in Berlin, marked an important step in transferring Sudan's heritage data into a systematic digital format. These efforts were crucial for the development of the Sudan Heritage Register (2021-2022), as there was no national digital register of Sudan's archaeological sites that could serve as a foundation for specialized applications in emergency situations. The outbreak of the military conflict in April 2023 heightened the need for a specialized Heritage @ Risk Database, specifically designed to manage and monitor cultural sites under threat.

The Heritage @ Risk Database, developed with the open-access iDAI.field platform, offers a modern digital solution for both the emergency management of heritage sites in active conflict zones and the development of a nationwide digital hetritage register of Norhern Sudan. By adapting iDAI.field for this purpose, heritage data could be integrated into a flexible framework that supports the recording of archaeological sites, their risk assessment, and the reactive management of endangered cultural assets. The database combines site inventories, risk monitoring, and satellite imagery, creating a tool that enables the protection of cultural heritage during armed conflicts and afterwards. Furthermore, the export of data to GIS and other digital inventories enhances usability, allowing the current status of endangered sites to be effectively visualized, analyzed, and communicated.

This paper demonstrates how the digital methods employed — including GIS integration, modular database configuration, and tailored digital inventories — support heritage professionals in assessing risks, prioritizing interventions, and managing endangered cultural assets. It highlights the collaborative nature of this initiative, involving Sudanese cultural heritage institutions, archaeologists, and international partners, as a model for creating adaptable emergency databases that respond to the needs of endangered heritage. The paper aims to foster discussion on the application of digital methods for protecting heritage under bombs and share the lessons learned for safeguarding cultural resources in similar contexts worldwide.

75. Open-Access Satellite Imagery for Monitoring Archaeological Sites in Sudan

Mariusz Drzewiecki (Polish Centre of Mediterranean Archaeology University of Warsaw)*

Sudan's archaeological heritage encompasses settlements, cemeteries, and various sites of differing scales and wide chronology, starting from prehistory and finishing in modern times, preserved along the Nile and across the surrounding deserts. The material remains are increasingly imperilled by both natural and anthropogenic threats. The recent conflict has exacerbated these risks, rendering invaluable cultural heritage more vulnerable to looting, structural damage, and land encroachment. Field-based heritage monitoring in conflict zones is confronted with substantial challenges, including restricted access and safety concerns. This study examines the potential and limitations of employing low-cost open-access satellite imagery monitoring using open-source software.
By utilising freely available satellite platforms such as Sentinel-2, alongside high-resolution sources like Google Earth, this paper presents case studies tracking the status and immediate changes to heritage sites across Sudan. Through multi-temporal analysis using QGIS open-source software, changes can be identified promptly, enabling researchers and local authorities to address emerging threats effectively. However, notable challenges persist, the limitations posed by the spatial and temporal resolution of imagery which allow the identification of significant changes in land use but not small-scale disturbances such as illegal excavations.
Overall, the findings underscore the potential of open-access satellite imagery as a critical, accessible, and cost-effective tool for heritage monitoring in conflict-affected regions, providing an invaluable resource for safeguarding Sudan's archaeological heritage amidst ongoing threats. However, capacity-building initiatives involving archaeologists, remote sensing specialists, and heritage management organisations are essential.

Further reading:
Example of satellite imagery monitoring of selected heritage locations in Sudan using high spatial resolution data:
Gunter-Bassett, Madeleine; Bassett, Hayden; Welsh, William; Hanson, Katharyn; Fitzgerald, Kaitlyn; Maher, Abigail; et al. (2024). CULTURAL HERITAGE MONITORING LAB REPORT: CONFLICT-RELATED DAMAGE TO SITES IN SUDAN (11 December 2023). The Smithsonian Institution. Report. https://doi.org/10.25573/data.24638739.v1

Reports of the Cultural Heritage situation in Sudan prepared by the Sudan Heritage Protection Initiative:
https://www.heritageforpeace.org/sudan-reports/ accessed on Jan 15th, 2025

Mapping heritage at risk during the current conflict in Sudan by MAEASaM Project
https://maeasam.org/mapping_heritage_risk_during_conflict_sudan/ accessed on Jan 15th, 2025

Example of capacity building event:
https://pcma.uw.edu.pl/en/2024/09/22/workshop-cairo-monitoring-sites-in-sudan/ accessed on Jan 15th, 2025

508. Eyes in the Sky, Feet on the Ground: Evaluating Remote Sensing in Wartime Archaeology

Tohamy Altohamy (University of Cambridge)*; Stefania Merlo (Mapping Africa's Endangered Archaeological Sites and Monuments, Department of Archaeology, University of Cambridge); Dana AlSalamin (University of Cambridge)

Remote sensing has emerged as a powerful tool for archaeological documentation, especially in conflict zones, where traditional methods are limited by security risks and restricted access. Through satellite imagery and GIS analysis, heritage sites can be mapped, tracked, and assessed for damage or encroachment, providing essential data that supports heritage protection efforts (Casana and Laugier, 2017).

However, while this technology offers unprecedented capabilities in identifying and monitoring endangered sites, it also presents significant challenges that can limit its effectiveness. Remote sensing alone cannot replace on-the-ground verification, known as ground-truthing, which is often impossible under hostile conditions. Image resolution limitations, signal interference, and funding constraints further hinder comprehensive documentation. Additionally, the very use of remote sensing imagery for heritage monitoring raises questions ranging from data ownership to the responsibilities of foreign entities handling sensitive information to mention but a few (Davis and Sanger, 2021).

Using the case study of the monitoring efforts of heritage in Sudan since the inception of the current conflict in 2023, we use the lens of 'critical remote sensing' defined as 'inquiries and scientific practices cognizant of the embedding of power within the production, analysis, and instrumentalization of satellite imagery' (Bennet et al. 2022) to examine the success and failure of such efforts. This includes an examination of our team's work carried out within the collaboration between the Mapping Africa's Endangered Archaeological Sites and Monuments (MAEASaM) project and Sudan's National Corporation for Antiquities and Museums (NCAM).

This paper argues that while remote sensing is invaluable, its application, in particular during times of conflict, demands a careful balance between technical possibility and practical feasibility, with a focus on developing sustainable, locally driven documentation practices.

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149. From Air to Site: Evaluating Archaeological Changes in the Region of Tartus (Syria)

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Over the past decade, numerous projects have emerged that explore archaeological landscapes in Southwest Asia. Most of these initiatives rely on satellite imagery for mapping. While satellite remote sensing is highly effective for identifying archaeological sites, ground verification of these findings is equally important.

Changes and damages serve as visible milestones for archaeologists, historians, geographers, and geomorphologists in reconstructing the past and safeguarding the present. They stand as silent testimonies to historical actions and actors, providing crucial insights for mapping modifications over time.

This paper highlights the work conducted by MAPDAM (Mapping Damage. Research on the archaeological heritage) project in the region of Tartus and at the site of Amrit. The project identified several archaeological sites through remote sensing and subsequently verified these findings with on-site evaluations. Additionally, a survey using drone-acquired lidar at the site of Amrit uncovered important archaeological and geological features that are nearly impossible to detect using traditional aerial or satellite remote sensing methods, especially in densely vegetated areas. Utilizing an interdisciplinary approach and an open-access web GIS platform, MAPDAM provides the first comprehensive, large-scale dataset that explores damages and patterns of change to archaeological sites in the region.

265. Caucasus Heritage Watch: Satellite-Based Monitoring of Cultural Heritage in the Crosshairs of Ethno-Territorial Conflict

Lori Khatchadourian (Cornell University); Ian Lindsay (Purdue University)*; Adam Smith (Cornell University); Husik Ghulyan (Cornell University)

This paper discusses satellite-based monitoring of cultural heritage sites in the Nagorno-Karabakh region of the South Caucasus, which for decades has been the center of a long-simmering territorial and ethnic conflict between Armenia and Azerbaijan. Following the ceasefire that concluded the brief but devastating Second Nagorno-Karabakh War in fall of 2020, the co-authors formed a research collaboration called Caucasus Heritage Watch (CHW) to address the lack of evidence-based documentation of past and present abuses of cultural heritage in this intractable conflict. CHW emerged from our own long-term collaboration and the indispensable partnerships we have forged with scholars and heritage institutions in Armenia. As a non-partisan research group, we focus on documenting abuses of the region's cultural heritage using high resolution satellite imagery to inform public policy and encourage accountability. Our primary mission is to monitor heritage at risk of deliberate damage or destruction following the transfer of territories to Azerbaijani jurisdiction following the 2020 ceasefire agreement and the 2023 capitulation of the de facto Nagorno-Karabakh Republic (NKR). The territories ceded to Azerbaijan are home to hundreds of Armenian cultural properties, from medieval monasteries to modest early modern village churches, to cemeteries containing centuries-old tombstones and iconic engraved Armenian cross-stones (khachkars).

The impetus behind our ongoing monitoring work is the treatment of cultural heritage in the region during the decades between the end of the First Nagorno-Karabakh war in 1994 until the eruption of the second in 2020. Those decades produced countless rumors of both Armenian and Azerbaijani cultural heritage sites destroyed or damaged but, until recently, few empirical attempts to understand the extent of impacts or the role of state authorities in assaults on cultural sites. In 2022, CHW released the first of two year-long investigations on the treatment of cultural heritage in the years following the 1994 First Nagorno-Karabakh war. The first of these reports, entitled "Silent Erasure", is a 434-page detailed examination of 159 monasteries, Armenian churches, chapels, and cemeteries in Azerbaijan's Nakhchivan Autonomous Republic, an exclave situated between Armenia, Iran, and Turkey that is geographically separate from Nagorno-Karabakh but inseparable from the region's cultural politics. Using a combination of published and archival sources, Soviet-era topographic maps, and declassified satellite imagery we found that between 1997 and 2010, 108 of 110 sites (98%) were destroyed in a state sponsored program of cultural erasure. With the eradication of historic monasteries, churches, and cemeteries, the entire Armenian heritage landscape of Nakhchivan was eradicated. This was arguably the most extreme case of cultural erasure in recent history and it was conducted entirely in secret. Over one hundred publicly available ArcGIS StoryMaps supplementing the report provide an interactive account of each site and its destruction that went largely unobserved at the time. This program of silent erasure has yet to be condemned by either the US or the UN.

In our second special report, we conducted a parallel study that would provide the same kind of analysis of Azerbaijani heritage in the towns and villages that an estimated 550,000 Azerbaijanis were forced to abandon when they came under the control of Armenian forces and the de facto NKR after the 1994 First Karabakh War. Our investigation, "Between the Wars", released in April 2023, showed that the treatment of Azerbaijani mosques, mausolea, and historic cemeteries varied widely while under Armenian control between 1994 and 2020, reflecting the complexities of the disputed region's shifting political, geopolitical, and economic realities. Of the 109 cultural heritage sites we were able to assess, 38% remained structurally unchanged since the late Soviet period, 44% sustained some structural damage, and 15% were destroyed. As we show, Armenian authorities of NKR failed to prevent both widespread looting, but our forensic evidence shows no attempt to systematically erase the material traces of Azerbaijani history and cultural life, as had clearly happened to Armenian heritage in Nakhchivan. Major damage consisted mainly of large-scale looting and opportunistic asset stripping, which took place predominantly in the decade immediately after the 1994 ceasefire in the context of weak legal, political, and economic institutions.

This paper will also discuss the aims, technical affordances, and methodological limitations of CHW's ongoing efforts to document the shifting conditions of nearly 500 heritage sites in the territories ceded to Azerbaijan in 2020 and in the final ethnic cleansing of Armenians in NKR in September 2023. Given the cultural erasure in Nakhchivan, it was abundantly clear to observers that Armenian heritage sites within the transferred territories were at risk, threatened by the same policy of zero-tolerance for Armenian historic remains. In addition, since the end of the 2020 war, Baku has been signaling its plans for massive infrastructure and redevelopment projects in Karabakh, including the construction of new highways, hydroelectric plants, airports, and housing developments. The goal of our monitoring work is to not only record attacks but alert stakeholders, media, and governmental and non-governmental heritage preservation organizations through our monitoring reports, social media alerts, and online dashboard. Since the spring of 2021, we have worked with Planet Labs to conduct a program of cyclical satellite monitoring, tasking satellites to provide us with imagery several times a year to maintain regular surveillance of at-risk medieval and early modern sites. We aim to shine a light on threats to heritage in something like real time to deter future attacks by imposing a reputational cost and create evidence that can hold perpetrators accountable.

Overall, CHW has established that since 2021 Azerbaijan has destroyed 15 heritage sites, including historic churches and cemeteries, and damaged 12 more. CHW currently assesses 32 cultural properties as facing immediate threat of damage or destruction due to earth moving activity in close proximity. We conclude our paper with four observations based on our monitoring work to date:

1. Much of the damage and destruction of Armenian cultural heritage in Nagorno-Karabakh to date has been in connection with road work and redevelopment in villages and towns. It is not clear whether Azerbaijan is following its own cultural property laws concerning the regulation of construction work around cultural heritage sites, but these laws contain loopholes for the destruction of sites that the state deems insignificant and lacking in "heritage value".

2. Damage and destruction seem to be focused primarily on historic cemeteries, but we have also documented the demolition of two 19th century Armenian churches. Some of the historic cemeteries in Nagorno-Karabakh contain khachkars, an Armenian art form consisting of an engraved cross stone that is listed on the UNESCO registry of intangible heritage. These are at grave risk of destruction but present challenges to monitoring even in high-resolution satellite imagery.

3. Armenian churches and monasteries are undergoing cultural appropriation. Since the late Soviet era, Azerbaijan has promoted a fictional story of ethnogenesis that suggests a poorly known medieval kingdom called Caucasian Albania was actually the origin of modern Azerbaijan. This claim is without historical merit according to international scholarly consensus, but it is

invoked by the Azerbaijani government to legitimize the erasure of historic Armenian art and architectural inscriptions.

4. The global response to Azerbaijan's program of heritage erasure has been insufficient. The US and others were quick to condemn the Taliban, ISIS, and now Russia for their assaults on cultural heritage. Yet for its erasure of Armenian cultural heritage, which stands alongside assaults on Jewish heritage in WWII, Bosniak heritage in the Yugoslav Wars, and Uyghur heritage in Western China as among the worst heritage atrocities in history, Azerbaijan has not faced international condemnation consequences or censure. A case currently before the International Court of Justice is one important exception to this collective silence, but the US Government and international agencies can do more.

49. Beyond Detection: Generating Risk Factors for Attempted Looting via Automated Algorithmic Detection

Michelle Fabiani (University of New Haven)*; Shivanjali Khare (University of New Haven); Thomas Powell (University of New Haven); Jafar Vohra (University of New Haven); Kalyna Yurchuk (University of New Haven)

Introduction: Both manual (e.g., Cunliffe, 2014) and automated (e.g., Altaweel et al., 2024; Masini & Lasaponara 2021) methods of detecting and documenting archaeological looting are well established in archaeology. Manual efforts have helped to identify (among other types of site damage and destruction) some characteristics of looting, including proposed typologies (e.g., Cunliffe 2014), damage assessment toolkits, and time series of site destruction (Kopji et al., 2023). Automated efforts have created a substantial knowledge base on different approaches from supervised classification to texture-based extraction and analysis, to unsupervised classification and segmentation (e.g., Masini & Lasaponara, 2021) to deep learning (see Altaweel et al., 2024 for overview on each type specifically).

While the current literature has largely focused on establishing the most accurate and effective algorithmic approaches, less attention has been paid to what comes next (see Abate et al. 2024 for exception). What should the data resulting from the algorithms be used for beyond detection and identification?

The current study presents preliminary results on an ongoing interdisciplinary project attempting to address this question. Specifically, it argues that it is possible to scale up the current approaches to automated detection to look at multiple sites concurrently over a long period of time. In doing so, it is aims to create spatiotemporal data on attempted looting activity where the probable looting pits are linked over time. In this way, the resulting data will be immediately relevant for questions on changes to probable looting pits over time and most importantly what are the risk factors (social, environmental, economic, political) that predict attempted looting activity.

Methods and Materials: This project builds off the algorithmic approach developed by Masini and Lasaponara (2021: pp. 135), combining geostatistical analysis to extract spatial patterns related to looting pits with unsupervised classification (ISODATA algorithm) and segmentation (LISA Geary's C) with neural networks to link probable pits over time. The data used to train and fit the model come from Very High Resolution (VHR) Imagery from Maxar technology on 632 archaeological sites in Lower Egypt from 2015 to 2023 (over 3,000 site-scenes).

Results: The preliminary results discuss the unique challenges facing the project as well as the approaches to addressing them. Algorithmically, challenges include scaling automated change detection, including the diversity of landscape, site spatial extent, and spatial resolution. Analytically, the choice to use historical imagery adds a layer of complexity in terms of validation, as ground truthing is not a viable option. We discuss the validation strategy and next steps for the data construction and subsequent analysis.

Discussion: To move towards a proactive approach to cultural heritage protection, it is imperative to know which sites are most likely to be looted and in response to what kinds of factors. Conflict is the most discussed, but threats to these sites can come from many sources. At the same time, algorithmic automated change detection for attempted looting activity have come far enough that it is possible to start scaling them to produce analytically useful data. Ultimately the project discussed here aims to generate both a reproducible method and data that can help to generate a concrete set of social, political, economic, and environmental risk factors for attempted looting at archaeological sites in Lower Egypt.

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461. Digitizing Archaeological Heritage in Odesa (Ukraine)

Mariia Lobanova (Odesa Archaeological Museum of the NAS of Ukraine)*

Since the beginning of the full-scale war, the Ukrainian museum institutions have faced several challenges. These include moving collections to a safe place, evacuating, and quickly documenting collections. In addition, some employees joined the army, while others left for safe countries or safer regions of Ukraine. There was a need to develop an active action plan to implement in these circumstances.

It is also the fate of the Odesa Archaeological Museum of the National Academy of Sciences of Ukraine. This is one of the oldest museum institutions in Ukraine. It was founded in 1825 and is celebrating the 200th anniversary of its opening. In total, the museum's collection includes about 160 thousand items. It consists of archaeological sites from different historical periods in the South of Ukraine. One of the most outstanding parts is the collection from the ancient Greek sites from the Northern Black Sea region. The museum also has the largest collection of Egyptian antiquities in Ukraine and sculptures from Cyprus. In addition, the museum annually receives materials and samples from archaeological excavations in the South of Ukraine. The organization also has a scientific archive and a library.

In July 2023, after the massive shelling of the Odesa city centre, the museum building was damaged (“Damaged Cultural Sites in Ukraine Verified by UNESCO”). Windows were smashed, and the ceiling fell in one of the rooms. Cracks also appeared on the walls and ceilings.

The beginning of the war and the damage significantly increased the digitalization of the museum's collections. Before that, electronic lists of materials were created, some artifacts were photographed, and museum employees partially digitized the archive.

The digitalization process benefited from assistance from organizations such as UNESCO, ALIPH, and the Museum for Change. Help was also received from various European countries such as Poland, the Czech Republic, Switzerland, and Germany. Equipment for the digitalization of collections was accepted. UNESCO also helped with the process of photographing the artifacts. A professional photographer was hired, and a project was implemented. Thanks to that, more than 25 thousand items were photographed.

The archival materials were also digitized. At the beginning of the war, the most important items were documented. Now, there is a systematic scanning of artifact passports. For this purpose, students from Odesa universities are involved as volunteers. In 2024, 32,000 passports were scanned by employees and volunteers. All of the above information helped with the all-Ukrainian register of the museum fund (database).

An important part of the archival collections was many glass photographic negatives. CER and the Museum for Change organized the scanning project. In total, more than 5,300 images were made during the campaign. These are materials from archaeological excavations, ethnographic materials, and photographs from the everyday life of the museum and Odesa in general.

Since the beginning of the war, the museum has been closed to visitors. In August 2024, a temporary exhibition was opened in one of the rooms. As part of the exhibition, the Scientific and Research lab Archaïc prepared 3D models of the artifacts. They were available at the exhibition and online.

The engagement of volunteers and students is helpful for digitizing collections in the absence of many employees. A special course, “Digitalization of Cultural Heritage,” was developed for better cooperation at the Odesa I. Mechnikov National University. There, students actively study modern digitalization methods, learn how to work with the equipment, and listen to guest lectures with specialists. As part of the course, they also collect a database of sites in the Odesa region based on publications and archival materials.

Thus, the war greatly affected the work of the Odesa Archaeological Museum. Exhibition activities have almost stopped, but at the same time, active digitalization of materials is ongoing. The museum participates in many projects and engages students from Odesa universities. It is promising to continue photographic recording and digitalization of the archive and publish these materials.

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25. Quality and Relevance in Digital Contingency Planning for Endangered Historic Environments: Lessons from St. Sophia Cathedral in Kyiv.

Gunnar Almevik (University of Gothenburg)*; Jonathan Westin (University of Gothenburg)

The geopolitical reality in Europe today necessitates the integration of contingency planning into societal development, where the protection of cultural heritage must play an important role. The cultural heritage can be deliberately violated to erase history and weaken a people's connection with the past, paving way for appropriation and misinformation. Its safeguarding can bring hope and resilience in social crisis and war. Russia's aggressive warfare towards Ukraine show clearly the need to begin such work during peacetime. From the full-scale invasion in February 2022 until October 2024, UNESCO has listed 457 historic monuments and sites in Ukraine that have been totally or partially destroyed, and where in many cases scarce documentation remains.

Digital documentation of cultural heritage is a crucial initial step in preserving information for the future and an important component of the knowledge base for contingency planning. 3D digitisation of built heritage can also be valuable for regular heritage management processes. In many nations and international institutions, there is consensus, underpinned by strong policy, that cultural heritage must be digitised, yet there is a lack of cohesion and guidance on how to proceed (European Commission 2022).

This paper set off from the research and contingency planning project to document Saint Sophia Cathedral in Kyiv that is now threatened by missiles and drone attacks in the ongoing war. The main research question is how to optimise the selection of technical instruments and processes in relation to both the properties and values of cultural heritage and the informational needs and conditions of heritage management, in order to achieve high-quality and relevant digital outputs?

The Saint Sophia cathedral was built in the 11th century and is part of a larger heritage environment with residential buildings, workshops, a chapel and belltower surrounded by walls. The cathedral is a complex material and spatial construction, and the interior walls are covered with in all 260 square meters of original mosaics and 3000 square meters of murals. Inscribed in the walls are approximately 7,000 shallow inscriptions on different languages and language systems, evidencing the long history of trade, exchange and diversity of European crossroads.

The project has tried out different technologies, specs and work procedures, attending to the different scales and properties of the heritage assets. The main technologies involve laser scanning, structured light scanning, photogrammetry, and reflectance transformation imaging. The challenge to optimise the technical instruments and processes also involve balancing quality with resources, such as time, budget, skills and site restrictions whereof many related to the extreme situation of war.

In 3D documentation, quality is often defined by the performance of 3D technologies, using quantitative measures such as point resolution, resolution rate, and scan range, among others. Numerous metrics exist for assessing both objective and perceptual quality in 3D outputs (Bakken Storeide et al. 2024). Our conclusion is that there is no exclusive prerogative of quality in 3D documentation. The optimal 3D technology, resolution, and post-processing techniques must be determined based on the properties, scales and cultural values attributed to the heritage asset and the knowledge, skills and requirements or restrictions of stakeholders involved in its safeguarding and sustainable use. Historic environments are inherently complex, and a rich documentation necessitates the use of various complementary technologies and types of outputs (Westin & Almevik 2024). The critical question of inadequacy must also be addressed, as 3D technologies cannot capture the full range of properties inherent in cultural heritage.

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124. Tears of Tigrai Archaeological Site: The Case of Mai Adrasha

Gidey Gebreegziabher Gebrekrstos (Warsaw University)*

Mai Adrasha, located in the Tigrai region of Ethiopia, offers vital insights into the socio-cultural dynamics of ancient civilizations in the Horn of Africa. Researchers are investigating the significance of Mai Adrasha within the larger historical framework of Tigrai, especially during the era leading up to the emergence of the Aksumite civilization. Systematic excavations and artifact analyses, including pottery and architectural remnants, have been undertaken to reconstruct the daily lives, trade networks, and cultural practices of the region's former inhabitants. The results indicate a complex society marked by skilled craftsmanship and extensive international trade, underscoring the area's role as a central hub in the ancient world. This research also addresses the current challenges facing the site, particularly considering a recent war in Tigrai involving the Ethiopian government and neighboring nations such as Eritrea and Somalia. Issues like traditional gold mining and environmental degradation further hinder the preservation of this archaeological site. The investigation has assessed the damage caused by the war and its effects on the archaeological repository through archival research, surveys, and digital documentation, highlighting the urgent need for preservation efforts to safeguard this invaluable heritage. Ultimately, this research not only enhances our understanding of Mai Adrasha and the destruction it has suffered but also emphasizes the resilience of Tigrai's archaeological narratives amid ongoing challenges. A major concern is the deterioration of the Tigrai archaeological sites, worsened by inadequate management strategies, insufficient attention from local authorities and professional leaders, and the disengagement of local communities. This study lays the groundwork for further discussions and conclusions regarding the preservation and management of these essential archaeological resources.

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A. The Archaeological findings Store before the War (Picture Gidey Gebreegziabher, 2019)

B. The Archaeological findings Store after the War (Picture: Gidey Gebreegziabher, April 2022)

C.The archaeological Site of Mai Adrasha before the War (Picture: Gidey Gebreegziabher, December 2016)

D. The archaeological Site of Mai Adrasha after the War (Picture by: Gidey Gebreegziabher, April 2022)

337. 27 Days of Russkij Mir in Jahidne: The Archaeology of a War Crime

Grzegorz Kiarszys (The University of Szczecin)*; Marek Lemiesz (The National Institute of Cultural Heritage of Poland)

Yahidne, a small village located over 100 km northeast of Kyiv near Chernihiv, Ukraine, became the site of harrowing atrocities during the early stages of the full-scale Russian invasion in 2022. On March 3, just seven days after the invasion began, Russian forces from the 55th Guards Mountain Motor Rifle Brigade (based in Kyzyl, Tyva Republic) entered the village. Having failed to capture the city of Chernihiv, the Russian military resorted to widespread terror against civilians in the region, executing unarmed inhabitants on sight.

The local school became a temporary Russian garrison, with soldiers occupying the upper floors. Civilians were rounded up, arrested, and forced into the school's cramped basement, which was repurposed as a prison and human shield for the occupying forces. Over 350 civilians, including more than 70 children, were confined to approximately 200 square meters of space. The youngest was a 1.5-month-old baby, and the oldest a 93-year-old elder.

Conditions in the basement were inhumane. Prisoners were deprived of basic necessities such as access to toilets, clean water, and sufficient food. Poor ventilation made the space damp and airless, and the psychological toll was immense. Reports indicate that Russian soldiers frequently tortured and harassed prisoners.

As the situation deteriorated, elderly detainees began to die from exhaustion and lack of care. Initially, Russian soldiers refused to allow the removal of corpses, forcing prisoners to endure the trauma of sharing the confined space with the deceased. Eventually, some bodies were moved to a boiling room or hurriedly buried in a nearby cemetery under fire from Russian guards, who reportedly shot at civilians during these makeshift funerals for their own amusement.

Occasionally, prisoners were briefly allowed outside but were kept in visible open areas to serve as human shields against potential Ukrainian attacks on the school building. Civilians were sometimes released to feed their animals, though most livestock, such as cows and pigs, had already been slaughtered and consumed by the soldiers.

After 27 days of imprisonment, on March 31, 2022, Russian forces withdrew from Yahidne as Ukrainian troops advanced. The retreating soldiers looted nearly everything of value from the school and surrounding homes, destroying anything they could not carry.

The tragic events in Yahidne have been extensively documented in journalistic reports and documentaries, highlighting the village as a symbol of the atrocities and war crimes committed during the Russian invasion of Ukraine.

This war crime left behind a significant amount of material evidence, much of which has been instrumental in the investigation of these atrocities. Ukrainian investigators meticulously gathered items, including DNA samples, that have already led to the identification of many Russian perpetrators. Among the evidence were personal and military items left behind by retreating soldiers, such as uniforms, newspapers, half-eaten military rations, cigarette butts, and other discarded materials.

The school itself, which had been transformed into a prison and temporary garrison, bore the scars of its occupation. Its interior was thoroughly devastated, with teaching aids, textbooks, and other educational materials destroyed or defaced. The walls of the basement bear haunting evidence of the human resilience and despair experienced by the prisoners. Children's drawings adorn the walls of the basement, a stark contrast to the horrific reality endured within those confines. Deprived of natural light and a sense of time, the prisoners scratched a crude calendar onto the wall to keep track of the passing days and nights. On the sides of the door in one of the rooms, prisoners documented the names of villagers executed by Russian soldiers, and the names of those who perished in the suffocating basement. These remnants, though seemingly mundane, provide critical insights into the conditions endured by the victims and the behaviour of the occupying forces, serving as tangible reminders of the horrific events that unfolded in Yahidne.

In 2023, the interiors of the Yahidne school were scanned as part of a Ukrainian-Polish collaborative initiative led by the ministries of culture of both nations. This project produced detailed 3D scans, CAD plans of the building, and comprehensive photographic documentation. The work was commissioned and supervised by the National Institute of Cultural Heritage of Poland (NID). Simultaneously, staff members from the Museum of Chernihiv undertook the crucial task of cataloguing selected artefacts left behind at the crime scene. These artefacts included personal belongings, remnants of military equipment, and other items that stand as silent witnesses to the atrocities committed in the school and its surroundings. Another valuable source of information about the events in Yahidne is high-resolution satellite imagery of the area. These images vividly document the extent of the village's destruction, including craters left by explosions, buildings and nearby forests and fields in fire, field fortifications, and military vehicles parked near the school.

We are currently witnessing an ongoing debate about how best to commemorate the Yahidne war crime. The former school building, indelibly scarred by the atrocities of March 2022, will likely never return to its original function. Instead, there are plans to transform it into a museum dedicated to preserving and sharing the memory of these tragic events. In this presentation, we will highlight the potential of digital tools for documenting evidence of war crimes and disseminating this knowledge to a wider audience. Although the remote sensing techniques employed in this case study will be addressed, our primary focus will be on the processes involved in creating heritage sites associated with traumatic events and examining how these places acquire cultural meaning and value.

352. The Production of Austronesian Maritime Cultural Landscapes: from Spatial Characteristics and Knowledge Structures

Hongpeng Luo (Tianjin University)*; Jie He (Harbin Institute of Technology Shenzhen)

The oceans have recorded the magnificent epic of human civilizational exchanges. The origin and spread of the Austronesian language are a classic example of early human migration across oceans. In the 16th century, Western explorers discovered that the inhabitants of the Pacific Islands not only looked very similar but also pronounced many words with almost the same meaning. The Austronesian language family is the only one found so far that is mainly distributed on islands, and it is one of the most widely distributed language families in the world (Diamond 1988). The term 'Maritime Cultural Landscape' was first coined in 1978, and in 1992 Christer Westerdahl established a research framework for it (Westerdahl 1992), which contributed to a paradigm shift in maritime archaeology that began to influence the world. Maritime cultural landscapes focus on the interaction between people and the sea, this theory comprehensive interpretive approaches that emphasize the integrated use of remains and culture (e.g., marine landforms, underwater shipwrecks, coastal ruins, ceremonial traditions, oral histories, etc.). Hypotheses about the origins and diffusion routes of the Austronesian have now been developed by international scholarship, and these studies have shaped the movement across the sea of the Austronesian and built the Austronesian maritime cultural landscape.

The research questions are, how was the Austronesian maritime cultural landscape formed? What kind of spatial features and knowledge structures does this maritime cultural landscape have? What are the key archaeological, linguistic, and genetic findings and elements from which these spatial features and knowledge structures are derived? How have these key elements organized and shaped today's perception of the Austronesian?

Objects of study, various types of material and non-material information related to the Austronesian. Material information includes sites, burials, etc. Non-material information includes language, place names, perceptions, and so on. Materials used in the study, including maps, charts, routes, research reports, etc. The research methodology comprises three levels. Firstly, at the empirical level, extract and identify both tangible and intangible empirical information related to the Austronesian languages from various materials and integrate this information into a Geographic Information System (GIS) to form a spatial database. Secondly, at the conceptual level, structure the non-spatial information of the Austronesian languages into an "observation-analysis-induction" knowledge structure. Knowledge is a generalized summary of the practical experience of human society, and knowledge graph visualization technology presents the abstract knowledge graph as an intuitive graphical interface. Thirdly, at the cognitive level, use tools like least-cost path analysis, viewshed analysis, and network analysis to analyze and simulate the spatial characteristics of Austronesian maritime movements. Link the knowledge structure to these spatial characteristics, acknowledging that the study of Austronesian languages involves more non-geometric, non-geospatial information. However, mapping this information to geographical space is crucial for quantitative analysis. This approach allows the cognitive paradigm of Austronesian maritime cultural landscapes to be presented in a visual form(Kuhn and Hacking 2012).

The anticipated results of the research will construct two types of relational networks: a spatial network and a knowledge network. These networks will be overlaid to represent and interpret the process of modern human cognition of Austronesian maritime cultural landscapes. This research discusses how knowledge is produced. The spatial characteristics and knowledge structures will

also be used to verify or match the diffusion paths and methods of the Austronesian languages proposed by archaeologists and linguists (Figure).
Currently, adverse factors such as landform changes, marine pollution, looting, and corrosion are rapidly destroying underwater and island historical sites. The interpretation of maritime culture is urgent. The study of Austronesian maritime cultural landscapes has the potential to integrate discovered sites and existing scholarly knowledge over a vast geographic space and an extensive time scale and contribute to a digital approach that integrates spatial features and knowledge structures.

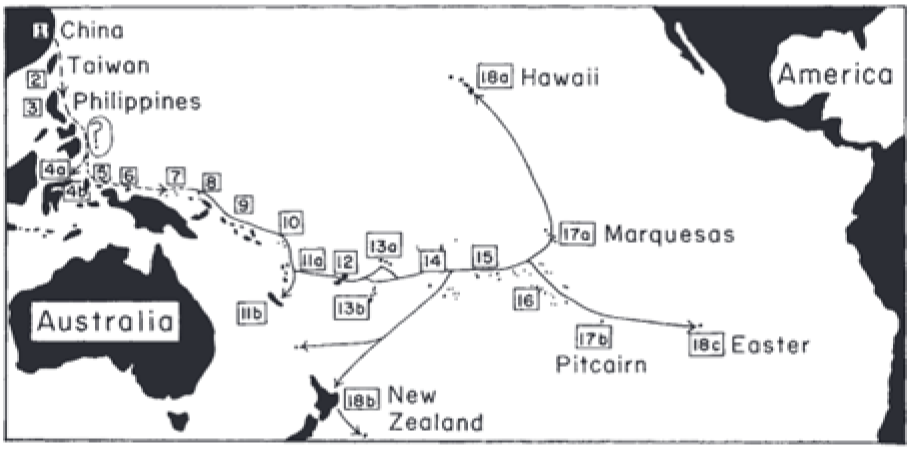

Figure: Model of the origin, and diffusion of the Austronesian. (source: Diamond, 1988)

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247. Unraveling Identities: A GIS-Based Approach to Weapon Burials and Maritime Networks in Bronze Age Western Greece

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Introduction

This paper, as part of my ongoing PhD research, explores the relationship between the so- called “warrior burials” in Western Greece in the transitional phases from the Late Bronze to the Early Iron Age, and the maritime exchange networks that facilitated the movement of goods, ideas, and cultural practices across the Mediterranean. During the latest phases of the Late Bronze Age, the Eastern Mediterranean appears to have experienced a significant crisis, which also seriously affected the Aegean Greek world, as evidenced by the collapse of the Mycenaean palatial system, and deep changes in many aspects of material culture, from settlement patterns to mortuary practices, and from pottery styles to metallurgical technologies. The period following these dramatic changes, known as the Late Helladic (thereafter LH) IIIC or Post-palatial period, is often viewed as an era of general decline and degradation. However, recent research shows that the impact of palatial collapse and other concomitant changes varied considerably across different regions.

Western Greece and the Ionian islands are a prime example of regions that seem to have flourished during the 12th century BC (Moschos 2009), with many sites established for the first time or continued to be inhabited from the previous period, and still engaged in overseas contacts (Giannopoulos 2022). The most notable feature of this period, in terms of both material culture and human practice are the so-called “warrior burials”, wealthy burials furnished with various types of bronze weapons, such as daggers, spearheads and swords, as well as other objects of high quality, such as jewelry. Some of these objects were either imported or influenced by areas outside the Aegean, especially Italy. It is still debatable if these burials accurately reflect the existence of warrior groups, or whether they represent the articulation of broader elite identities, such as those local or regional leaders, merchants, or even pirates. Indeed, recent analyses of such burials have shown their possible connection and access to long-distance interregional networks, but more evidence is admittedly needed to determine the exact role of these groups and the character of their engagement to maritime interaction (Giannopoulos 2022).

Material and Methods

This study addresses several crucial questions, such as which elements of the burials indicate foreign origins or external cultural influence, how these imported Italian objects found their way to Western Greece, and what was the role of maritime trade routes for their mobility. Moreover, another question of particular importance relates to the role of such exotic items within the social and political dynamics of elite groups in Western Greece, during a time period when much of the Eastern Mediterranean was in political turbulence. By using Geographic Information Systems (hereafter GIS), this study aims to investigate whether the location of these burials and their proximity to key trade routes may provide clues about the identities of the “warrior burials”.

GIS is used to create models of maritime travel and reconstruct possible sea routes that connected Western Greece with other parts of the Mediterranean, particularly towards Italy and the west. These models consider key environmental factors, such as the speed and direction of sea currents and wind, as well as the configuration of the islands and the coastline of Western Greece and the Ionian Sea, which most likely influenced the feasibility and frequency of sea travel (Indruszewski & Barton 2008). Additionally, the models incorporate anisotropic movement, recognizing that maritime travel is not uniform in all directions; instead, it is influenced by factors such as prevailing winds and currents, which create directional constraints on movement. Maps that examine the feasibility of movement in the Patraikos Gulf and the Ionian Sea at different times of the year have been produced to highlight the most advantageous routes throughout the year, with the use of GIS tools such as least-cost-path and accumulated surface analysis. By integrating GIS into the archaeological data, the study aims at reconstructing possible trade routes and investigates how environmental data and the geographic location of burials might reveal more about the identities of those burials and the character of maritime activity.

Results

On the basis of the preliminary results of the GIS-based analysis, some maritime routes connecting Western Greece with Italy and the Aegean, were used more frequently than others, especially in specific seasons, during which environmental factors, like sea currents and prevailing winds, were less favorable for other possible routes. The analysis also verified the strategic position of specific Ionian Islands, which constituted an almost unavoidable point of passage for people and products throughout the Mediterranean. This supports the hypothesis that individuals buried with weapons in those islands may had access to long-distance networks. Burials close to key coastal places may suggest engagement in trade or piracy, as these people may have had direct influence over or involvement in marine activities. Thus, the study of the maritime routes and their relation to burial locations is beginning to reveal interesting patterns, which need further analysis and discussion. Seasonal variability in the feasibility of travel also imply that some burials correlate with periods of considerable movement of goods, therefore suggesting that the individuals buried there may have held important roles in managing, facilitating or obstructing trade, rather than being strictly warriors. This approach will attempt to move beyond traditional interpretations, which attribute to these individuals a “warrior” identity and discuss the possibility of other social roles and identities.

Discussion

The implications of the above study are not confined to the understanding and interpretation of the “warrior burials” but refer also to the wider issue of the connectivity between Western Greece and the Ionian Sea and other Mediterranean regions to the west and north during the transition from the Late Bronze to the Iron Age. By generating and using GIS-based models, this paper aims to reconstruct not just the most probable routes used in this period but also the strategic value of certain locations-such as the Ionian Islands and the pivotal coastal sites in the Patraikos Gulf and Western Greece. These sites, often located at the crossroads of important sea routes, became vital nodes in a decentralised but dynamic network of interaction, during a period without palaces or any other dominant political institutions. By examining the geographical and environmental context alongside archaeological data, the paper illuminates the adaptation strategies of communities that thrived through maritime connectivity.

In conclusion, this research intends to explore the placement of the “warrior burials” in Western Greece within a highly interconnected Mediterranean world during the Post-palatial period, at least in the part of the Mediterranean. These individuals could have served a variety of roles depending on their proximity to trade routes, access to foreign commodities, and to important coastline locations. By integrating archaeological analysis into GIS modeling, this study aims to provide novel perspectives on the identities and the agency of individuals buried with weapons and their connection to the long-distance networks that influenced the political and social environment of Western Greece at that period.

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304. If a Cornishman Were to Pray, All He Would Ask for Is a Good Wreck: A Social Network Analysis Approach to Tracking Illicit Maritime Movement in the Celtic Sea (1690-1715)

Adam Dawson (University of Oxford)*

This paper uses graph theory, in conjunction with archaeological and archival methods, to visualise the relationship between illicit maritime actors operating in the Celtic Sea, principally Cornish smugglers working with pirates based in Ireland, France, and to a lesser extent, Spain. This is undertaken in two ways. First, by using HDBSCAN to look at the connections between locations mentioned by pirates tried by the High Court of the Admiralty. Secondly, using Graph theory to visualise the relationships between Cornish MP's during the "Rage of Party" (1690-1715). The combination of these studies reveals the Celtic Sea unified seafarers from several nations who were operating against the interests of British Whigs in the 17th and 18th centuries.

Literature Review

The typological nature of archaeology creates the ability to link wide ranges of sites and materials in both the spatially and temporally, and as a result SNA has proved a useful method for many researchers. Golitko et al. (2012) use the Brainerd-Robinson coefficient to network Mayan obsidian assemblages to demonstrate changing social interaction during the Maya collapse. It is also a method that has proved particularly useful in the field of maritime archaeology where the limitations of the seascape make networks less visible. Three particularly notable examples of this work are Knappett's research on the Aegean Bronze Age Knappett, Evans, and Rivers, 'Modelling Maritime Interaction in the Aegean Bronze Age'; Knappett, Rivers, and Evans, 'The Theran Eruption and Minoan Palatial Collapse'., Leidwagner's revisualizing of the Roman world through its network analysis Leidwanger, 'Maritime Interaction and Mediterranean Communities'; Leidwanger and Knappett, Maritime Networks in the Ancient Mediterranean World., and Sindbaek's approach to the Viking expansion in the Scandinavian Iron Age Sindbæk, 'Networks and Nodal Points'; Sindbæk, 'The Small World of the Vikings'.. SNA is used below to track the changing political trends in Cornwall between 1690-1715 to identify how and why major political interests of the time may have interacted with Cornish smugglers. This approach has its origins in Padgett and Ansell's groundbreaking research on the rise of the Medici family in Florence, utilising the large volume of archival research undertaken on the family in the 1970s and 80s (Padgett & Ansell 1993, 1265–8), which echoes the method used in this research. By networking the marriage and business relationships of the Medici, Padgett and Ansell helps explain the rise of Cosimo Medici (Padgett & Ansell 1993, 1309–10).

Methodology

English/British piracy trials from this period place a great deal of importance on place with most examinations involving accused pirates listing their birth and the various locations they have visited during and after their as a pirate. Consequently, it is possible to map the key locations related to piracy at this time. Trends in the data are then highlighted using density-based clustering which uses machine learning to group together concentrations of points based on their relative distances. The specific method used for this dataset is HDBSCAN, a form of hierarchical clustering that uses variable distances to identify clusters where there is sparse noise (isolated points). Given the relatively high density of points in certain areas, accompanied by noise splattered across the globe, this was the most appropriate method for this work. Clusters then make it possible to evaluate locations related to piracy at this time.

For the Cornish political networks data was collated from The House of Commons 1660-1690 and The House of Commons 1690-1715 Hayton et al., The House of Commons, 1690-1715; Henning, The House of Commons, 1660-1690.. Electronic versions of both these volumes are available online and can be accessed via https://www.historyofparliamentonline.org/ (accessed 04/10/2024). This encyclopaedic resource details every member of Parliament elected in Cornwall between 1690 and 1715 as well as providing brief biographies. An adjacency matrix linking together the major relationships between MPs was constructed by cross-referencing the many articles present in the compendium. For each period the 'hairball' data (all data unfiltered) is displayed first to show the relative strengths of each party in Cornwall during the ministry. Then a refined version of the networks showing the political interest groups are displayed. The interest groups present a clearer picture of the main political forces active in Cornwall at that time. the interest groups are divided into factions based on the Girvan-Newman score. For each network a politician's prestige is measured by closeness, betweenness, and degree, the percentage value of these scores is averaged to create an overall 'prestige' score. This score is then used to weight the size of the nodes, with the larger nodes being more prestigious and the smaller ones less so. The top 10% are initialled to give an indication of the most important members of each network. A table providing the scores is also provided ordered from highest mean score to lowest. Whilst betweenness and closeness are expressed as percentages in the table, degree is not, as the actual number is more intuitive for a count score.

Results

The analysis of Cornish political relationships suggests that some form of a 'smugglers lobby' did exist in Cornwall. Each ministry contained at least one prestigious individual that had some form of connection to smuggling. These smugglers and politicians also have tangible relationships to Irish seafarers whom the British government considered pirates. The smuggler lobby appears to become increasingly powerful in the build up to the 1715 Jacobite Rising where they played an important role in passing information between English Jacobites, Irish pirates, and the exiled court. The locations frequently mentioned by pirates tried by the Admiralty Court correlates with the areas that smugglers with links to Cornish MP's operated in. By recreating the maritime cultural landscape of these seafarers, this paper wishes to initiate discussions about maritime groups who are labelled as illicit for political reasons.

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282. Data at the Helm: Environmental Statistics and Maritime Movement Modelling

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This paper presents methodologies for analysing and visualising 4D environmental datasets, demonstrated by a comparative analysis of ABM navigation simulations within the Mediterranean as part of The Practical Mariner project. Archaeologists simulating maritime movement are increasingly using 4D hydrodynamic and aerodynamic datasets to represent currents, winds, waves, and other ‘environmental’ factors in their models. Although there are many meteorological and oceanographic heuristics for evaluating these datasets (see Thiébaux 1999), their use in contextualising archaeological analyses is rare. To address this analytical gap we have developed GIS scripts to process 4D netCDF datasets into rasters that represent basic meteorological/hydrodynamic statistics. The scripts we present here are written in Python, using the netCDF4 library to read multidimensional inputs and convert them into NumPy arrays. The script then filters these arrays based on temporal and geographic boundaries set by the user. Statistics are then performed on these filtered arrays and the results are converted into rasters and tables using the ESRI ArcPy library.

Archaeologists seeking to model maritime movement have access to large, growing datasets from sources like NOAA’s National Data Buoy Center and the EU’s Copernicus Marine Data Store. The Copernicus data archive, for example, contains more than thirty years’ worth of detailed forecasts. The size and extent of these datasets presents opportunities for modellers, but also creates significant practical challenges. Performing simulations that sweep large parameter spaces can be resource- and time-consuming, and the data that is produced in these huge analyses can also be difficult to parse. As an alternative, we propose a data-driven methodology in which basic hydrodynamic and meteorological statistics (i.e. wind/current direction/velocity mean, range, frequency, standard deviation) are used to select data subsets tailored to conditions suggested by particular research questions.

There are several methodological advantages to this approach. Firstly, it dramatically reduces the number of simulations needed for a narrow analysis by reducing the size of the parameter space that the simulation needs to iterate through. For example, an analysis that seeks to compare voyages on clear days and stormy days can be based on a few selected dates, rather than the global minima and maxima of an analysis of a years’ worth of simulation results. Secondly, it makes the results of simulations more directly comparable with non-computational analyses of seafaring that tend to describe conditions in subjective terms like ‘favourable winds’ and ‘foul weather’. By being able to identify data subsets that approximate these conditions we can create models to test these theories more directly. Thirdly, having a better understanding of input datasets helps us interpret the results of our models. The scripts presented here can help detect whether arbitrary data subsets (i.e. observations for a particular calendar year) are biassed with respect to the full range of data. Fourthly, these statistics can also drive the creation of hypotheses, by flagging environmental conditions that may have helped or hindered seafarers.

The scripts presented here are also useful for visualising 4D environmental data as well as for interpreting it. It can be difficult to communicate weather patterns through GIS without using animations, pages of tiled maps, or complicated tables. The scripts presented here output meteorological/hydrodynamic statistics as raster images, which can be easily processed in GIS.

Also presented here are scripts that build frequency tables - the basic components of a traditional wind rose - for defined polygon areas and times within a larger dataset.

To test the usefulness of this data-driven methodology we compare its results to a 'traditional' comprehensive programme of simulations of maritime movement in the Mediterranean. To begin with, we select a subset of the Copernicus Mediterranean Sea Physics Analysis and Forecast dataset. We then perform simulations of sailed routes suggested by archaeological evidence and Classical sources (see Arnaud 2005) for the entire period using the NavABM sailing/navigation model (see Smith 2020). We then calculate seasonal statistics for the same six-year period, using those statistics to identify days with favourable and unfavourable conditions. By comparing the aggregate results of the comprehensive analysis with results for days identified by analysis of the data, we can see whether the data-driven approach is useful for identifying conditions that are expressed in the results of the model.

Our aims in presenting this comparative analysis are to promote environmental data literacy within the maritime-movement-modelling community, suggest methodologies that make modelling less time-consuming, and open up a broader debate within the community about how we use and communicate our data inputs. We also plan to make our scripts available on GitHub so that researchers can use them to inform and design their own analyses of maritime movement.

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89. Using Wind Patterns for Maritime Cost Surface Creation: Practical Issues and Solutions

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Introduction

Understanding past mobility is vital for understanding the ancient world, particularly when looking at economic exchange or settlement patterns. Methods have been used and developed for decades for terrestrial mobility but including the sea in any model comes with considerable additional difficulties and complexities. However, it also adds essential nuance and detail. Indeed, in the Roman world, movement across the Mediterranean was the primary means of transporting goods and people long distance. Attempts have been made to understand and model this aspect of mobility but often a trade-off between detail and nuance and accessibility and reproducibility is necessary. This paper seeks to address this by providing a highly nuanced model for understanding maritime mobility, based on existing computationally demanding models, and altering the underlying methodology to ensure that it is far more accessible and reproducible. The research questions being addressed are-

- How can wind patterns be most effectively utilised to create a model for maritime mobility?
- What can Cost Corridors applied to such a model tell us about the network of Roman maritime mobility in the Mediterranean?

Materials and Methods

The methodology builds upon existing methodologies and seeks to streamline and improve their utility. The focus is on the construction of a cost surface using historical wind patterns, while innovative cost corridors analysis is employed to show the usefulness of this cost surface for targeted questions about maritime mobility more broadly in a Roman context.

The wind patterns are derived from the Copernicus Climate Data Store, specifically the ERA5 hourly data on 10m u- and v-components of wind. These data cover the whole Mediterranean and the wind patterns every hour from 1940 to 2023 inclusive. These wind patterns are then used to create a cost surface based on how wind direction and speed may impact the relative cost of sailing. Two slightly different approaches are compared here. First, the cost surface is created using exact wind patterns, for specific timeframes. Cost corridors are generated across all of these, and the corridors and costs averaged to produce a final output. This is a very computationally demanding approach. The second approach reverses this order, averaging the huge quantity of wind pattern data to create a single cost surface and then generating the cost corridor based on this. This takes a fraction of the time and computational power of the first, simply by switching the steps and averaging the wind patterns before generating the cost surfaces.

Results

Despite the significant difference in computational demands between the two approaches of cost surface generation, the results produced by each are near identical. As we may expect, the variation in cost surfaces generated using the first method is quite significant, and results in a wide range of corridors and associated costs. This of course, reflects the highly variable nature of wind patterns and the impact on sailing conditions. However, once these are averaged, we get a result that is functionally identical to that produced through the second methodology, where wind patterns are averaged to begin with.

Discussion

The most significant takeaway from this methodological comparison is certainly the lack of difference between the results of the different approaches. Methodologies similar to the initial approach outlined here have been discussed previously and are rightly accepted as being excellent examples to follow for modelling maritime mobility. The only real issue is the difficulty in reproducing these results without powerful hardware and prohibitively long computing time. The second approach is essentially a development of this first, but one which produces almost identical results with a fraction of the computational power. There may be some instinctual aversion to the second approach as it explicitly averages wind patterns, something which undeniably comes at the cost of the nuance and precise understanding of exact sailing conditions under exact wind conditions. However, this model is not attempting to reproduce exact or specific journeys under exact or specific conditions, but rather provide a broad regional overview of patterns of maritime mobility, rendering this level of nuance and detail not only unnecessary, but cumbersome and unhelpful. More importantly, with the results being the same whether wind patterns themselves are averaged or the probabilities of non-averaged winds are used afterwards, any criticism of the second approach in favour of the former is purely ideological and not based in practical approaches to deepening our understanding of past mobility. While neither are perfect representations of reality (they remain models of course), the results represent some of the most cutting-edge quantitative data for ancient maritime mobility, with the second approach having the benefit of being readily accessible and easily reproducible in a way which the first is not. Ultimately this paper shows that, in this specific context of a broad understanding of general patterns of potential mobility, our approach represents the most effective means of capturing the complex detail of maritime mobility, while maintaining accessibility and reproducibility for the broader community of researchers.

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11. Measuring Potential Sailing Mobility in Antiquity: Methods, Application and Outreach

David Gal (University of Haifa, Department of Maritime Civilizations and The Leon Recanati Institute for Maritime Studies)*

Introduction

In the recent decade, several computer-based tools have been developed to provide quantitative measures of potential sailing mobility with the objective of supporting maritime network analyses. These solutions primarily used Geographic Information Systems (GIS) cost surface analysis or similar methodologies to compute sailing mobility. The sole output measure of potential sailing mobility was sailing time expressed as duration between point of origin and destination or expressed by an isotropic surface showing equal time distances achieved sailing from the point of origin.

Drawbacks of these solutions included the input of averaged wind at seasonal or monthly temporal resolution and the exclusion of the human factor in modelling sailing mobility. Wind patterns in the Mediterranean Sea are characterised by a high degree of variability, both inter- and intra-diurnally. Mediterranean merchant ships in Antiquity possessed limited windward capabilities and highly relied on wind direction. Therefore, using averaged wind erased all knowledge of wind variability, a key factor in sailing mobility. The ancient mariners were prudent sailors and clearly would pick and choose the conditions in which they would sail or alternately prefer to wait on land for better conditions. The human element is a major factor in historic sailing mobility, and the non-inclusion of the mariners' abilities and limits was detrimental to examining sailing mobility.

Methods

The underlying understandings adhered to in the development of the presented methods were: a) wind variability is a key factor in sailing mobility dictating the use of high-resolution wind data, both spatially and temporally; b) all three factors of sailing mobility (the ships, the environment, and the mariners' limits of reasonability) need to be modelled, as the investigation of maritime links requires measures of practical sailing mobility; c) direct non-stop passages from point to point and breeze-cycle driven coastal sailing are two distinct modes of sailing; and d) it can be shown that in the Mediterranean, modern winds equal ancient winds. Consequently, Gal, Saaroni, and Cvikel developed two methods to measure the potential sailing mobility of direct passages and coastal sailing voyage segments (2021a, 2021b). These follow the same concept shown by Pascal Warnking in 2016, simulating multiple sailings with weather routing software throughout a large set of real meteorological data at high resolution and then applying statistical analysis to the outcome set of simulated sailings.

The method for direct sailing passages used a 15-year set of meteorological data at a spatial resolution of 27km and a temporal resolution of 1 hour to conduct 5479 daily simulated sailings for every passage. The human factor was applied to the simulated sailing records by a set of criteria defining the mariners' limits of reasonability. This divided the simulated sailings into a subset of sailings that would have been practical and a subset of sailings considered non-practical to conduct by human crews.

The method to measure coastal sailing mobility used a wind dataset at 3km spatial and 1-hour temporal resolutions. This fine resolution was required to resolve the small mesoscale breeze events adequately. Coastal points 5 nautical miles (nm) apart were defined along coastal stretches of about 150 nm. Twelve daily sailings, at hourly intervals, were simulated from every point to each of the three adjacent points. This facilitated measuring the ability to advance along the coastal stretch using the appropriate land or sea breeze for propulsion.

Results

Investigating sailing passages using these new methods produces a rich set of novel measures. The prime measure of sailing mobility is the coefficient of mobility which reflects the proportion of days in a month for which a departure would culminate in a practical sailing passage. I.e., the monthly probability of finding favourable winds for a given passage. A measure of passage duration/effective speed is also given. Furthermore, the methods provide measures of time spent waiting for suitable winds reflecting the frequency and duration of favourable winds. Data on sailing characteristics include the distribution of points-of-sail and measures of windward sailing encountered in the simulated sailings. Data on passage weather and sea conditions is also summarised, including statistics of sailing days lost due to stormy weather.

Discussion

The methods' contribution to archaeological research falls into two primary study categories. The first is the input of quantitative sailing mobility measures to downstream quantitative processes such as maritime network analysis or historic economic modelling. The coefficient of sailing mobility provides a better representation of edge costs than sailing duration alone. Similarly, in the case of economic modelling, considering time spent waiting and the count of possible annual round trips provides a closer representation of shipping costs than the sole measure of net sailing duration. The second study category is that of mapping potential sailing mobility to illuminate how historic maritime links might have been conducted, e.g., assessments of regional seasonal sailing patterns or investigations of inter-regional seasonal routing options and preferences.
The toolkit for running simulated sailing passages and producing the statistical summaries is being maintained operational in support of ongoing research projects and collaborations. All generated data is added to a growing atlas of potential sailing mobility published in an open-access data repository (Gal, Saaroni, and Cvikel 2023). Nine hundred direct sailing passages involving over four million simulated sailings have been examined and published. Twenty-one stretches of coastline have been measured for coastal sailing mobility, involving 47 million simulated coastal sailing runs.

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262. It’s a kind of magic: Houdini, CFD and the procedural reconstruction of ancient Greek and Roman sailing ships and the analysis of their sailing capabilities. A methodical overview.

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Introduction and Context

Interest in questions of economic history has once again increased rapidly in ancient studies. A central component of this interest is the question of connectivity and transport costs. While there nowadays is consensus on the high degree of networking and market integration in the Roman imperial period, which indicates an early form of globalisation, significant uncertainties remain about the specifics of transport via the Mediterranean. The multifaceted and complex nature of the sources concerning shipping routes, winds, and ship characteristics constitutes the main problem here. Various approaches attempt to address this (Stanford: ORBIS, Trier: DIMAG), but they remain unsatisfactory as they do not come close to covering the much more complex ancient reality. This is primarily because a key and still inadequately resolved research question lies in the many different types of ships in antiquity, which are visible in the archaeological record as shipwrecks. The few replicas of ocean-going merchant ships and a trireme (Kyrenia II/Liberty, Bissula, Olympias) for which measurements on their performance could be taken, compared to over 1,300 different ancient wrecks found, make it difficult to apply their data to all ancient ships without further comparative analysis.

Based on my ongoing PhD project, this paper aims to propose a possible solution to this problem in the form of a broad multidisciplinary approach, which examines sailing properties using digital ship reconstructions based on archaeological findings of shipwrecks and ancient historical sources. One goal of this paper is also to demonstrate that determining sailing characteristics using digital 3D models and simulations can provide a valuable and cost-effective alternative to elaborate real-life replicas, which, due to their immense effort, can only study a single ship at a time. This includes in particular not only the simulation of the hulls but also that of the sails (both square and fore-and-aft sails), which has not yet been endeavoured extensively for pre-modern era ships. This has therefore great potential to supplement and expand existing and ongoing research projects with additional realistic data from other ship types.

Methodology for Determining the Performance of Ancient Sailing Ships

Digital 3D reconstructions offer an alternative to financially substantial real-life replicas: they require less time and resources while remaining flexibly customisable. With the advancement of more efficient computers and software applications, it is now possible to solve complex and intricate physical problems such as the fluid dynamics of ships using simulations with algorithms based on physical laws, yielding results that correspond to real conditions teams (cf. Casalone et al. 2020). An advantage of this approach is that simulations can be conducted at a real-world 1:1 scale, and at the same time the ship's behaviour can be tested under variable sea and wind conditions. In modern shipbuilding, this approach of computational fluid dynamics (CFD) is now almost exclusively used over traditional tests in towing tanks by ship classification societies, shipyards, and even sailing regattas.

Methodology for Creating 3D Models of Ancient Ships

Creating variants of similar 3D models using ‘traditional’ techniques such as polygon modelling or CAD is comparatively tedious. Given this context and the fundamental challenge posed by the

wide range of ship types, this paper adopts the innovative approach of procedural 3D modelling (Suarez et al. 2019 and Hinz 2023).
The advantages of this approach are significant: Procedural means that each step of the 3D modelling process is non-destructive and remains replicable, i.e. it is possible at any time to modify values (such as the ship length), objects, individual elements, etc., which are then applied automatically by all subsequent modelling steps. These values can be released as parameters and collected in a dedicated menu, which can then be intuitively reused for modifications and adjustments at any time – even by laypersons in the field of 3D modelling (cf. Hinz 2023, 219–222). This results in immense time savings, as each element only needs to be created procedurally once and can be immediately reused in the future. This allows us to create a new variation of a single ship in the shortest time possible but also to configure a completely new ship or different ship type from these existing elements within mere minutes.

Application and outlook

The integration of the various methods and the innovative creation of 3D reconstructions of ancient ships and their subsequent digital analysis and simulation is a significant contribution to the study of ancient sailing ships which will result in a new, comprehensive database on their performance, which explicitly considers their wide range of different ship types and shapes. Through this quantification, based primarily on classical and computational archaeological sources and methods, an important contribution to the research of the ancient (Roman) economy and maritime trade can be made, which can be further utilised by both archaeological and historical research projects for further studies. For an example of such an application, these sailing characteristics will also be used in my PhD project to calculate routes within a computer-based navigation model. This GIS-based route model in combination with an additional network model will analyse and highlight the most possible and favourable ancient sailing routes in the Mediterranean for a specific ship type.

Case Studies

The applicability of the simulation model to analyse the performance of sailing ships and its use in a navigation model will be tested using several case studies to validate its functionality. Initial case studies will compare the few trial voyages of ancient ship replicas and the fragmentarily recorded routes from antiquity with the corresponding simulated routes and sailing data.
Additionally, the reusability and applicability for other epochs will be illustrated through two further case studies, one each for the Middle Ages (possibly as a collaboration with the German Maritime Museum – Leibniz Institute for Maritime History) and the Napoleonic era (HMS Victory).

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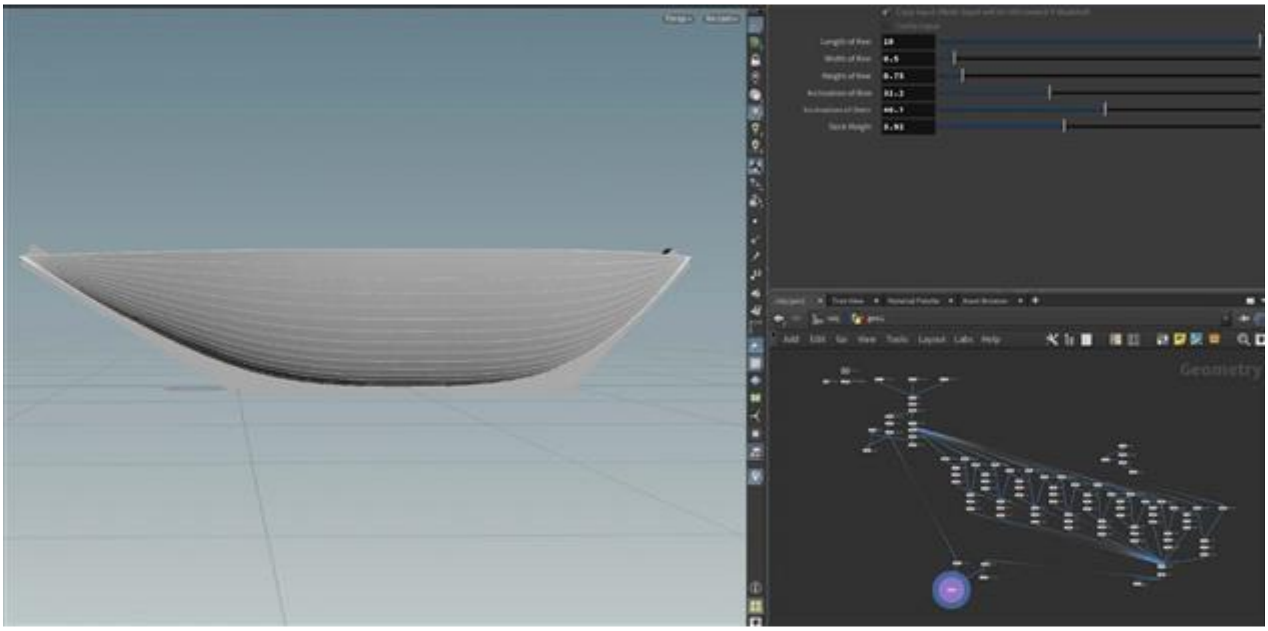

Fig. 1: Early prototype of a procedural ship model made in Houdini for my master’s thesis to highlight the main advantages and functionalities of such a procedural model.

494. Integrating Agent-Based Modelling and Experimental Archaeology for the study of Middle Palaeolithic sea-crossing scenarios. The Inner Ionian Sea Archipelago as a case study.

Christina Papoulia (University of Crete)*; Angelos Chliaoutakis (Geo-Arch-Sat, IMS, FORTH); Panagiotis Zervoudakis (University of Crete); Nikos Papadopoulos (Geo-Arch-Sat, IMS, FORTH)

Background

The sea is rarely incorporated in theoretical models of palaeolithic human dispersals. When examined, it is either regarded as a resource, a water crossing challenge or a now submerged terrestrial route to new territories (Galanidou and Papoulia 2023). In our evolutionary history, once the sea as an obstacle was crossed, a novel relationship with the environment was born. Buoyant vessels enabled prehistoric communities to traverse large bodies of water and transport people, goods and ideas. Although the islands as laboratories for cultural change have attracted a lot of research attention, the sea as a social arena for technological experimentation has yet to be fully understood. Lately, new data from the NE Mediterranean have instigated a debate on the 'seafaring' capacities of species other than Anatomically Modern Humans. The scrutiny of palaeolithic seaward dispersals demonstrates various methodological challenges and epistemological biases that inevitably shape archaeological interpretations and build established narratives (Papoulia 2017).

Due to the lack of preserved aquatic vessels, the study of Palaeolithic seafaring and boatbuilding technology is bound to be performed in absentia. In this context, theoretical and computational modeling combined are able to assist archaeological interpretations and significanlty inform our understanding of the challenges of crossing the sea water. SeaROOTS, a two-year research project funded by the Hellenic Foundation for Research and Innovation – HFRI, aimed at investigating aspects of seaward mobility within an enclosed archipelago at the Central Ionian Sea. To do so it used an interdisciplinary toolkit based on three different proxies: (a) stone tools, (b) artificial communities and (c) an experimentally constructed sea-vessel. Here we discuss the research methodology and preliminary results of the SeaROOTS Agent-Based Model produced and discuss it in accordance with the SeaROOTS experimental project that aimed to construct a logboat with a replicated Middle Palaeolithic toolkit.

Methodology & Results

An Agent-Based Model (ABM) was developed in order to simulate the potential maritime routes assumed by artificial Middle Palaeolithic communities depending on the respective paleoshorelines configuration and the anticipated environmental constraints. The model aimed at investigating the possible, probable, impossible and improbable sea-crossing scenarios between the isles, islets and mainland coasts of the Inner Ionian Sea Archipelago. SeaROOTS ABM is a multi-level ABM developed using the NetLogo modeling environment. It utilizes "LevelSpace" (NetLogo extension) in order to supply agents with a mobility model (LCP algorithm) while deliberating and interacting within the existing model (cross-level interaction). Unlike most existing agent-based models used in archaeology SeaROOTS agent-based system includes completely autonomous, utility-based agents (Chliaoutakis and Chalkiadakis 2016), representing artificial Stone Age communities, with partial knowledge of their environment, for simulating their evolution and potential maritime mobility, utilizing alternative Least Cost Path (LCP) analysis modeling techniques ((https://www.comses.net/codebases/8ca8240f-2345-4df2-ba86-e65013faf8ea).

Two groups of hominins, Neanderthals and Homo sapiens, were chosen in order to study the challenges and strategic actions employed as a response to the fluctuating sea-levels, as well as probability scenarios with respect to sea-crossings via buoyant vessels (rafting) or the human body itself (swimming). SeaROOTS ABM simulates various scenarios and investigates the degree climatic fluctuations influenced such activities and interactions during the Middle Palaeolithic. SeaROOTS working hypothesis was that the Neanderthals were indeed capable of the idea and the development of the necessary skills and techniques in order to construct a seaworthy vessel. The project's successful experimental logboat construction supports the aforementioned hypothesis and was able to provide important insight into the boatbuilding process unravelling its chaine operatoire. The ABM simulation results raise significant points in terms of environmental constraints, types of crossings (sea-vessel or swimming), population size and geographic distribution. These are affected by both environmental conditions and reconstructed topography of the corresponding scenario period.

Discussion

The integrated methodology employed allows for an articulation and testing of new hypotheses on the relationship between palaeolithic communities and the sea that contest long-established narratives and furnish archaeological discourse with powerful new perspectives. SeaROOTS ABM results demonstrate that it can be readily applied in large, real or reconstructed geographic environments and time periods, and can provide insights or suggestions and help achieve better utilization of archaeological data on various archaeological hypotheses, regarding artificial hominin dispersal and mobility.

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285. Pytheas: a fast and agile ABM software for the study of ancient seafaring

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Seafaring played a central role in the movement of people, ideas, goods and technology since prehistory. The presence of cultural traits including artefacts, iconography and recently also aDNA found on different sides of a stretch of open water makes this apparent. Studies of the chemical composition of bronze artefacts now suggest that e.g. Scandinavian societies exchanged metals over great distances, importing up to a ton of copper from the British Islands alone during a period between c. 1600-1400 BC (Bengtsson et al. forthcoming). The existence of such a massive network of imports required investments in the maritime forces of production such as boat building and training of crews for long distance travels (Ling et al. 2018). Yet, the nature of these long-distance journeys, the technologies needed to accomplish them and the logistics underpinning such journeys are currently poorly understood.

To start teasing apart different aspects of long-distance seafaring in the Bronze Age, we developed Pytheas, an agent-based modeling (ABM) software to simulate vessels navigating both in open ocean and along the coast. In this paper we present the software, along with a case study of its use to simulate navigation along the North-Atlantic Façade during the Bronze Age. The software has been developed specifically to be used with the polar diagram of a specific pre-historic type vessel (Bengtsson et al, forthcoming) and is geared to help answer questions such as: how long would a voyage last? What are the factors that limit an ancient boat for undertaking long distance voyages across the sea? How often could voyages between two points take place? What navigation strategies could maximize voyage success?

Pytheas is a seafaring simulator written entirely in Python. It was developed with good practices of software engineering in mind, and as such it is efficient, modular, tested and well documented. It was built with an analogous architecture to the one used for example in the popular ABM Python package Mesa (Kazil et al., 2020): the user can define a trip instance (called a Travel, in the terminology of Pytheas) by first defining a Boat (a unit of software that regulates the logics of movement of a boat on the ocean) travelling on a Map (a unit of software that contains all the spatio-temporal data for the Travel at hand). It can make use of data from different sources to calculate displacement of a boat on the ocean, given a starting and ending point. At its most essential, the software needs three pieces of input to function: (i) a polar diagram, a mapping that determines effective velocity of a vessel paddling (or sailing) given a wind speed and a direction; (ii) wind data for the region over which we simulate the travel; (iii) sea currents data. At present, waves data do not affect the navigation algorithm of Pytheas, but they can be used post hoc to assess the environmental conditions encountered during a voyage.
The polar diagram is arguably the most important piece of information required: it maps wind direction and speed into effective velocity on the boat. To develop one, different aspects of a vessel are taken into account, such as the hull shape and its performance on water. In our case study, we simulated navigation with the Hjortspring Boat, thanks to the existence of performance data for its reconstruction, as well as a 3D hull reconstruction. Environmental data were obtained from physical reanalyses from the Copernicus Marine Service: these consist of wind, current and waves data on a grid of between 2.2x2.2 km and 10x10 km, at a temporal granularity of 1h to 3h, between 1993 and 2020.

As a case study, we used Pytheas to study navigation along the North-Atlantic Façade, and we output different aspects of each voyage. For any given starting day and time, the user set up a Boat object for a Travel instance between two geographic locations and was stopped only once the target was reached, or after a maximum number of travel days had passed. In our simulations, Pytheas stored several parameters every 15 minutes (in-simulation time), such as Boat location, bearing and local environmental variables. For the case study, we simulated navigation from Limfjorden (Denmark) to Southern Iberia along the North-Atlantic Façade. We split the whole voyage in several manageable voyages and showed which conditions are needed for optimal trips. Daily departures were simulated between 1993 and 2020. For each voyage, we then analyzed data and produced outputs such as the average time on the water per voyage, the fastest time to completion and the environmental conditions encountered. This allowed us to get a generic picture of what a voyage of this length would entail from the perspective of the sailors. Post hoc, we used wind and wave data to assess whether a trip is feasible despite in-simulation completion: for example, encountering very high wave could compromise a boat in ways that the underlying model is not able to address. Unsurprisingly, voyages were generally faster in summer than in winter; interestingly, however, simulations showed that navigation during winter could still be viable – provided the sailors would be able to survive the cold.

Most importantly, the simulation of these long voyages did not employ super-computing strategies or parallel computing of any sort. Pytheas ran on a laptop, with longest voyages taking a few seconds to simulate. In general, the software is fast to set up with different parameters and does not require to occupy a high-performance computer for weeks to obtain results. As such, it can also be set up quickly and can be used in several ways. As we showed, it can be used on its own, to calculate statistics about seasonal duration of trips or difference in duration for different technologies – if good polar diagrams of the boats used for these simulations are provided. It can also be coupled to other approaches (e.g. least cost methods, network analyses) to provide more detailed analyses for specific voyages. Finally, we have found its speed to be great for exploratory simulations of new routes and new polar diagrams.

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108. Modeling Ancient Maritime Voyages in Sewn Plank Canoes: Seasonality, Safety, and Seaworthyness

Mikael Fauvelle (Lund University)*; Alvaro Montenegro (Ohio State University)

The Channel Islands of southern California are home to the Chumash and Tongva people, who have been trading and voyaging between and along the islands and mainland coasts of southern California for thousands of years. After around 500 CE ancient Californians started using a new type of boat, the sewn plank canoe which was one of the most advanced boat types ever built in North America. In this paper we use agent-based ocean voyage modeling to examine the capacities of a range of indigenous boat types to travel important routes in the Channel Region at different times of the year. Our results indicate that while several different boat types would have been conducive for voyaging from the mainland coast to adjacent islands such as Limuw (Santa Cruz) and Pimu (Catalina), voyages to outlying islands, including Tuqan (San Miguel) and especially Haraasnga (San Nicolas), would have been difficult for much of the year in dugout or reed boats. We argue that early mariners plying these routes would have been under strong pressure to innovate faster and more seaworthy craft, possibly leading to the eventual development of the sewn plank canoe. We also contextualize our results with data from similar types of boats in other world regions.

267. The HUGASEA project: Simulating Waterways and Social Networks between Ancestral Villages in the Central Salish Sea, Pacific Northwest Coast

Alberto Garcia-Piquer (Autonomous University of Barcelona)*; Colin Grier (Washington State University)

Studying the past of past peoples that lived in maritime and aquatic environments without including watercraft would be like studying present societies without automobiles. However, how boats were integrated in the economics and everyday life of past seafaring peoples, particularly in the case of small-scale and/or hunter-gatherer societies, has yet to be fully explored. How and to what extent did the type of watercraft technology used by seafarers shape the relationship they had with their landscape and seascape? How did watercraft and seafaring support the settlement patterns archaeologically documented? How did watercraft support the kind of social interaction that we see in prehistoric or historical times? In summary, how was watercraft technology implemented not just as a technical innovation but in a social context? The HUGASEA project has addressed this issue by studying the interplay between watercraft, environment and social strategies on the rugged coastlines of the Americas, an exceptional region to find answers to these questions, with a multi-disciplinary approach. A combination of computational methods has been explored, including the analysis of ethnohistoric and archaeological data with GIS-based methods and the development of an Agent-based modelling (ABM) approach. In this paper, we present a study case from the Northwest Coast of North America. The Salish Sea is a flagship region of the Northwest Coast, and its archaeological record has supported multiple interpretations of the history of Salish peoples. Dugout canoes played a central role in almost all dimensions of Coast Salish peoples' social and economic life. Dugouts were the cornerstone of the exchange system between people and communities, which has been interpreted as a way of managing spatial and temporal variation and fluctuation in the availability of resources (Suttles 1960). However, as pointed out by Ames (2002), there remains a need for theorizing boats and maritime mobility to better characterize how watercraft technology shaped precontact and historic social dynamics along the Northwest Coast. How did advanced dugout technology support the spatially-extensive social interaction networks documented in the Salish Sea in the historic period? Did the recurrent use of specific seaways and maritime routes influence patterns of social connectivity across the region? Could histories have unfolded differently if other types of watercraft or settlement strategies were used? To explore these questions, we have developed an Agent-based model (ABM). The HUGASEA model is an ABM that simulates the movement of agents paddling a canoe across a simulated seascape. The objective of the model is to identify the most recurrent maritime routes between one or multiple source(s) and destination(s), evaluating the degree of connectivity between given locations in terms of navigation time and/or risk. In this paper, the design and mechanics of the ABM are presented. Results, scenarios and parameters drawn from ethnographic data, the archaeological record and hydrodynamic computations with 3d models of historical canoes are explored. We will try to defend the importance of developing specific tools to approach spatio-temporal problems, particularly seafaring and maritime routes, where dimensions of time, space and experience must be considered. Finally, the applicability of the model to other rugged seascapes and maritime societies are discussed.

314. An Agent-Based Model for Seafaring and Community Resilience in Oceania

Katherine Jarriel (Purdue University)*

Introduction

Residents of small Pacific islands face devastating effects from climate change, such as sea level rise, loss of biodiversity, and intensifying ocean storms. This project aims to combine Indigenous and local peoples' environmental knowledge (ILEK) from communities in Yap State (Federated States of Micronesia), the Marshall Islands, and Hawai'i with quantitative computer models of archaeological and paleoclimate data in order to understand how ancient seafaring knowledge can inform the revitalization of traditional, sustainable practices in the present. This research project emerges from a partnership with researchers at the Universities of Hawai'i at Hilo and Mānoa and community stakeholders, who include titled navigators and seafaring practitioners.

The research question is: how effective were archaeological and historical responses to environmental challenges, and how might they be used to enhance island communities' future resilience? Beginning from the well-documented sawei support network in Yap State (Tamagyongfal, et al. 2023), this project utilizes an agent-based model to understand which cultural, environmental, and decision-making parameters impact the success of inter-island voyages. Then, the model is applied to several case studies representing different time periods, with varying types of historical and archaeological evidence: modern-day and historical typhoon response, the initial period of Yapese colonization by European powers, and the earliest settlement of the islands approximately 2kya. Testing a variety of case studies and time periods will allow the analysis of different past conditions that may reflect the challenges faced by present-day community members. By focusing on traditional, sustainable seafaring in the past and present, this research project directly engages with a pressing issue that thousands of island communities across Oceania face: how to adapt to environmental hazards when global post-disaster relief systems fail. This paper presents the model's development and preliminary results from the case studies.

Methods

Given both the challenges of the archaeological and historical record of Oceanian islands and the ethical issues of testing human decision-making during natural disasters, an agent-based model (ABM) is an appropriate method for evaluating individual decision-making in the past and under hazardous conditions in order to explore how different parameters and variables impact the overall patterns of the system.

The model's design follows community-engaged research (CEnR) and ILEK practices. The research questions and model purpose are driven by community stakeholder interest. The development of the model occurred through iterative consultation with stakeholders, who included titled navigators from Yap, the Marshall Islands, and Hawai'i. As a result of those conversations and ethnographic fieldwork carried out by the projects' collaborators at UH Hilo and Mānoa, the project has been able to implement innovative, culturally informed variables into the model, such as averaging environmental inputs based on a lunar calendar, celestial navigation, and the use of animal species as navigational markers. This also allowed for a continual evaluation of the model's accuracy from the perspective of individuals who are deeply familiar with seafaring practices and the specific region in question.

The preliminary model includes an agent, representing a single outrigger canoe with a navigator and crew, that attempts a journey determined by user inputs. The agent making decisions according to environmental and cultural parameters, such as island visibility, celestial navigation, and the presence of bird species. The agent senses its environment, selects stochastically from a range of available headings, and then travels in one-hour intervals relative to wind speed and velocity, repeating the process until it reaches its destination or the voyage terminates.

Results
While the presentation will focus on the development of the ABM, initial results from four different case studies will be presented, ordered from most recent to oldest: 1) the Mawar typhoon of 2023, for which exists both detailed environmental evidence and interview data from community members; 2) the 1907 typhoon, which resulted in the colonially-driven relocation of several islands' populations; 3) the early colonial period, where European accounts document the sophisticated navigational knowledge of Indigenous Oceanians; and 4) the period of initial island settlement (approximately 2kya), where sea levels and atoll emergence may parallel projected climate futures. Each of these case studies represents varying environmental, archaeological, and historical data, as well as different circumstances of human decision-making. A chronological comparison of multiple case studies allows for the assessment of how individual decision-making affects system-wide travel patterns, as well as which model parameters and variables have the most influence on decision-making. Further comparison of the model with the archaeological and historical record allows for the clarification of further questions about navigational decision-making in the past.

Discussion
Overall, this project produces knowledge in two ways: one looking back and one looking forward. In looking back, this model allows us to understand ancient seafaring, supplementing the archaeological and historical record through a dynamic consideration of intercommunity interaction. Looking forward, it offers an interactive educational tool via the development of a website to complement recent efforts by Oceanian communities to revitalize traditional seafaring practices, bolstering sustainable travel and personal connections in the face of climate uncertainty.

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72. Hyperconnectivity, and Fact-Checking- Modeling Witnessing as a Traditional Coast Salish Mechanism

Adam Rorabaugh (Simon Fraser University)*

An unintended consequence of low cost maritime travel may be hyper connectedness, creating social situations where information can be readily passed before it is verified- an issue not limited to modern digitally connected societies. In traditional Coast Salish societies, the peoples of what is now Western Washington and Southwestern British Columbia, oral traditions were verified through a process called witnessing. Witnesses would be trained to recount and verify oral history and traditional teachings at high fidelity. Here, a simple model based on dual inheritance approaches to genes and culture, is used to compare this specific form of verifying socially important information compared to modern mass communication. The model suggests that witnessing is a high fidelity form of transmitting knowledge with a low error rate, more in line with modern apprenticeships than mass communication. Social mechanisms such as witnessing provide solutions to issues faced in contemporary discourse where the validity of information and even fact checking mechanisms may be biased or counterfactual. This effort also demonstrates the utility of using modeling approaches to highlight how specific, historically contingent institutions such as witnesses can be drawn upon to model potential solutions to contemporary issues solved in the past in traditional Coast Salish practice.

345. Just over the horizon. Towards practice-based digital models of ancient seafaring

Greer Jarrett (Lund University)*

Computational models in archaeology are increasingly diverse, but still struggle to record, analyse, and represent maritime environments and mobility. In this presentation I will give an account of my doctoral research on the reconstruction of Viking Age seafaring routes, and the role that digital models have played in this research. The project began with a series of experimental voyages onboard historical Norwegian boats throughout Scandinavia, with the goal of identifying the primary affordances of traditional navigation and route choice. This fieldwork served as a window on potential Viking Age maritime mobility patterns, and demonstrated that ancient seafaring in this region was accompanied by a culturally-specific worldview which was contingent, embodied, and dynamic. These are attributes which current digital models struggle to include. Instead, they lean towards abstract, impersonal, and pre-determined analyses (partly due to the predominance of modern western worldviews in their design), severely impeding our understanding of how ancient seafaring cultures might have understood and navigated their world. This does not mean that computational models cannot be used in our studies of ancient maritime mobility, but rather that we require alternative critical approaches which can account for the inherently contextual and uncertain nature of this form of travel. I will highlight several instances from my own research in which digital analyses have served to complement the experimental voyages, such as topographical reconstructions of Viking Age sea-levels and analyses of sailing performance. I will also explore areas in which digital models have fallen short of the cognitive and experiential aspects of seaborne travel, such as trans-scalar navigation, judgement-based route choices, and time-based geographies. Some suggestions as to how alternative, “navocentric” models could be constructed will be given as a conclusion to this presentation.

300. Using eco-cultural niche modeling to explore the co-evolution of climate and lithic technical traditions (Middle and Recent Gravettian, France, 32-26.5ka calBP)

Anaïs Vignoles (University of Liège)*; William Banks (CNRS/UMR 5199 PACEA); Laurent Klaric (CNRS/UMR 8068 TempS)

Introduction.
A frequent hypothesis in archaeology links material culture variability with the environmental context of humans producing it. In this presentation, we want to reflect on the cultural and environmental factors that may have influenced the appearance, generalization and disappearance of the Rayssian technical tradition during the Middle Gravettian (ca. 31-28.5 ka cal.BP; Klaric et al. 2021). The latter is characterized by an original method to production for small marginally retouched bladelets, presumed to be armature implements for hunting weapons, called the Raysse method. It is conceptually different from those used before (Noaillian) and after (Recent Gravettian), which aimed at producing more traditional Gravette and microgravette points. The initialization and termination of this tradition are chronologically associated with periods of high climatic instability, such as Heinrich event 3 for its appearance or the GI4 climate amelioration for its disappearance. However, these chronological correlations do not necessarily mean that the people using these traditions occupied significantly different environments. In this presentation, we evaluate the extent to which the technological trajectory of the Rayssian is influenced by the occupation of different environmental conditions, using the approach of eco-cultural niche modeling (ECNM).

Approach.
ECNM is an approach derived from distributional ecology, that allows one to model the relationship between environmental variables and occurrences in both environmental and geographic space. Applied to cultural data, one can identify the set of environments in which a population using a specific cultural trait (or several) lived at the scale of its chronogeographic distribution, commonly called the eco-cultural niche. Eco-cultural niches can be approached through a variety of algorithms, and once modeled, they can be compared in environmental and geographic dimensions.

Data and set-up.
In this study, we use Noaillian, Rayssian and Recent Gravettian sites as occurrences for the three different technical traditions, derived from a critical inventory. We then chose climate variables simulated from the HadCM3 model (Arsmtrong et al. 2019) to represent the climatic environment: coldest month temperature, warmest month temperature and mean annual precipitation. We explore a chronocultural scenario based on Banks et al. 2024, where we compare the Noaillian around 31 ka to the Rayssian around 30 ka, and then the Rayssian around 30 ka is compared to the Recent Gravettian around 28.5 ka. We also compare the Rayssian and Noaillian north of the Garonne River valley to the Noaillian in the Pyrénées at 31 and 30 ka, since the Noaillian in the Pyrénées lasts longer than the more northern Noaillian.

Niches modeling and comparison.
We model the eco-cultural niches associated to these different archaeological units using a simple ellipsoid model in a tridimentionnal climatic space. The volumes are then compared, and the significance of this comparison is statistically evaluated. We also project the niches onto geographic space, to compare and evaluate the geographic dynamics of the niche trajectories

Results and discussion.
Our results indicate that technological and distributional changes are not associated with significant ecological differences during the Middle Gravettian, whereas the transition from the Rayssian to the Recent Gravettian is associated with a significant niche shift and expansion in both environmental and geographic dimensions. Building on the results of these comparisons, we propose an interpretive scenario in which climate did not play a significant role in the appearance and generalization of the Rayssian, but may have accentuated an environmental barrier between the Pyrénées and the Northern part of the Garonne River valley, which eventually led to the limited geographic distribution of the Rayssian. In contrast, we propose that the GI4 climate amelioration and associated vegetation and biological changes, may have destabilized the social organization on which the transmission of the Rayssian was based, leading to its decline towards less standardized methods to produce armature implements of the Recent Gravettian.

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504. Spatial modelling of paleoenvironments associated with landscape formation and early human occupation at Jojosi, KwaZulu-Natal

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The Middle Stone Age of southern Africa is well known for many intensively studied archaeological sites that provide insights into ancient human lifeways and environments. What most of them have in common is that they are located in caves and rock shelters where favourable taphonomic conditions prevail. However, this leaves a gap in the archaeological record: early human hunter-gatherers are characterised by extensive mobility, but the density of open-air sites in this region is clearly underrepresented. The Jojosi Dongas, a badland landscape in north-eastern South Africa (KwaZulu-Natal), is an exceptional environmental archive where gully erosion and deposition have accumulated traces of landscape activity over more than 500,000 years (Will et al. 2024). Well-preserved knapping floors have been found in these sediments, allowing the reconstruction of prehistoric stone tool manufacture dating back as far as MIS 6 (Riedesel et al., preprint). This raises a number of questions: What were the environmental conditions like for the ancient inhabitants of Jojosi? What is the impact of environmental change on the availability of resources and thus on the attractiveness of this high-altitude region? How can we reconstruct environmental conditions when proxies such as pollen and phytoliths are missing due to difficult taphonomic conditions in an open-air environment? We present an approach in which we reconstruct vegetation dynamics using computational models and evaluate their influence on site formation and human settlement.

Our approach involves examining the Pleistocene sediments from a sedimentological and geomorphological perspective to identify phases of landscape activity in the cut-and-fill deposits and to place them in a chronological context using luminescence dating. In addition, we simulate the dynamics of the spatial displacement of the locally dominant biomes, savanna and grassland, using paleoclimate models. This also provides information about the availability of plant resources over long periods of time, and in particular during the period of human settlement.

Our results show that climate variation, modulated by the shift in the biome, has an impact on the geomorphic activity of the landscape. The results also show that the archaeological finds coincide with stabilising phases in landscape development, but that the early inhabitants could inhabit different climates and biomes.

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289. Modelling the landscape of the Acheulean activity on Lesvos Island, Greece through an affordance-based GIS approach)

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Introduction

Activity of Middle Pleistocene hominin groups has been recently evidenced on Lesvos Island, NE Aegean (Galanidou et al., 2016). Stone tools attributed to the Acheulean technoculture have been excavated from fluvio-lacustrine deposits at Rodafnidia open-air site by the Kalloni Gulf and collected through extensive surface surveys over the southern and western part of the island. Absolute dates (OSL) for the stone tool bearing geological units place hominin presence at least between 300 and 200 Kya. Activity took place over topographically complex settings, predominated by the volcanic landscape and its resources (hot springs and volcanic rocks) and abundant water resources (paleorivers, palaeolakes). Hominin signal gets stronger during the glacial periods, when dramatic changes in palaeogeography occurred, involving sea-level drop and exposure of extensive terrain in areas previously dominated by marine environments, forming land bridges for movement and expanding the productive zones for exploitation between the land and the sea (Sakellariou and Galanidou 2017). Ecological properties of the palaeolandscape must have acted as attractors, shaping hominin preferences regarding occupation and dispersal. Here we use the study of edaphics (modern soil properties) as a proxy method to reconstruct landscape suitability, identifying areas that would have been preferentially targeted or avoided by hominins.

Methods and materials

Here we follow an affordance-based GIS approach (Gillings 2012) to reconstruct landscape suitability based on the spatial distribution of certain mineral nutrients that are vital for sustaining plant, animal and human populations over a certain physical landscape. These nutrients are incorporated in soils through the bedrock (parent material), allowing correlations between soils and underlying geology regarding chemical composition, which is likely to be consistent through time in cases where the bedrock remains largely unchanged. Soil properties are treated here as affordance variables, elements of the natural world which in interaction with the hominin factor could shape stronger or weaker chances for survival and exploitation. These possibilities can be predicted through suitability modelling. By tracing these elements and their distribution over modern landscapes, we can identify specific locations, likely to host attractive environments in the past, based on soil properties. Chemically rich soils of high edaphic potential would indicate more suitable areas for hominins in the past, suggesting higher ecological value and better opportunities for survival, exploitation and dispersal, while edaphically poor soils would coincide with less suitable areas in the past, with limited subsistence opportunities and barriers to movement. Soil analyses results have been processed within a GIS environment to represent a layer of suitability through an index (from more to less suitable), extracted from soil properties (from rich to poor). Suitability based on edaphics is combined with physical topography and major geological and pedological features identified through topographic, optical and multispectral satellite imagery.

Results

In the produced model, through the index of suitability we can observe variability over the study area. Discrete sections/zones can be identified, each with distinctive geoedaphic properties thus suitability values. Resourceful corridors, highly suitable for dispersal and settlement, can be discerned from ‘no-go’ areas representing natural barriers based on their geochemical composition, and thus reflecting low suitability for hominin presence and activity. The incorporation of the study of edaphics in predictive modelling, as an affordance variable, offers a deeper look into transitional/marginal environments, including wetlands and submerged landscapes. It allows to unify the terrestrial and underwater records making the consideration of the palaeolandscape and its nature more complete. Suitability can be traced spatially as a patchwork rather than a continuous condition, which is consistent with the mosaic nature of the landscape and its affordances during the Middle Pleistocene.

Discussion

New scenarios for hominin subsistence, settlement and dispersal potential on – and through – Lesvos and the NE Aegean are now proposed in a holistic consideration of the palaeolandscape, including the now submerged parts, which used to form a single terrestrial entity in the past palaeogeography. This adds a new strand in the discussion about the early Eurasian settlement, highlighting the trans-Aegean potential. The Lesvos case-study is a starting point for extending the approach not only to the submerged landscapes of the Aegean, but to other likely hot-spots, with similar characteristics in the eastern Mediterranean.

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196. From Small-Scale Models to Large-Scale Insights: Hunter-Gatherer Responses to Environmental Variability

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The interaction between hunter-gatherers and their environment—specifically, how their behavior changes based on resource availability—has been extensively studied. Ethnographic research suggests that hunter-gatherers employ a variety of strategies to adapt to different or similar conditions. Their mobility pattern, whether foraging (logistical) or relocating the entire group (residential), depends on the density and distribution of resources, and group size or traditions. Additionally, they may switch to or develop new subsistence strategies as needed. In recent decades, an increasing number of models have been created to examine these aspects of hominin behavior on a local scale, contextualizing them within varying environmental conditions. Agent-based models are frequently used in these studies because they can incorporate a wide range of processes related not only to interactions with different environments but also to intra-group dynamics. These models often depict foragers exploiting both stationary resources, such as plants or small animals, and mobile resources, like larger animals. However, these models face challenges in determining whether agents would survive under specific conditions. The commonly used frameworks for building agent-based models—such as central-place foraging or optimal-foraging models—do not inherently provide results that allow for reliable assumptions about potential survival rates. Moreover, there is an ongoing debate regarding the appropriate indicators for identifying unsuitable conditions for hominin occupation in general.
To investigate how hominin foragers might respond to varying environmental conditions, we developed and published an agent-based model (Reschke et al., 2024). This model simulates a group of foragers exploiting a detailed environment filled with both stationary and mobile resources over the course of one year. The foragers employ central place foraging strategies and various subsistence methods. As environmental conditions change, the group follows specific movement patterns throughout the year. Generally, they exhibit a higher mobility and consequently larger home-range size when resource availability is low. While the model does not provide direct predictions about the long-term survival of a hominin group, it illustrates how lower resource availability leads to larger home ranges and consequently lower population densities when applied to the wider region. Therefore, when our results suggest that population density in a region would drops below a critical threshold, we could assume that the scenario becomes unviable for long-term habitation as groups will struggle to maintain essential social networks, leading to population collapse in the broader area (Mandryk, 1993).
The primary aim of this study is to explore differences in foraging success, resulting mobility patterns, and indirectly assess long-term survival prospects within the reconstructed environment of the early Pleistocene Guadix-Baza Basin (Granada Province, Spain), during both glacial and interglacial periods (Altolaguirre et al., 2021). We use the extensive environmental reconstruction data from the area to perform a case study and test our methodology. We will examine three distinct subsistence scenarios that vary in terms of how foragers acquire resources. Given the limited evidence for hunting during the early Pleistocene, our scenarios will involve either catching smaller animals or scavenging. Additionally, we will assess the overall impact of meat consumption on the group by including a scenario where foragers solely gather and consume plant resources.
We expect to see differences in the mobility patterns of foraging groups across our scenarios. When comparing glacial and interglacial conditions, changes in vegetation units will influence

how these groups occupy space, as they must follow the vegetation that offers the highest resources depending on the season. In our three subsistence scenarios, access to meat will enable the group to improve their foraging success and compensate for the lack of plant resources during winter. While we anticipate a difference in population density between glacial and interglacial periods, we believe that the model results will indicate that even under glacial conditions, the population density will not decline to a level that suggests a long-term disappearance of the wider population.

Our current study aims to provide new insights into whether during the early Pleistocene the Baza-Basin offered sufficient resources for hominin foragers to sustain themselves. These findings will allow us to test the assumption that Mediterranean Europe did not present a significant challenge for early hominins in terms of resource acquisition throughout the year, both during interglacial and glacial periods. This approach will further be used within the framework of the Lateurope ERC project, to study the effect of the environmental variability upon populations inhabiting central and northern Western Europe. This will also involve evaluating how the role of meat may change depending on latitude or other factors. In Summary, this generalist model will not only be useful to understand hominin-environment interactions at the local level, but its outcomes could also be used to make inferences about population density and inter-group interactions.

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52. Advancing simulation modelling of forager hunting and resource management strategies in savanna biomes through indigenous ecological knowledge

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Introduction

The resource strategies and engagement of foragers in plant and animal management are among the most compelling topics in current archaeological research. Hunting and gathering practices are essential to understanding the subsistence strategies, ecological resilience, and social organization of foraging societies. Recent studies suggest that foragers, both historically and currently, employ optimizing behaviours and engage in niche-construction activities, such as controlled fire practices, to enhance resource predictability. These findings challenge traditional views of hunter-gatherers as passive, immediate-return foragers and instead portray them as active managers of their environments (Lightfoot et al., 2013).

Despite this growing perspective, the specifics of traditional hunting practices remain elusive due to their limited representation in the archaeological record. On one hand movement and behaviour strategies in the context of hunting with traditional means (i.e. hunting on foot, with a bow and arrow as opposed to firearms, and without the orientation instruments available today) have been insufficiently investigated to date. Furthermore, the role of fire management in promoting plant growth, attracting game, and ultimately increasing hunting success has yet to be incorporated into computational models of hunter-gatherer behaviour. This paper presents a collaborative project that brings together archaeologists and indigenous hunting experts to examine traditional hunting strategies and develop theoretical and computational models for understanding hunter-gatherer mobility and behaviour. By employing an agent-based model, we aim to reconstruct hunting bouts, offering insights into how environment, hunter, and prey interactions contribute to hunting success, and ultimately human survival in arid ecosystems.

Methods and materials

This study employs a mixed-methods approach that combines geospatial technologies, quantitative analysis, and qualitative data to explore traditional hunting practices. Over five field seasons (2019–2023), we collected georeferenced data during simulated traditional hunting bouts performed by Ju/'hoansi and Hai//kom San animal tracking experts in Namibia. These data, which include movement trajectories, heart rate, caloric expenditure, wind speed and direction, were collected in two different study areas that significantly differ in the amount, types and distribution of vegetation. The simulated hunting bouts used close-up (up to a distance of 50 m.) photographs as a proxy of successful shooting with a bow and arrow, and focused on Artiodactyla species present in the region, mainly antelopes. Additionally, we conducted formal and informal interviews to gather insights into traditional ecological practices associated with hunting.

To date, our analysis of the datasets collected during fieldwork has offered important insights into traditional hunting practices. Firstly, an analysis of the movement trajectories recorded during hunting via the methodology proposed by Reynolds et al. 2018 challenged previous research, which concluded that the movements of indigenous hunters are similar to Lévy walks (Raichlen et al. 2014). Observations during fieldwork also indicated hunters use more sophisticated foraging strategies than those usually associated with Lévy walks. Secondly, both qualitative and quantitative data analysis (logistic regression and multivariate logistic regression) highlighted the importance of woody vegetation distribution for hunting success, especially for determining successful close-range shooting with a bow and arrow. Thirdly, controlled fire practices performed nowadays by the San community in our second study area, the Nyae Nyae Conservancy, were researched via interviews and the analysis of MODIS Active fire and burned area products, contributing to a better understanding of the effects of fire management in savanna biomes. These insights were used to inform the development of an agent-based simulation model aimed at exploring the coupling of hunting and resource management in arid ecosystems

The agent-based model, implemented in NetLogo, portrays hunters and prey as agents with competing objectives within a dynamic environment. The model simulates complex interactions where hunters employ a sequence of actions, including searching, tracking, stealth approaches, pursuing, and shooting. The model grid, representing a hunting ground, includes units with varying environmental conditions such as vegetation, which reflect seasonal changes and fire management practices, and tracks, which hunters perceive and interpret to guide their movement. Both hunters and prey are initialized with individual traits, like height and speed, to capture realistic behaviour during the simulated bouts.

The simulation progresses in second-long intervals, capturing the timing sensitivity of hunting. It incorporates mechanisms such as detection-based reactions, three-dimensional line-of-sight perception, memory keeping of past sightings, planned waypoints, and agent communication. Movement is influenced by both internal factors, such as exhaustion and planned waypoints, and external factors like obstacles and attractiveness to prey (i.e. probability of prey not moving during a second). Environmental changes are modelled by track generation and impact on vegetation, as agents navigate and modify their surroundings. This context-dependent model produces quantitative outputs on movement trajectories, sighting frequencies, and hunting outcomes, providing insights into traditional hunting strategies

Results
The agent-based model highlighted that hunting trajectories are shaped more by deliberate, planned movements than by random searching, underscoring the importance of planned waypoints and responses to animal tracks. Sensitivity analysis of the model indicated that while most parameters produced weak linear effects, certain factors, such as those influencing line-of-sight, resulted in non-linear impacts on movement and hunting outcomes. Structural elements, like the spatial distribution of attractiveness to prey points and hunter planned waypoints, further influenced movement patterns.

In exploring fire management scenarios, simulations demonstrated that controlled burns could enhance hunting success. The results suggest that, with effective landscape knowledge and planning, fire management can improve the carrying capacity for foragers by creating a more predictable and navigable environment. This aligns with insights from game tracking experts, illustrating the benefits of incorporating controlled burns into foraging strategies to support foraging groups

Conclusions/Discussion
Ultimately, we conclude that Traditional Ecological Knowledge has the potential to contribute a better understanding of past socio-ecological processes and encourage new directions in modelling past human ecosystems

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218. Modelling Nomadic Spatial Behaviour in Times of Economic Intensification: The Case of Iron Age IIA Negev Highlands, southern Levant

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Modelling Nomadic Spatial Behaviour in Times of Economic Intensification: The Case of Iron Age IIA Negev Highlands, southern Levant The question of how human societies find ways to live and thrive in marginal ecological environments is fundamental to the research of arid regions. Commonly, subsistence practices in these environments (e.g., pastoralism, trade, agriculture) are tied to a certain form of mobility, whereas a shift in subsistence practices can lead to a change in how people utilize the environment and move within it. Yet, while archaeology is well equipped to identify and study mobile societies, the delineation of spatial trajectories and change is often hindered by the lack of direct knowledge regarding the duration of occupation of individual sites. To overcome this problem, I suggest using an agent-based model which enables the computational simulation of a human ecosystem, allowing us to test our assumptions regarding the formation of certain spatial patterns. The Iron Age (henceforth IA) IIA in the early first millennium BCE is a formative period in the history of the southern levant. For the first time in the history of this region, state formation processes resulted in the rise of territorial states, including Israel, Judah, and Edom. During this period, a unique archaeological phenomenon is witnessed in the Negev Highlands, a steppe region just south of the settled zone of Cis-Jordan – the appearance of hundreds of stone-built structures with material culture and architectural features connected both to the autochthonous desert culture and Mediterranean Levantine IA culture. Parallel to the prosperity of the Negev Highlands, this was also one of the most intensive periods of copper production in the nearby Arabah valley. These copper production sites yielded material cultural remains that resemble those from the sites in the Negev Highlands. Over the years, two different interpretations have been proposed to understand the IA IIA Negev Highland phenomenon. The first approach posits an external, state-driven force originating from the Kingdom of Judah, whereby the main sites are understood as part of a royal initiative to consolidate control over the kingdom's southern periphery and secure control over trade routes traversing the region. Around those main sites, interactions between the local nomads and Judahites resulted in a mixed material cultural record. In contrast, the second approach attributes the impetus to the autochthonous desert inhabitants, who leveraged the need for copper in the Eastern Mediterranean. According to this approach, the prosperity of the Negev Highlands is
the result of additional economic resources that prompted a partial sedentarization of the nomads. While the trade in copper clearly forms part of the subsistence economy, the balance between it and other practices, such as agriculture and pastoralism, remains under debate. Although the two approaches rely heavily on environmental and spatial reasoning, a systematic spatial analysis has yet to be conducted. This study aims to investigate the ways in which nomadic spatial behavior changed in response to diversification in subsistence economy. First, I created a geodatabase comprising the locations of sites and various environmental resources important to the debated subsistence practices. Then, I analyzed spatial correlations between the sites' spatial patterns and the distribution of various environmental parameters to determine which resources were prioritized by the inhabitants of the Negev Highlands during the IA IIA. Building on the insights from the spatial analysis, I built an agent-based model of the system's spatio-temporal development. This model simulates the annual development of the system, providing the ability to 'see' the reaction of nomadic households to different environmental scenarios. These scenarios can be either human induced, such as overgrazing, or nature induced,

such as drought. By doing so, the model allows for construction and permanent occupancy of sites, but also the possibility of seasonal usage and abandonment. To allow for a diverse set of simulation results, the model is stochastic and focuses on patterns rather than exact locations. The plausibility of the model is then evaluated by comparing the spatial patterns of the computed results with the archaeological record.

The major trend discerned in the spatial analysis phase of the research was unexpected. The majority of sites are concentrated at a specific area in the southern part of the Negev Highlands (fig. 1). Moving southeast in the Negev Highlands correlates with decreasing environmental stability, making it unlikely that households could repeatedly return to (or stay at) the same site without risking environmental degradation or experiencing seasons with insufficient rainfall in the surrounding area. This challenge traditional scholarly assumptions that stone-built sites are permanent and reflect sedentary practices. However, allowing for the possibility that stone-built structures were used only for a few seasons, these patterns become more understandable. The observed patterns offer insights into the adaptive strategies employed by nomadic societies in response to shifting ecological and economical conditions, highlighting their resilience mechanisms in arid regions. When integrated into the model, these patterns reflect a sustainable human ecosystem, that was adapted to the local conditions. This case study demonstrates the power of simulation in addressing questions related to non-sedentary societies in arid environments, which may shift their spatial behavior and subsistence strategies over timeframes too short to be discerned by traditional archaeological methods.

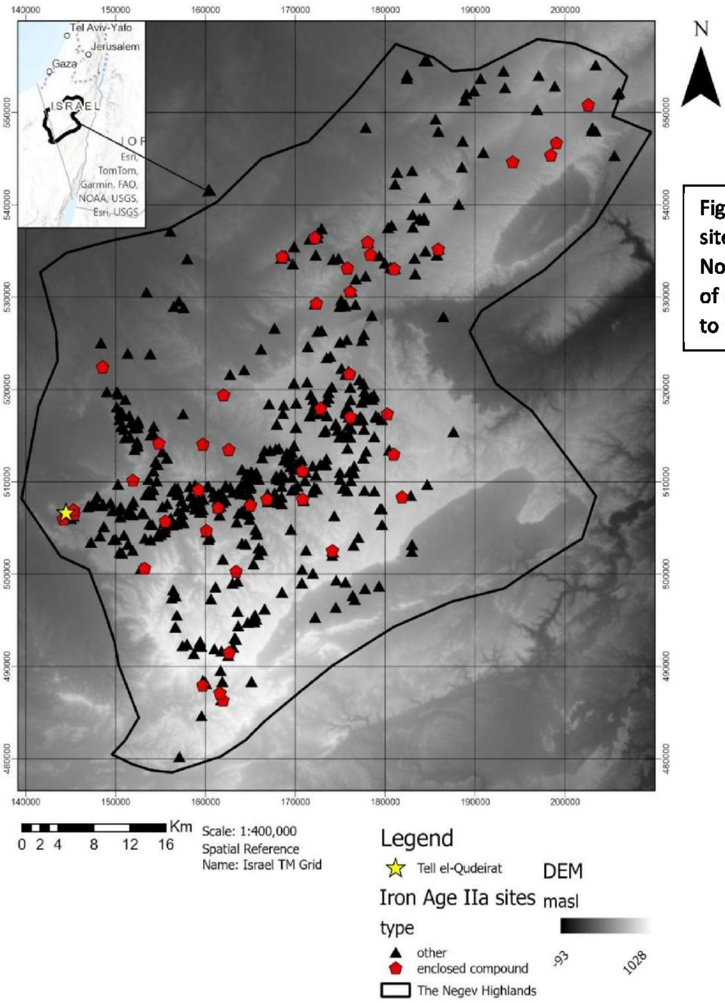

Fig. 1: Map of the Iron Age IIa sites in the Negev Highlands. Note the high concentration of sites from Tell el-Qudeirat to northeast

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252. Assessing circumscription in the castro landscapes: a cost-based site catchment analysis of Iron Age hillforts in north-western Iberia.

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The study of the processes that trigger the emergence of social complexity has been a major concern of archaeologists since the introduction of social theory into the discipline. Among the many hypotheses that have attempted to address this issue, circumscription theory clearly stands out as one of the most robust and influential. First proposed by Robert Carneiro in the 1970s, this theory suggests that demographic pressure combined with environmental constraints —whether geographical barriers or resources concentration— led to a process of increasing social complexity through conflict and warfare (Carneiro 1970). It is curious that circumscription theory, so often cited as a classic explanation of the origins of hierarchical and state societies, has rarely been seriously tested in archaeology.

The societies that inhabited the Iberian northwest during the Iron Age provide an excellent case study for assessing the impact of circumscription. Hillforts, known in the region as castros, were the only form of occupation on the landscape for more than seven hundred years, from the 9th century BC until the Roman domination. The absence of any other type of site, such as open farms or necropolises, means that everything we know about the Iron Age in this region comes directly from the castros. In this sense, the study of these settlements offers an extraordinary opportunity —rarely seen in archaeology— to understand the main processes that shaped the whole period through the analysis of just one archaeological feature.

Although several interpretative models have been proposed for the forms of organisation in castro societies, these can be reduced, without loss of generality, to two clearly differentiated groups. On the one hand, those who argue that there was a tendency towards social inequality as the Iron Age progressed, with a turning point in the 4th century BC (González-García 2009). On the other hand, those who propose an egalitarian interpretation, based on Durkheim's idea of segmentary societies, valid for the entire Iron Age until it was finally broken by the Roman influence (Currás and Sastre 2020). For both groups, testing circumscription theory is paramount to validate their hypothesis. In fact, the discovery that circumscription had an impact on the configuration of castro societies would be a sufficient condition for accepting the hierarchical model, just as its absence is a necessary condition for defending a non-hierarchical model.

The aim of this paper is precisely to provide a methodological and theoretical framework for modelling circumscription theory in past landscapes. Although the model has been applied to Iron Age Galicia as a case study, it is not limited by the peculiarities of this region and chronology. On the contrary, it has been designed to be as replicable as possible, allowing other researchers with similar interests to test circumscription theory in their own case studies.

More than 2500 sites have been included in this study, being the first of its kind to go beyond the regional level and carry out an extensive analysis of all the castros in Galicia. Testing the circumscription theory in these sites is equivalent to analysing the balance between population and resources in each of them. The first of these two variables, population, was estimated directly from the size of the habitable space within the enclosed areas, which were measured using remote sensing with LiDAR imagery and historical aerial photography. For the resources, I programmed a QGIS plugin in Python that creates a map of agricultural potential based on the DEM. This tool follows the FAO criteria to classify and combine the elevation, slope and soil erosion maps. It also uses machine learning to identify landscape features that have no agricultural potential at all, such as rocky soils, beaches or water bodies, as well as artificial features that should be corrected, such as urban areas, quarries and open-cast mines.

Two different types of site catchment analysis (SCA) were applied to test the balance between population and resources. In the first one, a maximum travel time was considered, and each castro was assigned a catchment area corresponding to the accessibility surface within this time. In addition, catchments were truncated by Thiessen polygons to ensure their mutual separation. In the second approach, however, instead of taking a maximum accessibility as a reference and then assessing the resources available within that catchment, the areas were extended as much as necessary to meet the needs of each castro. In this case, the territories were no longer separated by Euclidean distance, but by cost-based boundaries, for which a GRASS addon was programmed in Python. This second method proved to be more effective than the first, as it significantly improved the results, thus demonstrating the importance of considering cost-based boundaries over the traditional use of Thiessen polygons in SCA.

After applying both SCAs, two regions were selected where all the castros had a positive balance, and an agent-based model was developed to determine how far these regions were from reaching the carrying capacity of the land. In this ABM, the agents (castros) grow in population and replicate by a fission process in which new simulated castros emerge following a probabilistic surface created by site predictive modelling.

The results of both SCAs show that the vast majority of castros had sufficient resources in their immediate environment to sustain their estimated populations above subsistence levels. Moreover, the ABM applied in the two regions analysed shows that there was enough space for more than twice the number of sites before conflict over resources eventually occurred. Therefore, circumscription can no longer be maintained as an explanation for the supposed social inequality of castro societies; an alternative hypothesis is needed if the defenders of a hierarchical model want to keep their assumptions. Similarly, the refutation of circumscription theory alone is not sufficient to prove the segmentary model, but it certainly supports the idea that egalitarianism can be a valid analytical category for studying the castro landscapes. This opens the door to alternative views of Iron Age societies, contrary to a teleological perspective of social complexity and hierarchisation as an inevitable process throughout Late Prehistory.

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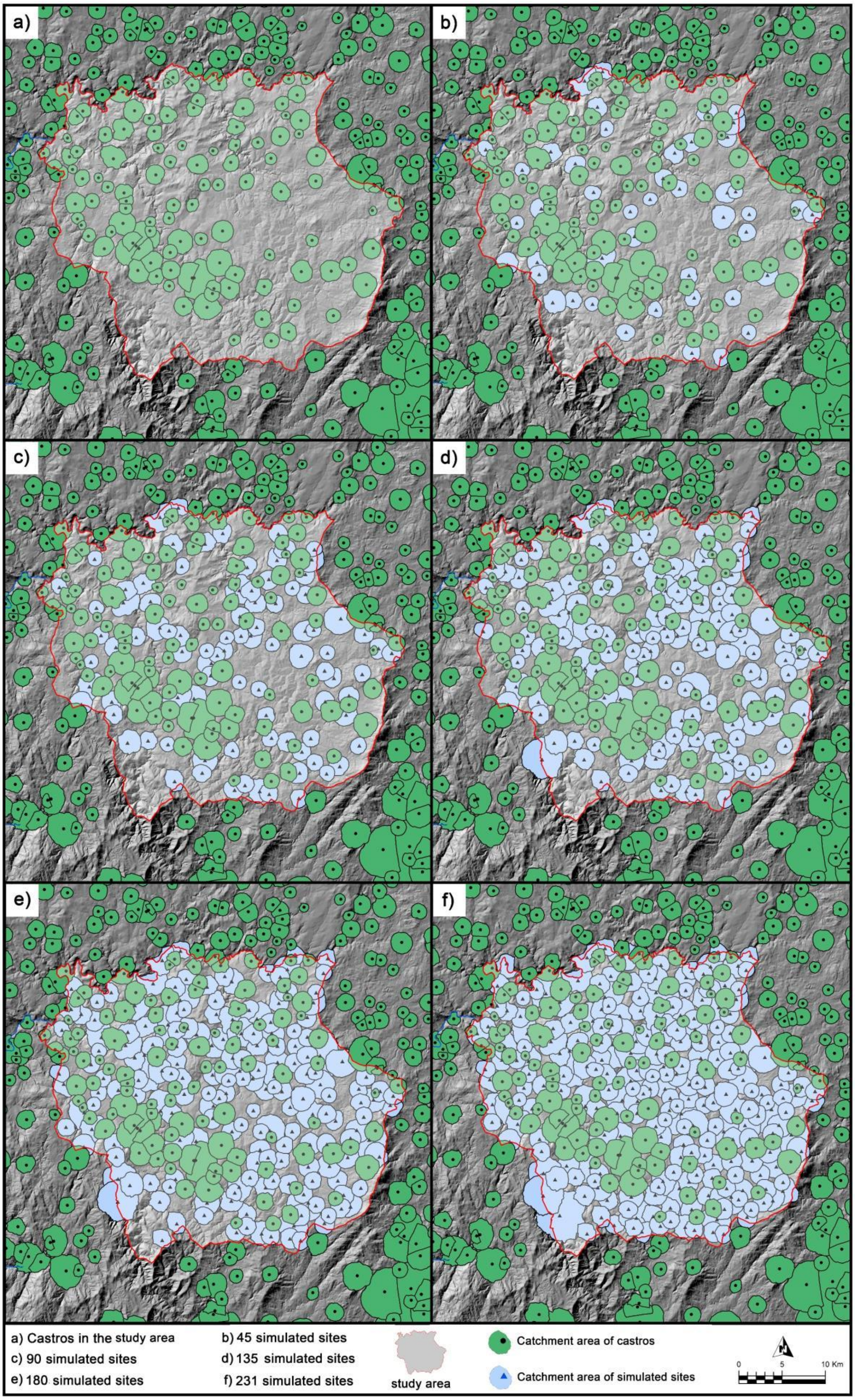
a)
b)
c)
d)
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f)
a) Castros in the study area
b) 45 simulated sites
c) 90 simulated sites
d) 135 simulated sites
e) 180 simulated sites
f) 231 simulated sites
study area
Catchment area of castros
Catchment area of simulated sites
0
5
10 Km

362. Climate variability and Germanic settlement dynamics in the Middle Danube region during the Roman Period

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Climatic variability has impacted past societies and represented a significant driver of the change. The aim is to investigate the effect of agroclimatic conditions and spatiotemporal changes in the Iron Age Germanic settlements (residential areas) in the Middle Danube region (the region of Moravia in the Czech Republic, Lower Austria and the Záhorie region in Slovakia) during the first four centuries CE (i.e. the Roman Period). Based on data from 773 residential areas with archaeologically determined temporal identification (represented through aoristic probability distribution), combined with high-resolution agroclimatic reconstructions resulting from robust isotopic analysis of tree rings (yearly resolution) demonstrate a coherent dependency of Germanic settlement structures to climatic conditions. The methods of sensitivity analysis and simulation modelling of archaeological data are employed to identify thresholds in the magnitude of change and susceptibility to the short- or long-term trends in agroclimatic conditions (quality and its change). An almost exponential increase in settlement structure during the first half of the 2nd century CE coincided with improved agroclimatic conditions, whereas settlement structure consecutive decline during the Late Roman Period temporarily overlapped with agroclimatic deteriorations. Peak cessations of residential areas in the late 2nd century CE appeared independent of regional agroclimatic conditions, being instead impacted by the extensive conflict of the Marcomannic Wars. We argue that separating periods of agroclimatic importance (key time blocks) and insignificance regarding the evidenced substantial changes in settlement structure (growth, decline or spatial shifts) is vital towards identifying possible causal environmental drivers of settlement dynamics and societal change in the Middle Danube region.

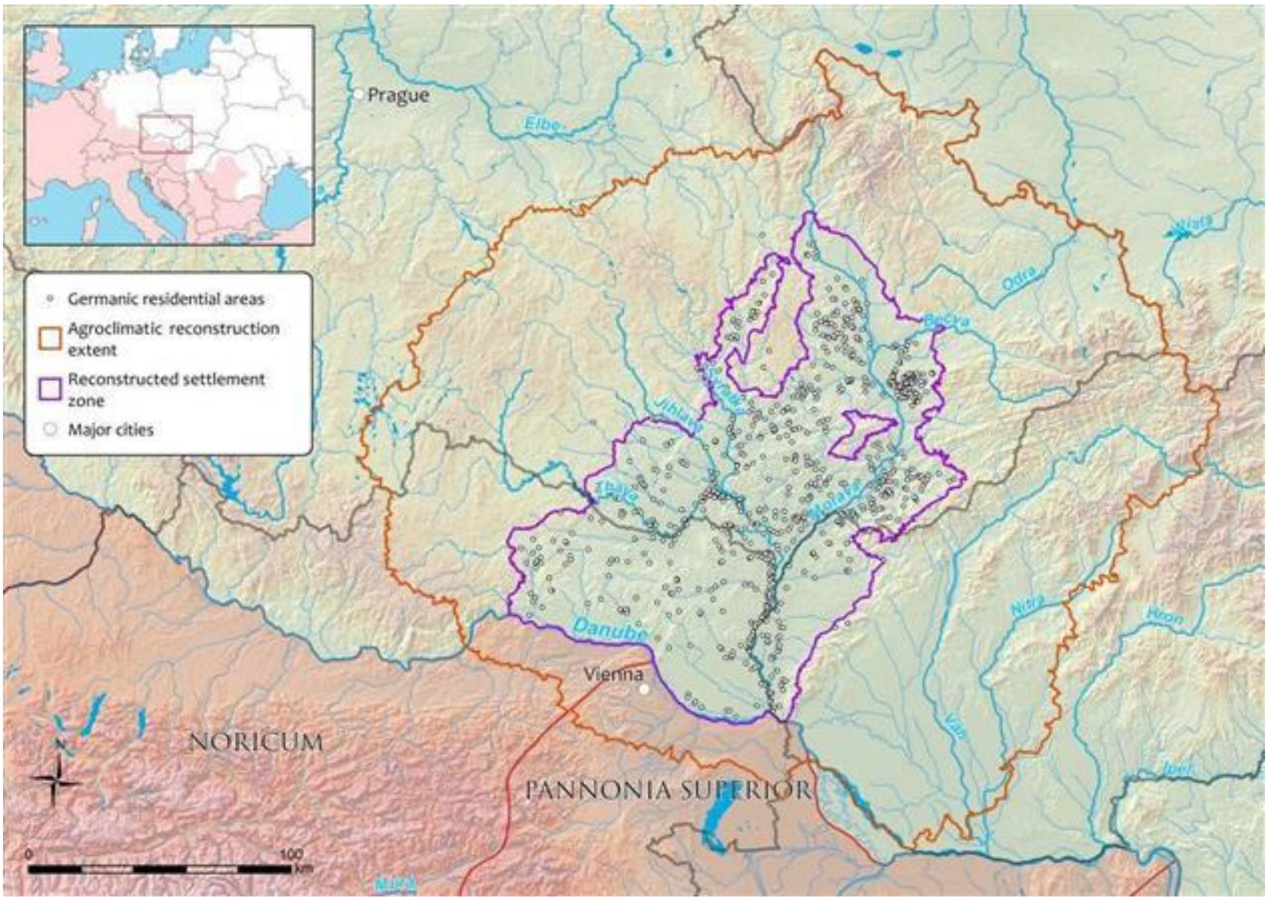

Figure 1. Delimitation of the study region of the 'Marcomannic' settlement zone (violet line) with point representation of identified Germanic residential areas (white dots) bordering Roman provinces (pink area and red line) together with the area covered by agroclimatic reconstructions (brown line).

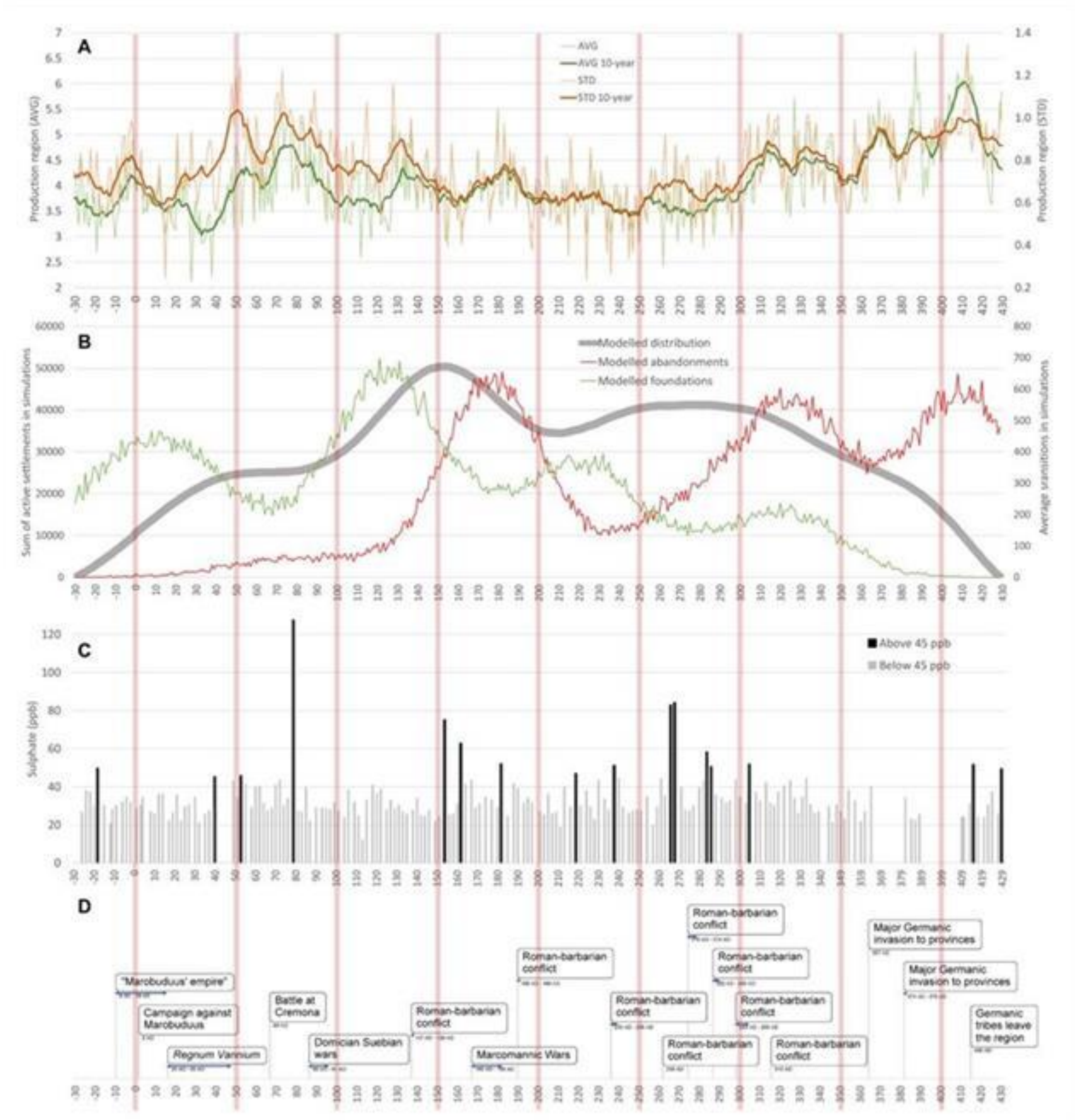

Figure 2. Environmental drivers and historical events from the Roman Period: A) Annual AVG and STD values of the Production regions recorded in the residential areas (regular curves) smoothed by a 10-year filter (bold curves). B) The simulation of the Germanic residential areas with the probabilistic development represented through the sum of active residential areas in all simulation runs (grey) and an average number of simulated foundations (green) and abandonments (red). C) Reconstructed volcanic activity from Greenland ice cores (GISP-2), with events depositing > 45 ppb of sulphate highlighted in black. D) Selected historical events reported in the narrative sources for the Middle Danube region.

206. Understanding past political landscapes: human-environment interactions and resource management practices among the Muisca

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This paper will present a series of computational models used to understand the human-environment interactions and resource management practices among the past Muisca ethnic group that inhabited the Altiplano Cundiboyacense (Colombia). The Muisca was an Indigenous culture that formed the Muisca Confederation that expanded along a large region (around 25,000 km2) of the Colombian Andes. The confederation was divided into two main subgroups, the Hoa and Psihipqua, each ruled by a cacique called Zaque and Zipa, respectively. The Muisca had a hierarchical political system which extended to the territorial organization. For example, the early chroniclers described that there were areas dedicated to the growing of crops to feed the larger population centres. One of these areas was the Valley of Tena, which was supposed to be the agricultural land of the population centre of Bacatá, located at the Sabana de Bogota, the main population centre in the Zipa territory. However, the role of the settlements of the Valley of Tena as temporary and only devoted to the growing of crops to maintain the larger population centre of Bacatá, in a system defined as microverticality, has been recently challenged (Argüello García, 2015). Argüello's research opens the door to reflect if the political and environmental patterns the Spanish chroniclers recorded during the early years of colonization were accurate for this region, something that has already been disputed for other regions of South America and the Caribbean (see, e.g., Herrera Malatesta, 2022). This paper will present new research on the human-environment interactions and resource management practices of the Muisca in the Valley of Tena through over 2000 years of history. To model and better understand this relationship, a new set of analyses applying point process modelling, Bayesian statistics, and network science will be applied for the first time. These methods allowed a detailed and deep exploration and analysis of the statistical and quantitative relations between settlement patterns and environmental features over time. The data for the analysis consists of a distribution of archaeological sites divided into three chronological periods (Herrera, Early Muisca, Late Muisca); a set of environmental features (e.g., soil maps, elevation, slope, rivers, etc.); and the spatial areas of known cultigens produced by the Muisca (e.g., maize, other tuber crops).
The resulting models were compared with the contemporary knowledge of Indigenous ecological practices in similar environments to accurately determine if the location and size of these settlements responded to temporary or long-term inhabitation, as well as to better understand the relationship between settlements and their ecological surroundings. These aspects are essential to argue towards microverticality. This paper will summarize the quantitative and interpretative models of past Indigenous ecological management and its relation to the political system of the Muisca.

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361. Integrating Remote Sensing and Computational Approaches in Amazonian Archaeology

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On-the-ground surveys are essential for advancing archaeological knowledge, as small-scale evidence, such as lithic artifacts, ceramics, wood, bones, paintings, and rock engravings, still requires in-situ examination. In tropical forest environments, however, dense vegetation has historically posed a significant challenge to discovering traces of ancient human occupation. Spanning 6.7 million km^2, the Amazonian rainforest was home to indigenous societies for at least 12,000 years and holds substantial potential for new archaeological discoveries. However, given its vastness, the exploration of uncharted and remote areas requires computational assistance.
Advances in computational techniques have made it possible to detect and map areas with ancient human footprints. With the development of remote sensing technologies such as Light Detection and Ranging (LiDAR) and Synthetic Aperture Radar (SAR), even well-researched archaeological sites have yielded new insights. The combination of these technologies with computational statistics enables researchers to pinpoint areas of interest within the Amazonia for further investigation, likely revealing archaeological sites concealed beneath the canopy (Peripato et al. 2023). Additionally, integrating remote sensing with statistical methods allows us to assess the impact of ancient human occupation on the current forest ecosystem and develop innovate approaches to handle archaeology prospection within extensive areas covered by dense canopy.
The integration of remote sensing technologies and computational approaches offers a transformative pathway for exploring the extensive and challenging terrain of the Amazonian rainforest, where dense vegetation can limit archaeological discovery. While traditional field surveys remain essential for analyzing small-scale artifacts, advanced methods using remote sensors such as LiDAR and SAR enable archaeologists to detect and map large areas, identifying hidden structures beneath the canopy. When combined with computational tools like machine learning, spatial analysis, and predictive modeling, these technologies help researchers prioritize high-potential areas, guiding a more focused and efficient approach to prospection. This not only accelerates site identification but also facilitates a deeper understanding of pre-Columbian landscape management, revealing the extensive influence of ancient human occupation on forest structure and ecology (Levis et al. 2017). Ultimately, these innovations offer a scalable, non-invasive methods to uncover the long-term complexity of Amazonian human-environment interactions, enriching insights into archaeology, ecology, and forest conservation.
SAR, an active remote sensing technology, has been used in archaeological prospecting and heritage monitoring. In tropical forests, SAR has been effective in mapping the Angkor Wat site in Cambodia. Variations in surfaces, such as forest arrangement, rock, moisture, and roughness, affect the phase and amplitude of the backscatter recorded by SAR, allowing for the identification of features beneath the canopy. SAR in the L and P bands provides greater foliage penetration, offering information about the forest understory and the underlying terrain. However, Amazonia's lack of monumental rock architecture, which was not a characteristic of pre-Columbian societies, poses challenges for SAR application in this context. Nonetheless, SAR's ability to extract data on forest and understory structure enables researchers to identify mature forests

that developed over ancient occupation areas, distinguished in forest inventories by higher basal area, lower emergent canopy, and denser understory. In satellite imagery (both SAR and optical), the forests that grew (regenerated) over areas that developed pre-Columbian activity also show lower biomass, height, and tree cover. Thus, SAR sensors, providing wall-to-wall data, can enhance research into the extent and influence of pre-Columbian forest domestication on present-day forest structure. Additionally, upcoming SAR sensors operating in bands with enhanced canopy penetration, such as NISAR and BIOMASS, can be expected to also contribute to Amazonian archaeological prospecting.

LiDAR, an active optical remote sensor, has revolutionized Amazonian archaeology by emitting laser pulses that penetrate dense forest canopies, allowing for digital reconstructions of terrain. By digitally removing vegetation, LiDAR reveals pre-Columbian earthworks such as geoglyphs, mounds, trenches, and roads that would otherwise remain hidden in field surveys due to ground-level views and thick vegetation. Recently, this sensor has been instrumental in uncovering numerous structures concealed beneath the forest cover. LiDAR's ability to reveal these features without requiring tree removal or deforestation has been essential for expanding knowledge of pre-Columbian territorial organization and landscape and forest management, allowing for analysis of forest structures domesticated in the past and subsequently regenerated. Yet, with 80% of the Amazonia still forested, extensive LiDAR data is needed to fully explore its archaeological potential. However, acquiring LiDAR data on a large scale, covering millions of km^2, remains financially and functionally prohibitive. Therefore, the integration of computational methods, such as machine learning algorithms, spatial analysis, and predictive modeling, has the potential to refine and guide archaeological prospection in Amazonia.

The use of computational methods enables a more targeted and efficient approach to Amazonian archaeological exploration. Machine learning algorithms, for instance, can analyze large datasets from LiDAR and satellite imagery to detect patterns or anomalies indicative of human-modified landscapes, helping researchers focus on high-potential areas for further study. Spatial analysis allows archaeologists to examine relationships between detected sites, natural features, and ecological variables, shedding light on how ancient societies selected and modified their surroundings. Predictive modeling further refines this process by using known site locations and environmental factors to estimate the likelihood of undiscovered sites. Together, these methods not only improve site identification precision but also deepen our understanding of landscape dynamics and human-environment interactions in the pre-Columbian Amazonia, providing a sustainable, resource-efficient approach to exploring its vast, dense forest areas. Several of the approaches discussed in this paper are being actively developed in the Mapping the Archaeological Pre-Columbian Heritage of South America (MAPHSA) project, which includes a variety of ongoing tasks. Among these, one key effort is the assessment and validation of predictive presence-only models (Moreira and Gamerman 2022) using real absence data, particularly in regions such as San Agustín and Tena in Colombia. To assess the performance of our model, we used survey data from three distinct regions in Colombia where the surveyed areas (with 100% coverage) were precisely delimited. In those areas, both the presence and absence of archaeological evidence were fully known within the surveyed polygons. Our results were then compared with those of widely-used predictive modeling algorithms in archaeology, including MaxEnt. This work contributes to a broader goal of improving archaeological prospection techniques and refining site identification accuracy across diverse South American landscapes.

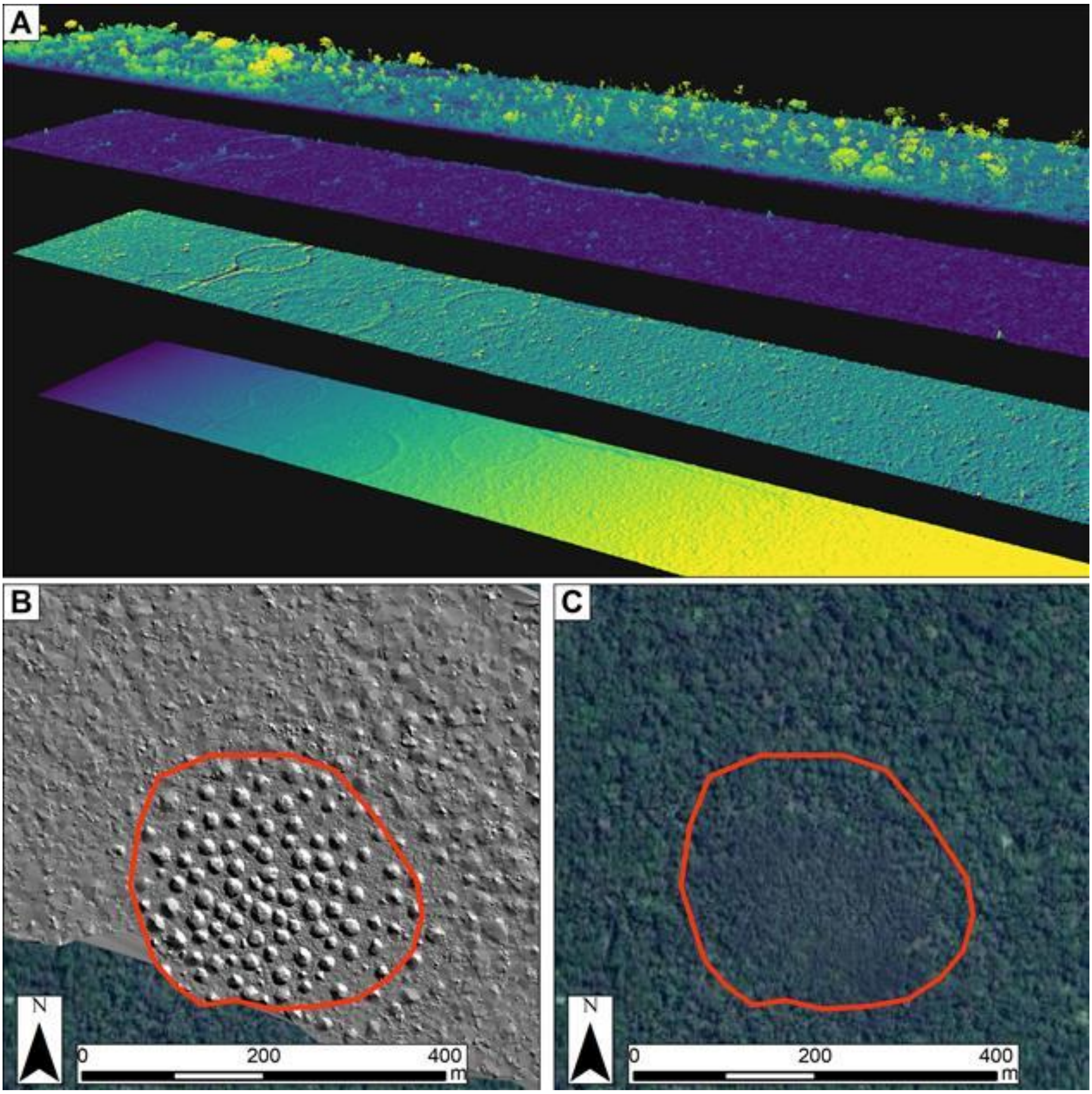

Figure 1. Pre-Columbian activity areas discovered beneath Amazonian forest canopy by LiDAR and their impact on forest structure. (A) LiDAR data outputs for investigating earthworks beneath the forest canopy. From top to bottom, the first is the LiDAR point cloud colored by its height. Followed by the terrain slope, hillshade, and elevation of an earthworks cluster, all obtained after the digital removal of the surface elements (forest). (B and C) A probable area of pre-Columbian mound visualized through digital forest removal using LiDAR data (B) and the different forest rugosity in the optical orbital imagery (C).

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184. Advancing flood simulation for understanding the ancient aquaculture systems and heritage of the Gunditjmara, at the UNESCO World Heritage Budj Bim cultural landscape, Victoria, Australia

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"The Budj Bim Cultural Landscape, a UNESCO World Heritage site in western Victoria, Australia, lies within the traditional Country of the Gunditjmara. The landscape is characterised by volcanic geology shaped into unique ancient aquaculture systems dated to at least c.6600 cal BP. These consist of a range of different constructions and modifications, from the digging of channels, creation of water races, ponds and a wide variety of both fish and eel traps. Understanding the nature and complexity of these systems has been challenging given colonial modification to the landscape in the form of drainage schemes, channelisation and other agricultural activities. A collaboration between the Gunditj Mirring Traditional Owners Aboriginal Corporation (GMTOAC) and researchers at the University of Melbourne has enabled a simulation and visualisation of water flows within some of these systems. These visualisations have been important for Community and researchers to understand how the engineering of the aquaculture systems appear to have functioned. In addition, several larger and more complex systems have been identified, enabling the Gunditjmara community to map, preserve, regenerate and story these places.

A high-resolution LiDAR dataset collected on behalf of GMTOAC by the state government of Victoria enabled a very high-resolution Digital Elevation Model (DEM) of the landscape to be visualised in a game engine. This 2.5-dimensional landscape model was imported into the Unity game engine where fluid simulation enabled reconstruction of realistic water flows through the lake system through to the river outlet. Known sites and areas of interests were identified from archaeological surveys conducted in the 1970s and 1990s. Cinematic fly throughs with adaptive camera views of the landscape were generated to capture the simulated flooding. The videos of these simulations were iteratively shared and refined with the Gunditjmara and led to simulated key flooding events across the pre-colonialisation landscape model. By expanding the visual narrative of flooding on Gunditjmara Country with local knowledge, new insights into the seasonal and cyclical nature of the systems have been gained. Gunditjmara, who holistically care for Country and manage the landscape in a variety of land management roles and have intimate knowledge of places identified, contribute to enriching the video simulations with audio as they narrate stories of the aquaculture system. By co-designing the research outputs for Gunditjmara this project aims to support their revival of cultural knowledge about Gunditjmara Country. Circular feedback has helped identify several new areas including channels and trap systems of interest, with ongoing ground truthing and evaluation of these finds.

The research project is distinguished by its multidisciplinary, place-based approach, with co-authors from a broad range of backgrounds, including Gunditjmara engaged in heritage and land management, archaeologists, spatial analysts, engineers, virtual reality specialists, and media creatives. Working within multiple knowledge systems exposed the challenges of researching

within university mandates and this project has informed how data work should be better practiced within institutional structures. The iterative methodology, guided by Gunditjmara and GMTOAC priorities, produced outputs that are globally distinct in their capacity to represent and convey the intricate aquaculture engineering systems of the Gunditjmara. This work continues unbound by this project and driven by Gunditjmara and GMTOAC timeframes.

The research is underpinned by a philosophy of regenerative design, which is rooted in reciprocity with nature, place-based wisdom, holistic systems thinking, and Gunditjmara-centred engagement and research methodologies. This framework fosters a deeper understanding of the landscape’s history, seasonal cycles, and natural patterns, leading to designs that are both resilient and sustainable. Ultimately, it supports the Gunditjmara in reviving cultural knowledge of their Country."

474. Daylight affordance as ecological approach to domestic activities in House A in the ancient city of Orraon

Claudia Maechler (Technical University of Darmstadt)*; Andreas Noback (Technical University of Darmstadt)

Introduction

Ancient Orraon was founded concurrent with several other small towns in Epirus and Acarnania in the Late Classical period. It was rebuilt after its partial destruction by the Romans in 168 BC and continued to be inhabited until the early Imperial period. Due to its location on one of the southern foothills of the Pente Pigadia (350 m above sea level), the settlement site was of outstanding importance for controlling the traffic and trade routes between central Epirus, which lay in the core area of Molossian rule, and the Ambracian Gulf and thus the Ionian Sea (Dakaris et al. 1976, Dakaris 1986).

The few literary and epigraphic sources in which Orraon is referred to as πόλισμα provide little information about the precise socio-economic organization of the people who settled there and how they dealt with natural resources. Any analysis must therefore be based first and foremost on the tangible remains, especially the architectural evidence.

The 5.5-hectare fortified settlement area was laid out as a so called „Streifenstadt“ with an orthogonal north-south aligned road network on a ridge sloping down to the west (Hoepfner 1999, p. 388). Little is known about the relationship between the settlement and its surrounding landscape as no survey work has yet been done in this area. However, thanks to the use of a local limestone as the main building material, the residential dwellings have been preserved to such an extent that a combined analysis of their architecture and the affordance of daylight as a natural resource allows to study domestic activities and their changes over the course of the settlement's history, which lasted around 300 years.

The concept of affordance as introduced by James J. Gibson stems from an ecological approach to human visual perception. An affordance “is equally a fact of the environment and a fact of behaviour“ (Gibson 1979, p. 129) as it binds a subject’s need and physical offerings into a single property. In contrast to the concept of “function” as a dedicated use of a spatial environment affordance allows for understanding of its possible uses based on the needs to fulfil multiple activities.

Daylight affordance can be understood as an intrinsic quality of a building’s geometry, surface properties and surroundings that depends on solar dynamic and local climate as ecological factors. It describes the spatial and temporal potential for activities under the conditions of human vision. The exploration of daylight affordance depends on, and extents building research methods as 3D-reconstruction and inherits their uncertainties. It adds climate-based daylight simulation to the researcher’s toolkit and relates it to the study of activities based on archaeological finds and to experimental archaeology to understand the visual need to perform domestic tasks.

Method

Geo-referenced reconstruction models are based on the three-dimensional documentation of the remaining building structures of the houses by aerial/terrestrial photogrammetry and laser scanning and were further differentiated by the study of the respective literature and archive material and comparable buildings in the region (e.g. Kassope). Information on the preserved architecture as well as important decisions and assumptions during the reconstruction process were recorded in a relational database.

Although House A in Orraon is one of the best-preserved ancient dwellings in Classical Greece, large parts of its original geometry have to be reconstructed. A computational approach was

chosen in order to determine the degree of variance and thus uncertainty within the reconstruction models, so that the statements made about possible activities within defined spaces remain valid. This enables the generation of reconstruction variants based on ancient reference data through database queries (e.g. on window openings) and their semi-automated conversion into geometries, which in turn can then be used as the basis for the daylight simulations. A digital terrain model of the settlement hill (aerial photogrammetry, ground sample distance 2 cm) and the surrounding area (Aster, Landsat DEM, overall accuracy ~30 m) complete the simulation environment.
For use in daylight simulation, the reconstruction model is designed as closed geometry of non-intersecting surfaces with strictly orientated surface normals. It maps the building topology (insula, unit, storey, room, building element) to a hierarchical layer structure that guarantees that for each element of the geometric model a specific material with a specific reflectance value can be allocated. Additionally, spectral reflective measurements were performed for roof tiles, limestone and plaster and converted to RGB values.
Simulation is performed utilizing the phos4dtools (Grobe et al. 2024). These implement climate-based daylight simulation based on solar positions and modern data of a Typical Meteorological Year (TMY) from Ioannina including clear, cloudy and overcast sky conditions for every hour of every day of the year. As this data is provided in equinoctial hours it has to be sampled for temporal hours that are closer related to the performance and description of historical tasks.
For accuracy and speed the phos4dtools implement an adaptive spatial sampling strategy based on the variance of illumination but combine this data to a fixed grid. Two measurement geometries are configured for different heights of observation. Firstly, the illumination of a horizontal plane from all directions above this plane (horizontal illumination) in the height of 10 cm relative to a rooms floor level, for task performed at floor level as well as general orientation and walking, and at 100 cm, as approximation for task performed on a table or a shelf. Secondly, the brightest illumination out of four vertical surfaces oriented in four directions orthogonal to each other, representing the illumination of an object that can be observed within a task from the optimal direction. The latter is provided for approximate eye height in sitting (100 cm) and standing position (150 cm).
The phos4dtools allow to summarize the daily results to monthly medians while maintaining the hourly resolution over the day. They preserve the geolocation of the measurement points and the topological room designations according to room books and the database. The simulation results were imported into a PostGIS database and were then further processed in an open-source GIS.

Analysis & Outlook

The analysis employs minimal thresholds for good human vision of colour and acuity (Grobe et al. 2024) in contrast to modern standards and metrics that aim for optimal visual performance. Activities such as weaving, cooking, dining, metal work etc. are assigned daily and seasonal timeframes, illumination geometries and working heights as well as their needs for colour and acuity. The results are plotted room by room and show the spatial distribution of the daylight affordance for the respective activity. The results a contrasted to functional attributions such oikos, andron, weaving chamber, workshop etc. derived from literature or based on finds.
Daylight affordance can widen the understanding under which lighting conditions domestic activities took place and extend the understanding where in the house an activity can performed best or indicate the use of rooms of unclear function. It can further indicate the multifunctional use of rooms typically associated with a single activity. In more general terms it introduces the dynamics of climate as ecological factors of visual perception to the field domestic architecture and activities.

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177. Utilizing Low-Altitude Imagery and Weak Learner Algorithms for the Detection of Archaeological Surface Ceramics: The Kophinou case study

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Introduction

In recent years, the application of remote sensing in archaeological research has grown significantly [1,2]. This study builds upon a 2021 case study conducted at an archaeologically rich site dated to Late Antiquity (6th-7th c, AD) in the vicinity of the village of Kophinou in the Xeros River valley, Cyprus (initially identified and surveyed in 2018 by the Settled and Sacred Landscape Project –SeSaLaC– of the Archaeological Research Unit of the University of Cyprus), with a focus on improving the detection of archaeological surface ceramics using low-altitude imagery. The initial approach successfully identified scattered archaeological objects, even when they exhibited high spectral similarity to the surrounding surface [3]. This study further explores the potential of cost-effective, low-altitude sensor data and machine learning (ML) algorithms to accurately detect and map archaeological surface ceramics. However, challenges were encountered in accurately detecting ceramics, particularly due to the issue of imbalanced data. To address this problem, a new methodology was developed to enhance the detection of surface ceramics. This research aims to address this literature gap by incorporating AI methodologies to manage non-uniformly distributed classes, using weak learner algorithms to provide a more efficient approach in terms of time and accuracy. The methodology presented here has practical applications for improving archaeological pedestrian surface surveys.

Methods and materials

The workflow included unmanned aerial vehicles (UAVs) acquisitions over the case study area using a DJI Phantom 4 Pro system and DJI Mavic 3 Multispectral platform. Flight altitude was set at approximately 15 meters above ground level, capturing images with a spatial resolution of 0.69 cm/px. The subsequent step involved standard photogrammetric processing to produce the orthophoto-mosaic. Finally, we employed two supervised pixel-based classifiers, namely the Random Forest (RF) and the Support Vector Machine (SVM) methods. Additionally, pixels with similar spectral characteristics were grouped together into segments, creating objects via an image segmentation process. Overall accuracy was assessed by using randomly distributed ground truth data to evaluate the detection (classification) performance. The process is illustrated in diagram 1 below.

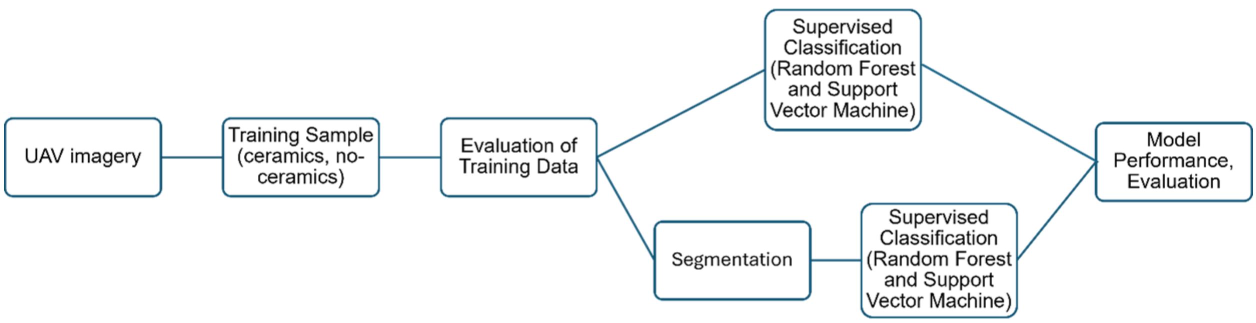

Diagram 1: Research methodology.

Results

Our training model involved two classes: 'ceramics' and 'no-ceramics', and therefore was considered as a binary classification problem. The results of the ceramics class varied in accuracy, with both RGB and multispectral images ranging from 7% to 16%, while segmentation images provided slightly better results with an accuracy ranging from 22% - 46%.

The low success detection rate can be explained as the majority of standard classifier learning algorithms are designed with the assumption of equal class distribution and misclassification costs. Nevertheless, these algorithms may provide poor results when dealing with imbalanced data sets. In the context of archaeological surface ceramics, accurate modeling is challenging due to small sample sizes, separability, and sub-concepts. Existing literature suggests solutions such as rebalancing class distribution and modifying learning algorithms. In 1995, researchers [4, 5] developed a boosting algorithm to enhance the classification performance of other learning algorithms, especially designed for imbalance datasets. “Adaboost” algorithm is a widely adopted method of boosting that enhances prediction capabilities for imbalanced data by giving an increased weight to challenging examples and combining weak rules through majority voting (Diagram 2). The p-value results indicated a significant difference in prediction errors, which decreased slightly (by 5%) after applying AdaBoost.

Diagram 2: Framework of the boosting algorithm processing steps.

Discussion

This study emphasizes the potential of using low-altitude sensor data and weak learner algorithms to accurately detect and map archaeological surface ceramics in a non-invasive manner. The findings indicate that these techniques show promise for advancing archaeological research by providing reliable and precise results. To ensure statistically significant spectral separability among the ceramics, lab-based spectral measurements will be conducted during the same flight. Additionally, further drone surveys are planned to improve data for algorithm training and outcome assessment. The future goal is to reduce noise, enhance the distinction between classes, and analyze imbalanced ceramics data using evaluation metrics such as the F-measure, G-mean, and ROC analysis.

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466. PotScan: A Mobile App Workflow for the Automation of Archaeological Surveys for the Detection of Ceramic Fragments using Deep Learning

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In recent years, studies have focused on automating archaeological surveys using unmanned aerial vehicles (Stek, 2016; Orengo and Garcia-Molsosa, 2019). However, not all sites, particularly those covered by densely populated forest (Berganzo-Besga et al., 2022), are accessible to drone technology. This workflow, outlined for the detection of ceramic fragments, is designed to address and overcome these accessibility challenges. Moreover, this app, designed as a mobile application, can be extrapolated to other resources with cameras such as quadruped robots, automating the survey while ensuring accessibility in complex landscapes. Likewise, this approach is an applied and didactic resource. It can be used for educational purposes.

Potsherd detection is carried out using Mask R-CNN, a Deep Learning segmentation algorithm already tested in other studies (Orengo et al., 2021). Likewise, the use of real-time kinematic, known as RTK, allows to achieve centimetric precision for the detection of archaeological features such as these. In addition, it includes a series of improvements over previous approaches to address the archaeological ceramic diversity and the little amount of data available for algorithm training, such as the use of novel open-access tools like ArchaeolDA (Berganzo-Besga, 2023) and approaches like curriculum learning (Berganzo-Besga et al., 2023). This workflow also places Mobile GIS at the center, since the exact coordinates of the ceramics are stored without any further use than the application. In this way, derivative studies can be carried out.

All the studies for archaeological ceramic classification (Santos et al., 2024) can be easily integrated into the workflow we have developed so that in the future, in addition to detecting potsherds, these detected ceramics can also be classified according to different image classification algorithms.

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456. Detection of Pre-Columbian Shell Midden Settlements in the Ciénaga Grande de Santa Marta Using Machine Learning

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The Ciénaga Grande de Santa Marta (CGSM) on Colombian's Caribbean coast presents unique challenges for archaeological research due to its extensive wetlands and dense vegetation. Traditional survey methods in such environments often encounter logistical constraints, high costs, and limited accessibility. To overcome these challenges, this paper presents a machine learning approach to analyze remote sensing data for detecting shell midden settlements dating to the Early Northwest South American Litoral and Formative Periods, approximately 5900–800 years ago.

We used high-resolution Pléiades Neo satellite imagery to annotate labels of shell middens in an area of 2 km2. Multispectral data from Sentinel and Landsat served as input for the model, aiming to identify vegetation and sediment anomalies associated with midden sites. Field validation assessed the accuracy of the predictions of the results.

Preliminary findings highlight the potential of this approach not only to identify unknown archaeological sites within the CGSM but also to offer insights into settlement dynamics. The methodology's design prioritizes scalability and adaptability, making it suitable for application in other regions facing similar environmental and logistical challenges. Inspiration is drawn from successful implementations of remote sensing and machine learning in archaeological contexts (Orengo et al., 2020), including the detection of anthropogenic landscapes in the Amazon (McMichael et al., 2014), automated tree detection in tropical canopies (Ahongshangbam et al., 2020), and spatial analyses of shell middens.

This research contributes to computational archaeology beyond advancing archaeological exploration. It informs conservation strategies by identifying at-risk sites and enhancing our understanding of human-environment interactions in tropical wetland landscapes.

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183. Soil influence on settlement patterns in Northern Kurdistan region (Iraq). Impact of soil quality indexes and other environmental covariates on archaeological predictive models in a semi-arid environment

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Background:
Environmental proxies strongly influence the distribution of archaeological settlements (Díaz-Rodríguez, et al. 2023). Understanding the interactions between humans and their environment gives us insights into the complexity of past societies' organisation and the landscape's cultural aspect (Wilkison, 2003). Soil impacts both biotic and abiotic factors and is, therefore, an essential element of an ecosystem's ecology (Scholten et al. 2017). Human use of soil to produce food and construction materials dates back to the Neolithic era (Teuber et al. 2017), yet the relationship between soil quality and site distribution has rarely been explored. We analysed settlement patterns at a regional scale, intending to identify how past humans interacted with their environment and, more specifically, whether soils were considered an essential factor prior to installation. In order to create a more holistic model of ancient human environmental interaction in this region, we evaluate soil quality indexes and a diverse set of additional environmental covariates in regard to their effect on site distribution.

Subject:
Three different soil quality indexes were computed, based on different models (Nabiollahi et al., 2018; Vogel et al., 2019), for four time periods ranging from the early Bronze Age to the Iron Age (3,000 – 330 B.C.). As this is a relatively large timespan, we used one index that was specifically designed to tackle time problems related to the weathering of soil components. Other covariates (Fig. 1) were included as they described the environment of the study area. Four different machine learning models, RF, GAM, AdaBoost and MaxEnt, were constructed to produce archaeological predictive maps. We artificially increased the size of the site location dataset by dividing each site into 25 x 25 meter cells. Additionally, we compared the most influential covariates with statistical tests to assess variability inside the different categories. Results presented the important influence of soils but also highlighted a strong sampling bias due to the archaeological survey's methodology.

Discussion:
Of the different models tested, MaxEnt showed - once again - its ability to overcome the issue of defining a "true negative" for archaeological input data (Yaworsky et al., 2020; Wachtel et al., 2018). The archaeological survey method used to determine site locations strongly influenced the importance of natural covariates, mainly elevation and distance to water resources. We also tackle the importance of the different soil indexes to the model and the difference between suitability for "conservation" vs. "installation". In this context, environmental elements do shape settlement patterns but their importance and magnitude of effect varies between time periods.

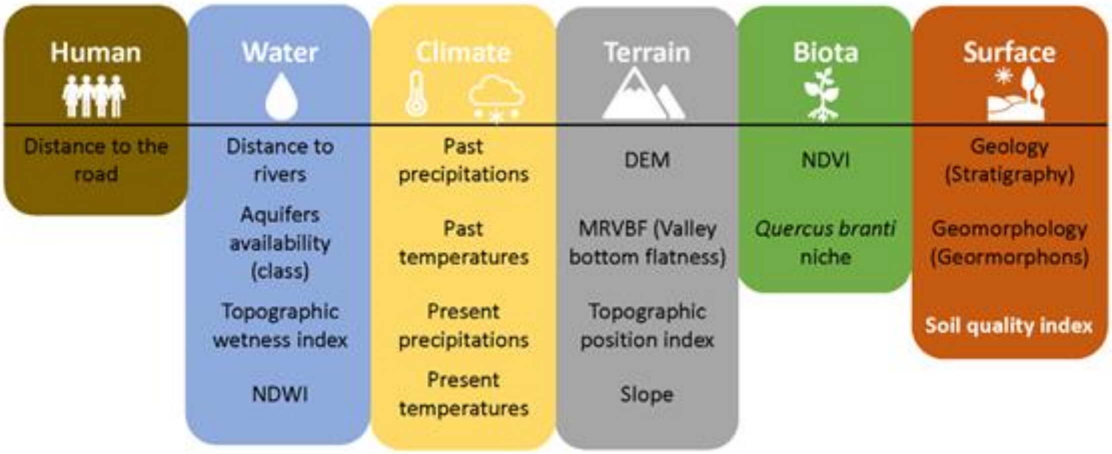

Figure 1 Covariates used for the archaeological predictive model

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390. Visibility and Spatial Autocorrelation in Field Survey: A Case Study from the Northern Apulia Coastal Survey using Bayesian Conditional Autoregressive (CAR) Models

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Field survey is a relatively cheap and rapid method of locating areas of ancient human occupation and of understanding long-term regional dynamics by collecting archaeological material from the ground surface of walked fields. The recorded artefacts are usually integrated into a GIS environment in order to map potential locations associated with historic human activity. One of the main drawbacks of surface surveys is that uneven levels of visibility (i.e. how much of the ground surface is exposed or covered by vegetation) can affect statistical analysis and, consequently, archaeological interpretation. This problem has long been discussed (see Attema et al. (2020) for a review), and some field strategies have been proposed to mitigate low visibility (Stek and Waagen 2022). However, these solutions can be difficult to implement when time and resources are tight, especially when new data need to be compared with old survey reports. This may be the case with commercially driven archaeological surveys, with particularly large target survey areas (where we cannot afford high-resolution archaeological sampling), or where revisiting old sites is not feasible.

In this paper, we aim to account for different levels of field visibility in spatial analysis using Bayesian conditional autoregressive (CAR) models. To test the effectiveness of the proposed solution, we applied the models to a recent dataset derived from the first Northern Apulia Coastal Survey (NACS) campaign in the area SW of the Roman colony of Sipontum (Puglia, Italy). The survey area covers approximately 220 hectares, where students identified over 33,000 fragments of archaeological material (e.g. tiles, lithics, pottery, mosaic tiles, etc.) from 64 topographic units. A topographic unit is defined as any type of archaeological evidence that can be identified during a field survey. Of these, we focus on 39 areas that were surface scatters and potentially evidence for ancient human activity or settlement on the local landscape.
CAR models allow count data to be modelled while accounting for spatial autocorrelation in the distribution of finds and statistically controlling for visibility conditions across survey units (Haining and Li 2020). In addition, the use of a Bayesian framework is advantageous for incorporating uncertainty into the model, helping us to better understand how survey conditions affect our observed patterns and how confident we can be in the spatial clusters identified.

Our results show that while high visibility positively influences the rate of artefact recovery, spatial patterns in the distribution of finds are still evident, particularly in areas where other evidence (e.g. aerial photography) also confirms archaeological activity. This approach has several strengths:
(a) it provides a methodological framework for analysing and integrating data from previous survey campaigns;
(b) it facilitates the prediction of the expected abundance of archaeological finds in inaccessible areas (e.g. private property or built-up areas);
(c) it allows us to assess the robustness of our interpretations by quantifying the uncertainty in both visibility effects and spatial patterns. This helps to identify areas where further investigation may be required.

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433. Introduction of the Building Information Grammar - a Semantic Rich Shape Grammar

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In this paper a first approach of a Building Information Grammar (BIG) is presented and discussed. The current approach is adapted to build a corpus of building relevant information and further transport numerical analysis data as well as encoded decoration occurrence, and/or complementary information with a shape grammar. In this paper a first approach of this system is introduced by a case study presenting Late Period funerary monuments at Thebes (Egypt).

BIG is based on two methodological concepts: Building Information Modelling (BIM) and description grammars. BIM is a process of modern building construction to manage semantic rich models (Borrmann et al., 2015) and includes methods to create and analyze spatial structures of buildings with additional semantic information. Used for ancient architecture and handled as a tool to analyze geometry and space relationships, it offers new possibilities for architectural heritage applications. The description grammar formalism transports complementary information with a shape grammar (Stiny and Gips 1972). 1981 G. Stiny introduced the formalism to complement shape grammars for the description of designs (Stiny 1981). Description rules are linked to shape rules and work parallel and simultaneous. Descriptions describe the generated design in other ways, such as, terms of rooms, walls, windows, and other architectural components.

In previous research these Late Period funerary monuments have been analyzed according to their architectural properties, including spatial analysis (reference excluded for review) and decoration occurrence and distribution (reference excluded for review), as well as their design formalism through an analytical shape grammar (reference excluded for review). Building Information Grammar BIG is an approach to combine these analysis data with the developed shape grammar to gather collected building information in the grammar. The shape grammar becomes an enriched grammar and a collection of information concerning the analyzed structures.
To some extent the shape grammar, developed in previous research (reference excluded for review) is transporting building information, such as room functions and conditions. Function information computations run parallel to a shape grammar and are classified as functional conditions (Stiny, 1981). Functional elements are related to the application of shape rules in the grammar. Beside their conditional behavior they provide insights into room function characteristics. At the current stage of research any additional information, such as decoration position in room or spatial relations, must be consulted separately. With BIG this process is simplified. Building information are attached to the shape grammar to present every gathered information of the analyzed structures. BIG can transport information concerning the analyzed buildings as well as rules of dependencies and intends to enlarge the shape grammar formalism.

Beside analytic functions to analyze existing designs, BIG also works synthetic to produce new designs combining building information and design production. Building information are analysis data which include building relevant data and metadata. Design production is given by a shape grammar to generate a set of design possibilities (design language). The relationship between building information and design production will enable the search for a best-fit-design based on analytic evidence. The process can be imagined as a design-circle: Analysis data are gathered to

provide sufficient data to develop the grammar. Additional data work as components to converge in an enriched shape grammar.
So far included metadata are passive in terms of completing and not directly influencing the shape grammar. With BIG secondary data can be used actively to influence the design computed by the shape grammar, determine, and improve its quality.

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17. Ariadne Redux

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In 2007, Knappett et al. (2008) proposed a cost-benefit model (termed ariadne) to help explain patterns of maritime exchange in the Bronze Age south Aegean. This provided a caricature of a Middle to Late Bronze Age maritime network which was surprisingly successful as an early exemplar of spatial interaction models. By that is meant that, given the qualitative nature of the data, it was possible to get a plausible narrative on distilling its highly quantitative outputs. A second ariadne paper followed, examining the change in maritime links after the eruption of Thera, which helped to consolidate the underlying agency of the model.

Although ariadne was seen is some quarters as a ground-breaking model, with hindsight it is not difficult to see how naïve it was. Improved archaeological data for the Aegean and further theoretical analysis for other spatial interaction models shows that there were two major omissions to the inputs of the model. Firstly, although wind is the driving force, Knappett et al. (2008) averaged over wind direction and seasonal wind variation, almost certainly a step too far. Secondly, the geographical scope of the network was limited. In particular, the authors omitted much of the northeast Aegean that was likely to have been important for resources as Cretan towns grew, which was one of the reasons for proposing the model.

In this paper we propose an update of ariadne, ultimately with the aim of accommodating both of these omissions. Because the outputs from (Knappett et al. 2008), against which we wish to make comparisons, are very qualitative, it is standard tactics in mathematical modelling to change only one factor at a time (monothetic analysis). As our first step, presented here, we incorporate wind explicitly, since this requires a structural change to the original model, while leaving the geographical range unchanged.

Structurally, the new model we are proposing goes beyond the simple cost-benefit analysis of Knappett et al. (2008) to incorporate some of Jaynes' 'epistemic modesty' (aka Maximum Entropy). We show that it can accommodate both the largely NW to N winds of the S Aegean and the different Summer/Winter wind strengths. In this, it calls upon the data of Gheorghiade and Spencer (2024) on Aegean winds as well as that of earlier work (Gal et al. 2021). This latter analysis, based on cost-surface modelling, shows how naïve the original model was.

The outcome is simple to state: the updated ariadne is still a caricature of maritime exchange, but a better one. The main technical difference is to rescale the strength of exchange to take headwind/tailwind sailing into account. If the direction from origin to destination requires sailing into the headwind so that tacking is required, in its most simple extension the strength of exchange is reduced by a universal factor. Otherwise, exchange is left unaltered. Moreover, this is sufficient to also accommodate the basics of stronger/ weaker seasonal winds.

Most simply, in comparison to the original model, we could add just this ONE new parameter (constrained by sailing data) which incorporates the key aspects of wind. This is important. The original set of sites consisted only of 39 and the extended version, to take the NE Aegean into account, will no more than double that number. Depending how we count, prior to the explicit incorporation of wind, the number of calibration parameters that define the model in Knappett et al. (2007) is certainly three: the availability of local resources, the benefits of inter-island exchange and the costs of maintaining the population and of networked exchange. As von

Neumann said “Give me four parameters and I can fit an elephant; give me five and I can make it wiggle its trunk.”

We would rather the new variant of the model didn’t wiggle its trunk, to leave some possibility of post-diction, which is the test for defining agency. Any more parameters and we are merely data-fitting.

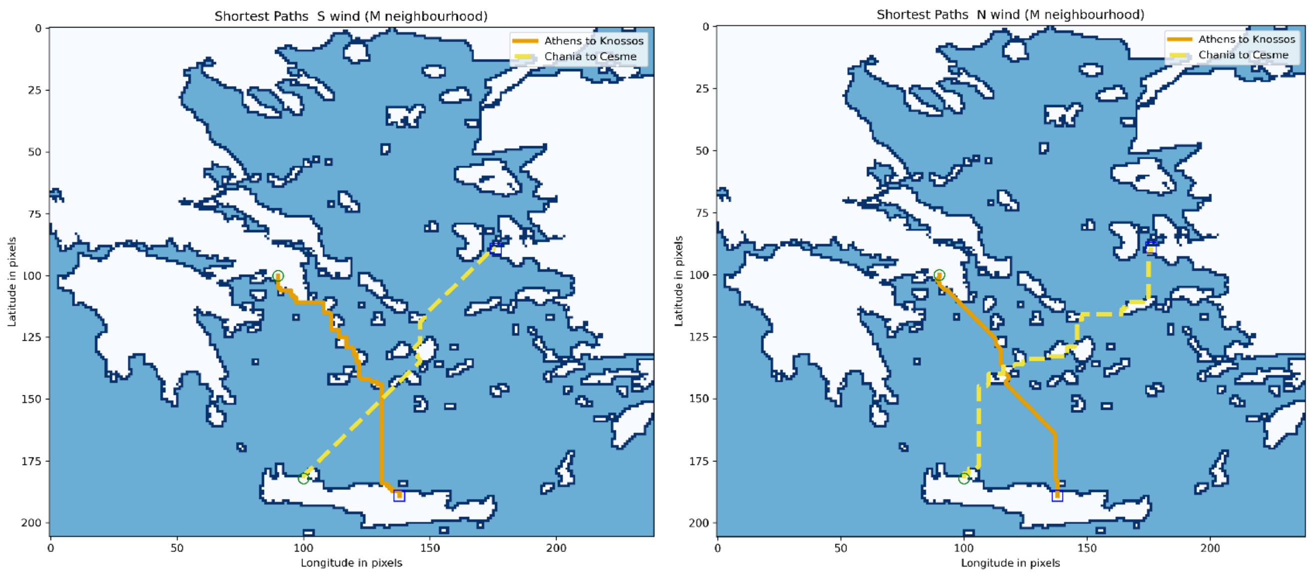

Figure: An illustration of the effects of wind on routes in the Aegean. Here we show exemplary trips from Athens to Knossos and from Chania to Cesme. On the right the wind is from the North and on the left, wind is from the South and there are clear differences between the routes. However, models need the length of such journeys as well as the frequency of each wind direction (neither represented in these figures) to determine connectivity.

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80. A Network View on the Big Exchange Project: Integrating and Analysing Heterogeneous Datasets

Mattis thor Straten (Kiel University)*; Steffen Strohm (Kiel University); Benjamin Serbe (Kiel University); Johanna Hilpert (University of Cologne); Tim Kerig (Kiel University); Matthias Renz (University of Kiel)

Archaeological research increasingly deals with complex, interconnected datasets involving diverse objects, such as finds, materials, and sites. Many tasks require a comprehensive understanding of the dependencies among these objects, represented as relationships between them.

Networks offer an intuitive way of representing direct and indirect semantic relationships between objects or entities, which are modelled as edges connecting nodes. Networks are already applied in the study of archaeological data, but they are typically homogeneous, focusing only on whether objects of a single type are related, without further semantic annotation. This approach fails to reflect the heterogeneous nature of archaeological data, where different types of objects and relationships, such as finds linked to sites and materials, coexist. Overlooking this heterogeneity can result in the loss of valuable contextual information. Heterogeneous information networks (HINs) (Shi et al. 2017) offer a solution by distinguishing between various types of nodes and relationships, thereby preserving the semantic complexity of archaeological datasets.

Various datasets from the Big Exchange project (Kerig et al. 2023), encompassing various archaeological finds of different materials, have been integrated into one HIN. By analysing the network structure, we aim to uncover cross-dataset knowledge and support domain-specific hypotheses. By retaining the diversity of object and relationship types, HINs enable more meaningful interpretations in archaeological contexts. A traditional network could only set finds, materials or sites in relation, while an HIN can connect finds, materials and sites with each other.

The upcoming sections will explain the concept of HINs and introduce the Big Exchange data utilized for their creation. Additionally, network analysis methods employed to uncover patterns will be discussed.

An HIN is a directed graph where both nodes and edges are assigned predefined types, representing different objects and their relationships. While conceptually similar to knowledge graphs, HINs employ a more streamlined schema, with a limited and manageable number of node and edge types. This manageable structure enables more precise and targeted network analyses, preserving the semantic integrity of the data. It for example allows for the explicit definition of sequences of node and edge types, capturing higher-order semantic relationships that are crucial for semantic network analysis.

The Big Exchange project (Kerig et al. 2023) investigates large-scale exchange systems in Eurasia and Africa between 8000 BCE and 1 BCE, focusing on raw materials of known origin. Analysis in this project is based on materials, their source and related find locations. By identifying and analysing key parameters that describe network characteristics over temporal and spatial dimensions, changes associated with economic and social dynamics can be systematically tracked.

In this project, 17 datasets originating from different research projects are integrated into an HIN. Each dataset contributes to the HIN by providing finds of a specific material type, context data, and spatial-temporal information. All aspects of the relational data are mapped to objects and

relationships. The spatial and temporal object types serve as connectors between the datasets, linking different materials via associated finds sharing them.
Close interdisciplinary collaboration ensures semantic accuracy by including domain expert knowledge and technical expertise into the data engineering and HIN modelling process. The features of the input data have to be mapped to object types, and relationships between them have to be identified and represented accurately.

The final HIN integrates diverse datasets into a comprehensive, information-rich foundation for knowledge discovery algorithms, used to obtain new insights by considering cross-dataset patterns. Key techniques include (for details see Shi et al. 2017):

- Clustering partitions the network into sets of nodes, such that the nodes in a cluster are similar to each other and dissimilar to objects in other clusters considering the network structure.
- Similarity measures evaluate the relevance between pairs of objects within the network. They can be used for similarity search, where the most relevant objects to a given query object are returned.
- Link prediction infers missing connections, helping to address incomplete datasets.
- Network motif search (Rossi et al. 2020) detects small subgraphs occurring at a higher/lower frequency in the HIN than in randomized networks. They indicate underlying structural patterns in the integrated data.

The application of these techniques reveals new insights, such as material dependencies found by similarity search, identification of frequent network motifs or differences in semantic clusters and spatial clusters of sites. These results offer deeper insights into the temporal and spatial development of the network structure. They open up new perspectives for the formulation of domain-specific hypotheses regarding, e.g., recurring network patterns. Potential shortcomings of the applied methods in an archaeological context, such as challenges in accurately mapping different datasets to a unified network structure, and the needs for adaptation will also be discussed.

The integration and analysis of multiple datasets in an HIN has enriched our understanding of the internal structure of the data. By preserving the heterogeneity of archaeological datasets, HIN analysis enables the exploration of patterns, adding new ways for analysis on top of wide-spread methods. Future work will focus on expanding the dataset, exploring new types of relationships, and refining the analytical methods to generate even more specific hypotheses, with the potential to reshape our understanding of ancient societies and their interactions.

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309. Using ERGMs to Compare Networks

Robert Bischoff (Arizona State University)*

Introduction

One challenge for network science is comparing different networks. Many methods exist, and each has advantages and disadvantages. One method that, to my knowledge, has not been used to compare networks in archaeology is an Exponential Random Graph Model (ERGM).

ERGMs provide insight into how networks form by estimating the underlying processes that shape the relationships between nodes and connections in the observed network structure. This allows us to test whether certain network features—like how archaeological sites are connected—are likely to have occurred by chance or because of underlying patterns of interaction. ERGMs are used to model the structural properties of an observed network by estimating parameters that describe the processes likely to have generated the network. Multiple networks are simulated from the ERGM using the estimated parameters, and these simulated networks are compared to the observed network. ERGMs are useful for understanding the structural dependencies in a network and estimating the likelihood that observed structural patterns are due to specific underlying processes. ERGMs allow various variables to be formulated to predict the network structure. These models can then be compared to see which model fits best.

This analysis uses the ArchMatNet agent-based model (ABM) (Bischoff and Padilla-Iglesias 2023) to generate simulated networks between hunter-gatherers. Two general types of networks are created: interaction networks between agents and material culture networks between camps. These networks are compared using ERGMs to determine whether the same underlying structures are found in each type of network.

Methods

ERGMs require a predefined model to be tested. Four models were used in this analysis. Each model includes an edge parameter, which means that the network edges are used as a predictor variable. Additionally, each model includes a band parameter that identifies which band each node (which represents a camp) belongs to. The triangle parameter represents triadic network structures where three nodes all share connections to each other. Two related parameters are called GWESP (geometrically weighted edgewise shared partners) and threetrail (two-paths or three trails). The GWESP parameter defines the propensity for two nodes with shared partners to form a triangle. This measures the likelihood that camps sharing connections with the same camp will form a direct link between themselves. Thus it is also closely related to the triangle parameter. The threetrail parameter captures a network structure where three nodes are connected through two edges (no triangle exists). This parameter detects the existence of paths to triads that go through an intermediate node. The four models are:

1. edge + band
2. edge + triangle + band
3. edge + gwesp + threetrail + band
4. edge + triangle + threetrail + band

We used a goodness-of-fit test to evaluate how well the ERGM replicated the structural properties of the observed network and assess the adequacy of the models in reproducing key network features. ERGMs are computationally intensive. A random sample of 100 ABM runs was selected and each run was fitted to the four models. The ergm package (Handcock et al. 2018) in R was used for this analysis. Unfortunately, the ergm function in R has a tendency to fail when trying to replicate certain network structures. For this reason, model 2 (edge + triangle + band) did not yield results and some other ERGMs did not return results as well. A final note for the ERGMs is that they require binary networks. All network weights were binarized by calculating the 75th quantile for the edge weights (counts of interactions or Brainerd-Robinson distance for material culture) and retaining links above that quantile.

Results

Table 1 shows the results of the ERGM simulations. For clarity, only one type of material culture (point) and one type of interaction network (visiting) are shown in this table. Other networks return similar results. The goodness of fit (GOF) test indicates that all models performed well at capturing the structures of the network (1 equals a good fit and 0 a poor fit). This GOF test is useful for statistical validation of ERGM results. The Akaike Information Criterion (AIC) is a metric used to assess the quality of a model. Lower AIC values indicate a better model fit. The AIC results indicate that both the gwesp and triangle parameters plus the threetrail and the default parameters fit the model well. These results are expected based on the triadic nature of the three camps within each band that each form strong connections with each other. The most important parameter appears to be the threetrail parameter. This parameter would matter in the ArchMatNet models because weaker ties between bands would be formed by some camps while other camps might lack those ties. The threetrail parameter shows that camps acting as intermediaries in the network is an important part of the network structure.

Table 1: ERGM Results

network	formula	gof	aic
point	edge + band	0.98	104.43
point	edge + gwesp + threetrail + band	0.99	95.38
point	edge + triangle + threetrail + band	0.98	89.25
visiting	edge + band	0.98	106.64
visiting	edge + gwesp + threetrail + band	1.00	93.10
visiting	edge + triangle + threetrail + band	1.00	96.44

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259. Paleographic Networks: when Paleography Meets Network Analysis

Eythan Levy (Bern University)*; Silas Klein Cardoso (Faculdade Unida de Vitória)

This paper presents a new methodology for paleographic dating, based on network analysis. Paleographic dating consists in assigning a date to the various paleographic features (i.e., “letter shapes”) of a given script. The discipline is of paramount importance for dating inscriptions otherwise lacking direct dating criteria. Currently, paleographic dating mostly uses intuitive approaches, based on paleographers’ intimate knowledge of scripts and inscriptions. Assumptions on development trends of a script (e.g., a shift from pictographic to linear shapes), coupled with historical dating of selected inscriptions, also play a major role in the field. Yet, these classical approaches are mostly heuristic and qualitative, based on unmodelled expert knowledge, resulting in several cases of divergence among experts regarding the dating of selected inscriptions.
As an alternative approach, we present a quantitative methodology for paleographic dating, based on network analysis of paleographic data. This approach uses the concept of chronological network analysis, a robust network-based formalism for encoding chronological relations using graph-theoretic tools, embodied in the ChronoLog modelling software (Levy et al. 2021). We illustrate our approach using a case-study related to the Paleo-Hebrew script appearing on Iron Age seals and seal impressions (8th-7th centuries BCE). We present a new paleographic typology of this script, a new database of paleographic features appearing on seals and seal impressions, a network analysis of the relationships between these features, and a chronological network analysis showing how to automatically extract paleographic dating estimates resulting from the network’s structure and from independently dated archaeological contexts and historical data related to the seals.

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4. Networking Social Behaviours in a 19th-Century Cemetery

Joel Santos (University of Leicester)*; Tânia Casimiro (FCSH-UNL)

This paper aims to show one of Lisbon's 19th-century cemeteries, Ajuda, from a network theory perspective, combining social organisation and network theory from a movement and visibility perspective.
For this, we have studied movement networks, bearing in mind when applying our method that cemeteries are organised as cities with streets and "houses" (tombs), and tried to understand whether the location of these monuments took into consideration the places where people frequently passed. First, we used the betweenness score; however, since a cemetery is a closed space with mandatory entrances, we adapted it before applying it. Successively, we optimised this idea of movement through visibility networks, considering the cemetery as a space where the existence or absence of visibility can increase or decrease attraction and, consequently, connectivity.
For this research, we defined 13 prominent tombs with characteristics that distinguished them from the main corpus of the small buildings. The characterisation was based on size, architectural features, and decorations, making them different from all the others. But what made them attractive? Was it just the architecture, size, and decoration, or was there something else? Their differences, as we identified, were some of the aspects that made them more attractive to people when visiting the cemetery because while some stand out over all the others, others are located in places that our network revealed to be of frequent passage, most likely influencing the decision for their location.
The choice of adapting the betweenness score was fundamental. Although the traditional formula can provide information about how people walk around cemeteries, we must consider two important situations. The first is about the intentionality that Katherine Crawford (2019) demonstrated regarding people's movement, although in a different case (the city of Ostia). We should not consider that people walk around in places randomly. To overcome this, we considered that certain places create an attraction to people, influencing them to go near that place. We introduced the strength of the attraction concept in the network calculation by considering that the roads that most attracted people should be weighted higher.
The second situation is about the betweenness calculation. As mentioned above, in most closed public places, like the cemetery, people always enter from the same location, the door. To consider, as the betweenness coefficient does, that people can randomly start walking in every node (road junction) is incorrect. To overcome this, we only partially calculated the betweenness score, considering that people always start from a particular node (the door in our case). See formula:

$$x_i = \sum_{door<k} \frac{p_{doork}\, n_i}{p_{doork}}$$

x_i = Betweenness centrality of node i (road junction i)

$p_{doork}\, n_i$ = Number of shortest paths between door and node k passing through node i
(i ^{1} door or k)

p_{doork} = total number of shortest paths between the door and node k present in the network

Successively, we needed to define what attracted people in the past, which is one of the most challenging things when constructing narratives about that past, knowing that, as archaeologists, we will never be able to fully address 'all potential forms of uncertainty' (Brughmans & Peeples

2023: 187). Considering the difficulty of discussing attraction and the uncertainty of the results based on archaeological evidence, in this paper, we suggested a theoretical proposal that we believe will open paths for future investigations. However, with the information we currently have, we can only partly demonstrate it mathematically. We discuss the connection between accessibility and visibility (Turner et al. 2001: 115-116). Accessibility is about the places we can go and the routes we must physically take to arrive there (the edges in our paper). Visibility is about the places people reach with their vision, regardless of whether they can get them physically. In the Ajuda cemetery, this is fundamental to understanding people's movement. Accessibility, unless we step on recent graves, which is forbidden, is only possible by the road segments (our edges). However, it is likely to be attracted to tombs or other situations connected to us by lines of sight (a different edge, which, for future considerations, we named attraction edges). This way, when feeling attracted, we would be pushed to move toward a specific destination (a tomb in our case) that is in our line of sight, although using the previously mentioned roads, increasing the use of those same roads.
Our study demonstrates that the owners of prominent tombs considered where people passed most when choosing the place to build their tombs.

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145. Automated Network Creation and Analysis for Understanding and Fighting the Illicit Trafficking of Antiquities

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The trade of art and antiquities is a grey market comprising legal and illegal activities, with noticeable variations in legality depending on location and historical context. After the wide looting and destruction of cultural objects that occurred during WWII, the 1954 Hague Convention and related Protocols were signed and, in 1977 and 2005, extended through the Additional Protocols to the Geneva Conventions. These were significant steps in setting shared international standards for safeguarding and respecting cultural belongings in the event of armed conflicts. Additional progress was made with the 1970 UNESCO and 1995 UNIDROIT Conventions - specifically on the prevention of trafficking and illicit trade -, and the 1998 Washington Conference on the establishment of principles for the restitution of art looted by the Nazis. However, the extent and ramifications of the market for looted objects, the relationships between all the entities involved, and the actual movements of the antiquities are still mostly uncertain (Brodie et al. 2022). Recently, Giovanelli and Traviglia (2024) introduced an innovative automated system that utilises Natural Language Processing (NLP), Machine Learning (ML), and Social Network Analysis (SNA) to construct a Knowledge Graph (KG) for antiquities, which can be applied to the investigation of cultural heritage crimes, permitting the study and description of the networks that enable trafficking.

This paper builds on Giovanelli and Traviglia's automated methodology for generating a KG to study the illicit trade in antiquities by focusing on databases of WWII-looted objects. Specifically, this research examines the provenance information on these objects, which typically falls into two categories. "Conventional" provenance information presents a typical structure, where events are organized chronologically from the oldest to the most recent and are separated by semicolons or periods. However, many databases contain provenance information that does not follow such conventions, which we consider "unconventional" provenance information. This work presents a promising pipeline for collecting, processing, extracting, visualising, and conducting SNA on the provenance data of WWII-looted objects through data scraping, Named Entity Recognition (NER) with ad-hoc fine-tuned models, Node Linking (NL), Relationship Extraction (RE), and Neo4j.

Data collection for this project involved developing over a dozen Python-based web scrapers, each customised for a different online database or repository of information on cultural objects confiscated or sold under duress during the Second World War. These tools collected data on hundreds of thousands of artworks and antiquities, which were then cleaned, normalised, and correlated in a post-processing stage to identify distinct entities (including individuals, dates, and locations) and relationships among them. Once these data were gathered and pre-processed, they were fed into a database based on Neo4j (cypher language), an open-source knowledge graph platform that combines native graph storage with built-in algorithms that allow further examination utilising several network analysis measures.

The network derived from this procedure was then checked against other registries and databases of flagged actors, including the wartime Office of Strategic Services' Red Flag Names List of individuals implicated in wartime looting. The network was also correlated with data from other looted and unprovenanced art databases to identify surprising connections with other registries of problematic objects. This comprehensive dataset, collected, organized, restructured, and analysed according to the statistical measures of SNA, offers promising insights into distribution patterns of nodes and cliques clustered around specific influential actors. This research enables the identification of items still available on the market associated with or distributed by these actors. Further, it aids ongoing provenance research into these objects, many under-documented during the war and lacking sufficient provenance from the following decades. This SNA system applied to the study of illicit trafficking of antiquities was developed within the framework of the EU-funded project RITHMS: Research, Intelligence and Technology for Heritage and Market Security (GA 101073932).

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84. Connecting Riverscapes: A Large-Scale Network Analysis of Archaeological Sites in Brazil

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Fluvial landscapes have always played a fundamental role in the spatial development of human societies, particularly in shaping the settlement patterns of past communities. Rivers and watercourses not only provided essential resources for daily survival—such as water for agriculture, fishing, and other subsistence activities—but also served as critical transport corridors that enabled the swift and efficient movement of goods, people, and ideas over long distances. As such, fluvial networks are reflective of both the spatial organization and social dynamics of past communities, embodying their interactions with the physical environment.
In this study, we employ hydrological data from Agência Nacional de Águas - Superintendência de Planejamento de Recursos Hídricos and archaeological site information from the Cadastro Nacional de Sítios Arqueológicos (CNSA/SGPA) to investigate the dynamic relationships between pre-Columbian communities and the waterways they inhabited in the whole Brazilian territory. This research is conducted within the framework of the Mapping the Archaeological Pre-Columbian Heritage of South America (MAPHSA) project. Previous studies from the South American lowlands have demonstrated that archaeological sites are frequently located in areas of high accessibility and in close proximity to watercourses. Building on these insights, our analysis will delve deeper into the spatial distribution of archaeological sites in relation to fluvial networks. The objective of this research is to elucidate the influence of river networks on the development, connectivity, and sustainability of ancient societies by combining large-scale hydrology data with archaeological datasets.
To achieve this, the network will be explored at both the macro and micro scales. Sites, as nodes of the network, wil be evaluated in terms of individual importance and also in terms of their clustering with other sites/nodes. By employing centrality measures and cluster/modularity analysis, we model the “importance” of archaeological sites based on their connectivity within river-based networks. This will enable us to evaluate whether network clusters correspond with known cultural affiliations.. Centrality measures, such as closeness and betweenness centrality, allow us to rank the significance of sites according to their positions in the network. Closeness centrality reflects the average shortest path from a site to all others, revealing how isolated or connected a location is in terms of waterway access. A low closeness centrality, for example, suggests that many water routes are needed to reach that site. Betweenness centrality, on the other hand, measures how often a site lies on the shortest paths between other sites, indicating its potential role as a hub in the exchange network. Sites with high betweenness centrality may have controlled the flow of goods and ideas between distant locations.

Furthermore, we apply modularity analysis—using the Louvain algorithm—to detect sub-communities or clusters within the fluvial network. These clusters help us assess whether the structure of the river network aligns with cultural and social boundaries, offering insights into how communities may have organized themselves along watercourses. Modularity detection methods, while underutilized in archaeological studies, provide a powerful tool for uncovering hidden patterns in settlement distribution.

To test the broader model, we focus on a case study in Southern Amazon, analyzing how smaller components of the network compare to the larger regional framework. This helps us explore whether patterns observed at the macro scale hold true in localized contexts and how river-based networks influenced both regional and local social dynamics.

Through this interdisciplinary approach—integrating hydrological and archaeological data along with advanced network analysis techniques—our research contributes to a deeper understanding of the complex relationships between natural landscapes and the socio-spatial organization of pre-Columbian South America.

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257. Deciphering the social complexity of a town through the spatial complexity of its buildings: spatial syntax applied to the Old Town of Al-Ula

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Al-Ula is an oasis located in the Madinah province, in the northwest of Saudi Arabia. Dominating the Wadi al-Qura valley, it was built around Jabal Umm-Naser, a large sandstone rock formation that juts out in the middle of the valley. The site was continuously occupied from the pre-Islamic to the Islamic periods. In its current state, the part of AlUla known as the Old Town was built during the 17th century, becoming the main settlement in the region until modern times, when residents gradually moved away. By 1983, the last family had left the Old Town. Thanks to this slow process of abandonment and the lack of further occupation, the site has remained largely unchanged and well-preserved, making it an invaluable object of study.

In this talk, we will focus on two aspects of this “frozen” urban landscape: the dynamics of circulation within the buildings and the various ways rooms were occupied, using the approach known as spatial syntax.

The spatial structuring of the buildings is a key component of AlUla’s traditional way of life, a legacy that has only recently been lost. This structuring is shaped by the norms of the community that inhabit the building, influenced by economic, social, political, and cultural factors. The Old Town, however, consists of various types of buildings that display different levels of complexity and standardization. It is divided into distinct districts and was historically inhabited by two clans (Battesti 2023, 7). To better understand the social structure underlying this spatial complexity, spatial syntax is an ideal analytical approach.

Spatial syntax comprises a set of theories and techniques designed for analyzing spatial configurations, which are represented and studied in the form of network graphs that allow for objective, space-related data comparison. This method enables us to characterize the social interactions occurring in the various rooms of a building, providing insights into the daily lives of the inhabitants and the different social dynamics of the time.

The primary data for this study were gathered from archaeologists' digital room plans, architects' structural plans of building elements, and topographers' surveys. All these data were compiled and standardised in a GIS. Based on this data, it was possible to apply the spatial syntax method and adapt it to the specific context of the Old Town. Applying this approach to such a large volume of data presents a completely new challenge in urban archaeology: one-third of the Old Town, encompassing 250 buildings (for a total of 900 rooms), was analyzed. The dataset was processed using the data science software R, following a strict methodology. First, a network graph representing the spatial organization of each building must be created. The second step involves calculating network spatial indicators from these graphs, such as depth, connectivity, and centrality indexes. Two types of indicators were created: local indicators, which refer to individual graph cells, and global indicators, which refer to the entire graph. From these graphs, statistical analyses were conducted to characterize different types of buildings based on their spatial organization, as well as various room types according to their spatial relationships.

The results highlight at least four distinct types of housing unit configurations. The first type comprises 15 single-room houses. Most indicators in this category are very low due to minimal circulation, with only one access point and one room recorded. The second type, which closely resembles the first, includes 46 houses and features a floor plan with only two rooms. The indicator values for this type are also very low, and circulation remains quite limited, with the only increase being in occupancy space. Both of these first two types have a standardized layout.

The third type includes most of the buildings, totaling 176 entries. These structures consist of 3 to 5 rooms, and most have an elongated floor plan that restricts distribution between rooms and offers limited circulation options. However, circulation is improved by the presence of an upper floor. Depending on the position of the staircase, the dynamics of circulation and distribution can vary.
The fourth type is the most complex, comprising 13 buildings that range from 6 to 15 rooms. A key feature of this type is the presence of one or more central rooms around which the others are arranged, along with multiple staircases.
This method has proved effective in the study of several types of domestic buildings (Hanson 1998, 3-4). Unfortunately, a poor state of preservation often discourages archaeologists from including modest domestic buildings in such studies. However, applying spatial syntax to all buildings, regardless of their perceived simplicity, enhances our understanding of their significance and distribution throughout the town. This approach allows us to identify spatial patterns from all buildings among the different areas of Old Town.
This case study serves as a methodological example of adapting spatial syntax to a diverse array of structures. As previously mentioned, an analysis of the spatial relationships within each room of every building will be conducted. Typological studies based on architectural analysis of the buildings and architectural elements (staircase, doors, etc.) are also being carried out at the same time. Our results will be cross-referenced with these analyses, and the archaeological artifacts found in each room to refine our understanding of their functions. Simultaneously, these findings can be integrated with data on the buildings themselves to better characterize them and potentially create sub-groups.
Once these statistical analyses are complete, we will need to cross-reference our findings with various elements of the town. We will investigate whether specific features and spatial distributions are linked to membership in one of the historically identified social groups.

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470. Tracing Pottery Networks in the Late Hellenistic and Early Roman Mediterranean

Dries Daems (VU Amsterdam)*; Danai Kafetzaki (KU Leuven)

The study of networks and connectivity aimed at uncovering the rich tapestry of complex interactions and exchanges that shaped ancient Mediterranean societies is a dynamic and multidisciplinary field that encompasses important contributions from archaeological, historical, and geographical perspectives.

The Hellenistic world in particular, consisting of a large interdependent network of kingdoms, dynasties, cities, associations, and people spanning the Mediterranean, Black Sea, Near East, and Western Asia, constitutes a rich context for the application of network analysis. Joe Manning (2018, p. 40) identified four major factors that changed the face of the Mediterranean during the Hellenistic age (323-25 BCE): (1) migration; (2) imperial expansion; (3) long-distance trade; and (4) interstate competition. The common denominator across these factors was the intensification of (political and economic) connectivity and (social and cultural) interaction networks across the Hellenistic world.

While most direct attestations of past interaction have been lost, we can use the ubiquity of material markers such as ceramic tablewares to trace the structures and underlying drivers of past networks. In this talk, we will present the results of a recent study developing an innovative approach to explore material culture as markers of connectivity and interaction by leveraging the complementary strengths of least cost path analysis and mutual information. Least cost path analysis provides crucial insights into the baseline geographical pathways of trade and exchange that can be compared with mutual information analysis to explore how material distributions deviate from this expected baseline. We apply this method to a case study using the ICRATES dataset of tablewares from the eastern Mediterranean (Bes 2015), focusing in particular on the material from late Hellenistic and early Roman times (150 BCE – 50 CE). By exploring the multifaceted factors shaping these distributions, we enrich our understanding of ancient economies and trade networks, as well as provide further insight into broader questions of (cultural) exchange and power dynamics in the ancient world.

The increasing popularity of network science in archaeology has resulted in a surge of exciting new studies in recent years, mainly relying on the tried and tested tools of social network analysis.(Brughmans and Peeples, 2023). This paper builds on this growing interest, but also takes a radically different approach through the combination of least cost pathways and mutual information as an alternative lens for the assessment of material culture distributions. The approach outlined here offers a novel methodological approach to help elucidating the myriad of multifaceted factors influencing connectivity and interaction in human societies. Through this study, we aim to not only enrich our understanding of ancient economies and trade networks, but also offer insights into broader questions of cultural exchange and power dynamics in the ancient world. This way, we tope to help pave the way for future research endeavours that seek to unravel the intricate threads of connectivity shaping past and present human societies.

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505. Exploring the structure of Roman terrestrial mobility: a network study of the roads of the Roman Empire using the Itiner-e dataset

Tom Brughmans (Aarhus University)*; Matteo Mazzamurro (Aarhus University); Pau de Soto (Universitat Autònoma de Barcelona); Adam Pažout (Universitat Autònoma de Barcelona)

Introduction

Terrestrial mobility in Europe, North Africa and The Middle East was entirely reshaped during the Roman Empire and structured human interaction potential in the region for the two millennia that followed. Here we report on the first quantitative exploratory network analysis at a high spatial resolution of the structure of roads in the entire Roman Empire.

A number of long-held assumptions about Roman roads have significantly influenced our understanding of the millennia-long development of terrestrial mobility in Europe, the Middle East and North Africa: the Romans built all the roads in their empire, they were all straight, led directly to Rome, and much of the present-day road network still follows older Roman roads. Yet a detailed quantitative understanding of the structure of terrestrial transport infrastructure during the Roman Empire does not exist, because a spatially detailed quantitative analysis of the roads of the Roman Empire to empirically identify and evaluate these assumptions has never been performed. We do not know how human interaction potential was shaped by road infrastructure during the Roman period and in the two millennia that followed. Identifying this structuring effect is crucial for studies of key phenomena in the region such as past epidemics, the millennia-long development of terrestrial transport and continental-scale trade, the spread of technological ideas, the growth of Christianity and Islam, and mass migration. Here we present the insights of the first such study.

Materials and methods

We will introduce the Itiner-e dataset (Brughmans et al. 2024) used in this study, and briefly describe how it was created. It concerns a major collaboration centred on projects MINERVA and Viator-e to create a spatially highly-detailed digital representation of all roads of the Roman Empire. Road data collection was based on a diversity of sources, from excavation reports and field surveys to milestones and ancient itineraries. Road digitization in GIS was aided by satellite photography, as well as historical and modern topographic maps.

The resulting Itiner-e dataset was subsequently represented as a Geo Json polyline file, the spatial structure of which was explored in GIS using techniques including sinuosity to explore straightness. It was also represented as a network dataset with 10399 nodes and 14765 edges, and analysed using exploratory network measures including edge betweenness, degree distribution, and clustering coefficient. Moreover, we explored the fit of the empirical Roman road network with a range of simple spatial neighbourhood models.

Results

The dataset contains 299,273.263 km of roads in a total study area of 5,271,920,243 km2, giving a global road density in the Roman Empire of 56.767 m/km2. We have identified low sinuosity in general, reflecting a road system with relatively straight roads. The network representation of the dataset has a global clustering coefficient of ~8%, making the network seemingly very sparse. However, over 47% of theoretically possible connections are present in the network. This, together with the fact that the network is connected within each contiguous land mass (continental Europe, Asia-North Africa, Great Britain, and various Mediterranean Islands), suggests that the road network was in fact quite densely interconnected. The network shows some similarity with the structures observed in a relative neighbourhood graph.

Discussion

Our results dismiss and reevaluate long-held popular and scholarly assumptions about Roman roads. They instead reveal the diversity of the structure of Roman terrestrial mobility in unprecedented detail. Our insights into the most foundational historical structuring of terrestrial mobility in Europe, the Middle East and North Africa, are crucial for understanding the long-term development of mobility in this huge area.

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410. Relating Roman Rings: an open and reproducible approach to understanding provenance patterns of wood using networks

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Wood was, is and will be on of the most important resources. While wood is one of the most sustainable and strongest building materials, wood is also prone to decay and therefore often lacking in archaeological contexts. In the Roman period many objects and structures were made of wood, such as road, bridges, ships, buildings, chairs, boxes and buckets. However, these are only found in very dry or very wet conditions. The lower Rhine area is such an environment, with high ground water levels and a high sedimentation rate, resulting in excellent preservation conditions for organic materials, such as wood. Over the past decades, wood has been excavated and part of this has been subjected to dendrochronological and dendroarchaeological research. This resulted in a large dataset of tree-ring material. While the find location is often known, the provenance of the trees, i.e. the growth region, is often unknown and has to be reconstructed. Determining the provenance of wood based on dendrochronological research is termed dendroprovenance. This is often based on matching tree-ring patterns with existing regional and/or site chronologies using various software packages. This process does not always comply with the aims of Open Science, since not all software is open, sometimes resulting in workflows that are not fully reproducible. This paper will address the following central research question: How to determine the provenance of wood using dendroarchaeology in a reproducible and open method?

Before being able to address the question in detail the data needs to be described, explaining the life history of the data set, what temporal and spatial patterns are present in the dataset. These patterns define the suitability of the data for further analyses and this will be discussed in the presentation.

Dendroprovenance is an important field of research aiming to determine the provenance of wood. A new method has been developed using network analyses to assess the provenance (Visser 2021; Visser and Vorst 2022). Networks are created using the pair-wise similarity of tree-ring patterns to build the edges, while the nodes represent the find location or the wood sample. The neighbours of a node in the network reflects the similarity of the growth patterns and therefore the trees probably grew in the same region. However, since wood could have been moved and transported in the past, various factors need to be taken in to consideration when interpreting the patterns, such as context, spatial location, growth patterns (Visser 2021, 244). These networks have lead to new insights in the Roman wood economy and has also shown that wood was only transported over long distances in specific projects, such as the road along the Roman limes or to construct Roman barges (Visser and Vorst 2022). Local wood procurement was the rule, and long-distance transport remained the exception.

The analyses and method were published as open as possible and all data and source code was made available upon request, but to advance the openness and reproducibility, a package for R was developed (Visser 2024). This package is reviewed and published with rOpenSci: https://docs.ropensci.org/dendroNetwork/. Building a package ensured that the methodology became more generally applicable. At the same time, lessons were learned, especially how to share a method in a reproducible and universal way (https://ropensci.org/blog/2024/06/06/from-scripts-to-package/).

This presentation will deal with the issues in the dataset and how network analyses using open software resulted in a reproducible workflow leading to new insights into the wood economy in the Roman period. It will also address some of the challenges of making research completely open by sharing scrips and a package, and how network science is an essential aspect thereof.

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23. Nodes, neigbors and networks: a comparative approach to Roman trade dynamics

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Networks are an integral part of understanding larger systems in the past. Economic dynamics rank among these systems, having no clear-cut and simple way to be understood. Thus, the only thing that archaeologists can do is conduct data investigation of Roman amphorae and table wares from several sites on the Mediterranean coast. These can give a good understanding of distribution patterns. Not knowing how these patterns were produced, we need to find a way to understand the formation of what we see in the archaeological record. One way to represent these distributions surely comes from network analysis, which has been conducted for the material presented in this study on the whole and various chronological sub-slices, revealing an interesting pattern that may not be the same for each period and material.
Several theories have been proposed, yet proving and disproving such theories is hardly achievable in the traditional sense, which is why this study turns to test several theories by using an ABM simulation approach that incorporates, among others, network structures that aim to explain the distribution of the archaeological finds.
Based on the regular framework of scientific modeling (Nakoinz – Knitter 2015), where the empirical record is compared to a simulated output based on theories, this paper focuses mainly on the network theories that seem rather obvious for Roman trade: state-driven networks, private networks, regional-networks and no networks at all. The model theory behind these networks will be presented, while the results of the simulations will be brought forth as well.
A first impression of how these network-based theories on Roman economic dynamics compare to the real-life record, will also be shown, evaluating if any of the suggested networks could have had an impact on the empirical data that we as archaeologists can find and analyze.

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239. Documenting and presenting material properties of archaeological artefacts in 3D

Sjoerd van Riel (Museum of Cultural History, University of Oslo)*; Letizia Bonelli (Museum of Cultural History); Alexis Pantos (Museum of Cultural History)

Introduction

Documenting material properties of artefacts in 3D is not only about creating visually engaging models. Describing these properties plays a crucial role in communicating and understanding of features essential to research, conservation and detailed study of artefacts. Even though metrically precise records of surface materials can be challenging to create, even carefully produced 'faked' versions can reflect subtle but meaningful details about the technical details of manufacturing techniques, or personal experiences with the original.

Approaches to reality-based capture of material properties is in some ways more advanced in the game- and film industries, while standardized workflows for capturing and presenting these properties in an academic archaeological context are still few and far between. However, those that do exist (e.g. Frost et al. 2023) illustrate that even relatively simple techniques such as cross-polarization combined with diffuse lit capture can provide insights into applications of glazes or the presence of pigments and other features meaningful to scientific debate.

In this paper we present ongoing efforts at the Museum of Cultural History to improve our documentation of these properties using both standard and developing methods (e.g. Brown et al. 2024). Rather than serving as a "how-to", the paper aims to foster a collective exploration of the benefits of a more inclusive approach to 3D documentation, explore common challenges and encourage the sharing of potential solutions that are applicable within the practical limitations of museum documentation programs.

Methods and materials

The Museum of Cultural History houses a vast collection of cultural heritage artefacts, from archaeological stone tools discovered in Norway to ancient Greek objects. Since the early 2010s, the museum has implemented 3D digitisation, primarily using Structured Light Scanning, photogrammetry and Micro-CT scanning. Despite their varied affordances and challenges, these technologies can be effectively integrated to achieve optimal outcomes.

Currently, much of the 3D digitization work is focused on the needs of new Museum of the Viking Age, set to open in 2027 and to feature innovative exhibitions displaying the renowned Oseberg and Gokstad ship burials. This work coexists with other digitization projects, such as UI3D (Understanding and Immersion in 3D) that focuses on better understanding the requirements for 3D data in the context of research and education. These efforts are not focused solely on the needs of students, but conservators, archaeologists, curators, exhibition designers and the broader public. This diverse client base requires flexible capturing and presentation strategies that can be readily adapted to meet users' needs.

With numerous 3D documentation projects underway, efforts to standardize and optimize workflows for capturing and presenting 3D data and material properties are ongoing. Current online presentation and distribution technologies are limited as is broader understanding of the importance of preserving these features, especially at an academic level. This presentation will reflect on some of these limitations, our approaches to circumvent them and some of the developing technologies that have been trialled to build on the extensive 3D documentation work at the museum over the past decade.

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164. Relative-Depth Imaging and the Digital Squeeze: Nonphotorealistic tools for Epigraphical Autopsy at the Athenian Agora

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Introduction

The Digital Epigraphy and Visualization project at the Athenian Agora (DEVA) has been developing new techniques to generate 3D models and enhance the clarity of damaged marble inscriptions at the Athenian Agora since 2019. The 3D data are the basis for 2D visualizations of the inscribed surface which both increase the legibility of deliberately carved ancient letter-strokes and distinguish them from later accidental damage. The visualizations superficially resemble those generated by the well-known Reflectance Transformation Imaging (RTI) technique, which is based on 2D photography, but they add 3D morphological information that is key to improving readability. The new 3D layers, known as Relative-Depth Imaging (RDI), supplement and often exceed what can be discerned during a personal autopsy of an inscribed stone.

In this paper, I will summarize briefly the imaging strategies developed for modelling Agora inscriptions, while focusing on a pair of case studies that represent the utility of RDI imaging for epigraphical study and reinterpetation.

Methods and materials

To date, most efforts in the area of Digital Epigraphy have concentrated on the encoding and dissemination of textual corpora online, which allow the rapid search and retrieval of annotated texts through interfaces such as the Searchable Greek Inscriptions from the Packard Humanities Institute. These corpora, however, are the end product of an extended process of epigraphical autopsy – an interaction between a human analyst and a damaged, incomplete, and partially effaced object. No one transcription is ever complete, and most well-known texts have no final agreement over which marks were deliberately inscribed on the surface, and how the text might be restored from the exiguous traces. Epigraphists have relied on a combination of hand-made line drawings, still photographs taken under raking light, and paper squeezes (a 1:1 copy of the stone made for epigraphical study collections) for documenting the evidence underlying a particular interpretation.

The DEVA project is contributing to the interrelated problems of recording an ancient text in a procedural manner – promoting objectivity – as well as presenting more subjective interpretations overlaid on this source evidence. DEVA builds upon my previous work developing RDI as a general algorithmic approach to surface enhancement (Sapirstein 2019), by applying these approaches to a new collection of challenging texts from the Athenian Agora in 2019–2023. The project has deployed a variety of new imaging methods to great effect, including techniques to record accurately the 3D geometry of reflective marble by means of photogrammetry with polarizing light filters, and to combine different styles of illumination in the final models. To date, DEVA has digitized a collection of 35 stones at the high resolutions, up to ca. 10,000 measurements per square millimetre, needed to clarify the minuscule lettering typical of Attic steles. In effect, we are creating a digital analogue to the paper squeeze which is not only more readily disseminated, but opens up new analytical potentials.

Results and Discussion

I will focus on the RDI products for two Agora inscriptions whose reconstructions have been hotly debated in recent years, I 6701 and I 7495 (Richardson 2021; Tracy 2024). The imagery largely supports the latest studies of these stones, but it has clearly indicated additions and corrections are necessary in several regions. All of the features identified through RDI are visible to the naked eye on the original stone, at least when assisted by raking light and a hand lens, but the technique helps the user quickly identify meaningful patterns concealed within a sea of distracting information caused by scrapes, breaks, and other accidental damage to the inscribed surface. The accurate orthographic projection and navigability of the digital images are particularly helpful in keeping oriented while working through a difficult line of text. The annotation of the scan with spatial references such as baselines and character positions is a simple but particularly effective use of the digital layers. I will also consider where RDI performs poorly, or at least where is provides an incomplete representation of the original subject. Although I will argue that RDI can entirely replace the functions of a paper squeeze, I have concluded that these combined methods are, ultimately, a useful tool that can greatly assist but not replace the embodied experience of an in-person scrutiny of the original stone.

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261. New Technologies for the Documentation and Visualization of Greek Pottery

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1. Introduction: Current State of the Art for the Documentation of Greek Pottery
The study of painted pottery represents one of the most important and enduring areas of research in Classical Archaeology, dating back to the middle of the 18th century. This is particularly relevant in the case of the vessels from Corinth, Athens and the Greek colonies in southern Italy and Sicily, which have been preserved in a wide variety of contexts in a large number of fragments and entire objects. The scenes depicted on them constitute the most significant pictorial sources for understanding the mythology and reality of life of the ancient Greeks. Furthermore, the vase paintings represent the most important chronological markers for the development of Greek art from the Geometric to the Hellenistic period.
In addition to the Beazley Archive in Oxford, the Corpus Vasorum Antiquorum, which was established in 1921, represents the most significant resource for the documentation and publication of vases. The publications are based on high-resolution photographs of all sides, which can be supplemented by details, as well as scaled profile drawings and concise descriptions. This combination of photography and drawing has remained largely unchanged for almost a century. In our presentation, we aim to discuss how new 3D methods can help to revolutionise the documentation of painted Greek vessels.

2. A New Approach of Documenting and Visualizing Greek Pottery
The principal challenge of the 3D recording of Greek pottery, particularly Attic black and red-figure vases, is their pronounced reflectance, which poses problems for all available 3D recording technologies like Structured-Light-Scanning or photogrammetry. Since texture, in addition to shape, plays a crucial role in the documentation of the vases, we decided to approach the problem using photogrammetric methods. As the object is rotated, the reflection remains static, with the light and camera position unchanged, resulting in an inconsistent data set that is difficult to process. Furthermore, the extremely dark and smooth tone presents an additional challenge, as it lacks the necessary features for the photogrammetric process. Additionally, the presence of specular areas significantly impedes the generation of a uniform colour and texture, necessitating extensive post-processing. Consequently, it has been postulated that the method is unsuitable for the 3D recording of Attic vases.
An approach is to utilise polarised light to either prevent or, at the very least, reduce the occurrence of specular reflections. In order to achieve this, a polarising filter can be utilised on the lens, which permits the passage of light that oscillates in a single direction. It should be noted that not all unpolarised light can be filtered out using this method; therefore, the light used for exposure can also be polarised. The filters can now be rotated so that they are at right angles to each other, thereby filtering out all unpolarised light. This method allows the effective removal of almost all unwanted reflections, facilitating the straightforward processing of the resulting images and the derivation of a 3D-model and a uniform texture, that accurately reflects the shape and appearance of the object. The filtering of reflections during the recording process results in their absence from the model, which exhibits a notable contrast in texture compared to the original. Consequently, a further step is required to reinstate these reflections within the model. In the context of Physically Based Rendering (PBR), the utilisation of roughness maps facilitates the simulation of reflections associated with diverse material compositions of the objects.

3. Results and discussion

The technical developments of the last decades have provided us with new and powerful tools for the documentation and publication of archaeological objects. Notably, the documentation of Greek pottery, which traditionally necessitates the input of various experts, has become significantly more straightforward and efficient.

Derivatives can now be produced from the model without the necessity of further contact with the original. We will demonstrate a pipeline that enables the production of high-resolution renderings in a virtual photo studio for conventional printed publications. In contrast to traditional photography, the potential for perspective or lens distortions resulting from spatial limitations during image capture is eliminated by the digital photo studio, which offers unlimited possibilities.

Additionally, the models can be used in web-based or virtual reality environments. Furthermore, the presentation will address the emergence of novel analytical techniques that are enabled by the utilisation of three-dimensional models, which are not encompassed by conventional methodologies. Subsequently, we will illustrate how the models can be permanently stored and made available in the research data repository of the University of Bonn (https://bonndata.uni-bonn.de/dataverse/akm). Through our contribution, we aim to promote the collaborative development of standards for the generation of 3D models of Greek vases and their exchange.

367. GCS Model: Developing 3D Reconstructions of Classical and Hellenistic Statues for Interactive Museum Exhibition based on the PSHuman Algorithm

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With the rapid development of deep learning techniques, automatic 3D reconstruction holds significant potential in cultural heritage. However, current research on the three-dimensional reconstruction of museum artefacts and enhancing interactive experiences for visitors is still in its initial stages. Take classical and Hellenistic statues as an example. These statues often exist in multiple versions or forms dispersed in different museums. Existing methods only provide simple image comparisons, offering limited contextual understanding and failing to meet the deeper interpretive needs of museum visitors. We present the 3D Reconstruction Model of Greek Classical and Hellenistic Sculpture (GCS Model), developed based on the PSHuman deep learning algorithm and trained with a customized GCS dataset. The GCS Model can generate high-fidelity, smoothly rotatable 3D reconstructions with rich geometric details and photorealism from a single photograph of a classical or Hellenistic statue. Preliminary results show that GCS models effectively facilitate the digital connection of sculptures across geographical boundaries. By displaying the generated 3D reconstruction output, visitors can engage in deeper comparisons of similar statues located in different museums, prompting thoughtful reflection on the artefacts. This approach contributes to the impact of virtual museum exhibitions and social media marketing while promoting cross-institutional collaboration and cultural dissemination.

Introduction

Promoted by techniques such as deep learning, the automated 3D reconstruction of ancient places has recently made significant progress in many application fields, such as the creative industry. In archaeology and heritage, virtually reconstructing places and artefacts of the past has been an established practice since the 1990s (Lercari and Busacca, 2020). However, in museums, utilizing artificial intelligence-powered techniques for automatically reconstructing 3D museum collections and enhancing the interaction between exhibited cultural artefacts and visitors is still at an early stage. Take statues from the Classical (c. 480–323 BCE) and Hellenistic (c. 323–31 BCE) periods as an example. They include originals and their gypsum replicas (plaster casts), usually in multiple versions or forms, such as complete or incomplete sculptures and fragments. When these statues have missing parts or severe damage, they are treated with different restoration techniques and displayed in various museums. Often, museum visitors encounter such fragmented or incomplete statues without access to their background information or thematic or typological contextualization. Some museums address this issue by providing visitors with simple comparisons using images of similar complete statues held at other institutions. However, we believe this approach has limitations in enhancing the depth of visitor understanding of ancient sculptures and allowing for a more complete interactive experience.

To solve this problem, this paper proposes the 3D Reconstruction Model of Greek Classical and Hellenistic Sculpture (GCS Model). This deep learning model takes photographs of Classical and Hellenistic sculptures as input and automatically generates derivative photorealistic 3D models with detail. Our approach is significant, especially about incomplete statues, as the GCS Model generates their 3D reconstructions using a few available photographs from similar sculptures we retrieve from other museum catalogs combined with our training dataset. The resulting 3D reconstruction can be displayed in interactive kiosks next to the exhibited object or on a museum website, thus enhancing the visitor experience and fostering cross-museum connections. We argue that the proposed approach enables a richer interactive experience for visitors, encouraging them to observe the collection more closely and think critically about the context of an object and its relationships with other artefacts from the same period, thereby enhancing the educational value of the artefact displays. For instance, using the output of the GCS Model, museum visitors can better appreciate individual sculptures in the collection and compare them with the 3D reconstructions of other versions of the same statue held at other museums.

Methods and materials

The GCS Model is built upon an advanced PSHuman algorithm, which we fine-tuned and optimized using our GCS dataset, tailored explicitly for sculptures from the Classical and Hellenistic periods. We chose artworks from these periods because they feature the structure of muscles and bones and the aesthetics of the human body in a realistic and naturalistic manner, which makes our automated reconstruction work more viable (Fowler, 1989). The GCS Model contains high-quality multi-view images of hundreds of sculptures and their corresponding high-precision 3D point cloud data, which we captured at Museum für Abgüsse Klassischer Bildwerke (MfA) in Munich, Germany. The MfA holds an extensive collection of 1:1 scale gypsum replicas of well-known Classical and Hellenistic statues.

Datasets:

We collected hundreds of high-resolution multi-view images of MfA statues using a Digital Single-lens Camera (DSLR) and the corresponding 3D scan data we captured using an Artec Leo structured-light laser scanner. These 2D and 3D data constitute the basis of the GCS dataset, which we also enhanced using other multi-view images that were scraped from the Web. We selected 80% of the data as the training set and 20% for evaluating the model quality, i.e. to assess the generalisation on real-world scenarios. Because machine learning models require large amounts of data to train on and the number of Classical and Hellenistic sculptures available in museums is not so large, we chose to supplement the GCS dataset with a modern dataset of natural human bodies as a supplementary dataset based on the high realism of the sculpture from these periods.

Algorithm:

PSHuman is a cross-scale diffusion algorithm that models the joint probability distribution of the entire body shape and local facial characteristics, enabling new perspectives rich in detail and free from any geometric distortion (Li et al. 2024). The algorithm provides body priors that prevent unnatural perspectives inconsistent with human anatomy. Finally, the generated multi-view and colour images are used to recover a realistic textured human mesh efficiently. We used the PSHuman algorithm to create our GCS Model using the following workflow for data processing and model training (Fig.1):

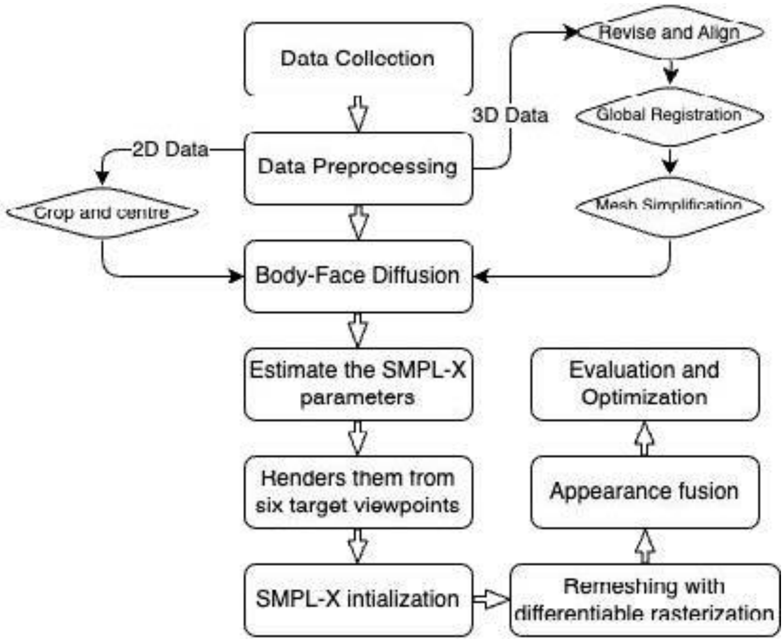

Figure 1. GCS Modelling Process.

Results & Discussion:

Our preliminary results show that the GCS Model generate good quality 3D reconstructions of Classical and Hellenistic statues by inputting a single statue image. The generated 3D models have rich geometric details, including intricate facial and body features, clothing texture, and wrinkles. Additionally, these 3D models effectively handle complex poses and occlusions while maintaining the accuracy of the human anatomy, which is a defining feature in the types of statues we worked on. Although the accuracy of the output is not yet suitable for research-level applications in Classical Studies, the resulting 3D meshes faithfully represent complete Classical and Hellenistic statues. They can be integrated into MfA's interactive kiosks or online catalog to create immersive educational and visually stunning visitor experiences, enhancing museums' educational mission.

To conclude, the proposed GCS Model delivered good results for the virtual reconstruction of Classical and Hellenistic statues. Therefore, our model has the potential to enhance the narrative of museum exhibits, increase the impact of virtual exhibitions and social media marketing, and promote cross-institutional collaboration between museums.

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475. 3D digitization of a composite medieval sword: challenges between dry versus wet surfaces

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Digital restoration plays a crucial role in the study of cultural heritage, offering valuable tools for the understanding, analysis, and preservation of artifacts and monuments. Three-dimensional models (3D), such as those created through close-range photogrammetry, enable researchers to examine objects in detail, regardless of their physical condition or location. This capability is especially important for fragile items that may be impossible to study using traditional methods. The ability to digitally merge components of an object aids in visualizing its original form, even when the parts cannot be physically reassembled. The study and digital restoration of complex objects present a range of challenges and opportunities like the following.

The diversity of materials requires specialized imaging and digital processing techniques tailored to the unique characteristics of each material. The conservation condition of objects, usually affected by wear, degradation, or missing components, further complicates digitization, necessitating expertise to reconstruct or digitally merge deteriorated sections. Additionally, the geometry complexity of objects with intricate curves, corners, and details demands extensive photography, sophisticated lighting setups, and time-intensive processing for accurate modeling. Finally, data synthesis becomes a challenge when integrating digital information from damaged or modified components into a cohesive and accurate 3D model.

To address these challenges, several innovative solutions can be applied. Integrated imaging techniques enable the detailed documentation of an artifact, ensuring nothing is overlooked. Virtual conservation allows for digital restoration and maintenance, minimizing the need for physical intervention and preserving the object's integrity.

This paper presents a case study of the conservation process applied to a composite waterlogged archaeological sword discovered in the main dock of Rhodes' commercial harbor during underwater excavations in 2013. The sword, a medieval weapon from the 13th century AD, falls into the “sword of war” category and consists of metal, and highly mineralized organic material - wood and leather. During conservation, the sword fractured into two segments, labeled A' and B'. Conservation and drying were successfully completed for section A', while section B' underwent analysis to assess the materials and extent of deterioration.

This study focuses on section B' of the sword, which is in a severely deteriorated state, making it unsuitable for the same drying technique used on section A', during which additional corrosion was detected on the metal surface, with all the associated implications. The purpose was to digitally document and restore the entirety of the sword, preserving its structural details, textures, materials and deterioration patterns by creating a precise three-dimensional model of the artifact. In this context, close range photogrammetry tools were explored to digitally restore both parts of the sword, and the methodology, procedure, and technological tools used, are presented. For section A', the conserved dried part, the 3D model displayed excellent detail, accurately capturing deterioration patterns, cracks, and color variations, as well as texture. However, the 3D modeling of section B', the waterlogged part, yielded less satisfactory results due to the software's limitations as well as complicity of the artifact. In particular, the sword’s metallic surface and reflective quality due to its wet state, uniform color and texture, and iron corrosion products created low color contrast, complicating the software's ability to differentiate points and complete the model accurately.

The attempt to reconstruct the two sections of the sword, dry and wet, through photogrammetry proved quite effective for capturing intricate details, textures, and color variations, although inadequately integrating aligned groups of images. Despite the fact that the resulting model did not present a fully unified sword, it helped the conservation team to visualize the connection between the two sections. Ultimately, this research aims to serve as a reference point for future conservation efforts, contributing to the preservation of the sword's historical integrity as an archaeological artifact.

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468. 3D Model Representations of Crosses with Micro-Relief Utilizing Photogrammetry and NeRFs Techniques

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Introduction

One of the main challenges in 3D digitization is how to create three-dimensional (3D) replicas of miniature art objects using easily accessible software and without the need for expensive equipment. In cultural heritage various 3D reconstruction technologies (optical laser scanner, structured-light scanner and photogrammetry), are widely used because of the accessibility and accuracy they provide. However, the recent advancements in Neural Radiance Fields (NeRFs) offer new views in the synthesis and address challenges such as reflective and complex surfaces. We want to investigate how NeRFs can contribute to 3D digitization in a controlled environment, specifically focusing on small dimensions and complex blessing and sanctification crosses made from various materials with different reflective properties.

Methods and materials

This paper examines three-dimensional digitization by analyzing religious crosses used for blessing or sanctification. The methods employed for creating the 3D models include photogrammetry and Neural Radiance Fields (NeRFs). This research examines the theoretical and practical aspects of imaging techniques such as photogrammetry and NeRFs and the contribution enhancing the digital technology to the visualization and presentation of artworks. It also addresses the various challenges and opportunities these methods present and the capabilities at creating the digital model as an accurate digital representation. Challenges such as complex material textures with different reflective properties.

Recent developments in computer graphics are providing powerful tools for modelling works of art, even those with small dimensions and intricate details in relief. Today, three-dimensional techniques in computer graphics can be employed to reconstruct and visualize the features of objects with complex material appearances. Accessibility and use utilization of 3D capture technology in cultural heritage has had in recent years; However, there is still a lack of knowledge, in many fields, use of expensive equipment is generally often considered essential.

Photogrammetry creates accurate 3D representations from overlapping 2D images. This method is both affordable and widely accessible. In many fields, it can yield high-resolution texture mapping for realistic visuals.

The addition of Neural Radiance Fields (NeRFs) technology, which uses neural rendering techniques to synthesize new views and capture complex surface details. NeRFs can also extract images from video, which serves as a valuable and user-friendly tool in this domain. The speed, quality, and low requirements of this method make it a beneficial option for creating a cost-effective alternative that meets satisfactory quality standards. NeRFs can effectively better manage the reflections and color variations caused by metallic surfaces, resulting in more realistic visualizations but the representation is a novel view.

Unique miniature objects, due to their construction techniques, fragile materials, and inherent vulnerability, can be challenging to access for documentation and study. The artifacts we examine include blessing crosses made from various materials, such as metal, curved wood, and semiprecious stones.

Micro-reliefs on crosses often exhibit fine, intricate details that necessitate high-resolution imaging and processing. Reflective or metallic surfaces can complicate 3D reconstruction, requiring additional pre-processing or alternative methods, such as polarized filters. Capturing

and preserving digital representations of religious artifacts for future generations, while providing virtual access for remote researchers, is vital for cultural and archaeological studies. The remote observation of complex miniature works of art is essential, as is the preservation of these objects. Achieving both objectives can be accomplished through the application of three-dimensional digitization and modeling techniques.
The latest approaches to data collection and visualization in 3D reconstruction techniques, such as Neural Radiance Fields (NeRFs), are fundamental tools for research, documentation, and innovation. This analysis examines the procedures involved in three-dimensional modeling and rendering techniques, along with the challenges and opportunities they present. The primary objective is to create a digital three-dimensional replica of an artifact using readily accessible software.

Results
This work aims to contribute to the limited body of bibliographic literature concerning the aforementioned miniature crosses and the digital modeling of small-sized, different reflective properties and highly complex artefacts. Comparative assessment is a central theme in research on Neural Radiance Fields (NeRFs), as researchers seek to understand their advantages and limitations compared to established 3D reconstruction technologies. This paper shows the ability of NeRFs to handle complex lighting conditions and produce detailed visual reconstructions in cases where the traditional point cloud from photogrammetry faces challenges and requires more expensive equipment. It is widely accepted that photogrammetry provides accurate geometric data and textures while Neural Radiance Fields (NeRFs) excel in handling complex light interactions and rendering high-fidelity details. These reconstructions are often superior for the models that have complex and reflective surfaces. This paper examines how NeRFs can address the challenges of photogrammetry on capturing the intricate micro reliefs and the reflective materials. By using neural rendering techniques, NeRF shows major potential in the future directions of the 3D documentation of complex cultural heritage objects.
Some results meet the standard expectations for realism that can be achieved. The primary objective is to create a digital replica of an object utilizing user-friendly software, eliminating the necessity for specialized equipment. Current technology has not yet achieved the level required to produce state-of-the-art 3D models with exceptional detail. Neural Radiance Fields (NeRFs) are regarded as one of the most promising tools for documenting cultural heritage, thereby making it accessible to a broader audience.

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359. Double-Hemisphere RTI for Translucent Heritage Objects

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This study introduces a novel approach to Reflectance Transformation Imaging (RTI) for examining translucent heritage objects, specifically Viking Age beads from Bygland, Norway. Traditional RTI techniques are limited in capturing translucency properties. We propose incorporating a backlit frosted glass or diffuser pane into the RTI workflow to enhance the documentation of translucent characteristics.
Using an automated illuminator with 50 LEDs, we capture images with and without backlighting. This method aims to improve the visualization and analysis of light interaction within translucent artifacts, contributing to more accurate physical and virtual replications. Potential applications include creating interactive museum exhibits and advanced digital renderings using techniques like Neural Radiance Fields or volumetric rendering."

308. Neural Rendering and 3D Reconstruction for Mass Digitization of Cultural Heritage? A Case Study of Medieval Tombstones (Stećci)

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Neural rendering techniques have made great progress in recent years and their application is spreading rapidly in the field of cultural heritage. Techniques such as Neural Radiance Fields (NeRF) and Gaussian Splatting, as well as other 3D neural reconstruction networks such as DUSt3R, show great potential to complement traditional digitization methods such as Structure from Motion (SfM) photogrammetry.

DUSt3R, NeRF and Gaussian Splatting are advanced techniques for 3D scene representation and reconstruction. DUSt3R focuses on efficient 3D reconstruction from unconstrained image collections without the need for camera calibration and uses pointmaps to combine monocular, binocular and multi-view tasks. It has shown great promise in geometric applications such as depth estimation and pose recovery (Wang et al. 2023). NeRF (Neural Radiance Fields) models scenes as neural functions that encode volumetric density and radiance, enabling photorealistic novel view synthesis through computationally intensive volumetric rendering. In contrast, Gaussian Splatting uses sparse 3D Gaussians to encode scene geometry and color, providing a faster and more efficient alternative for rendering while maintaining high visual quality.

Previous studies using NeRFs in the context of cultural heritage documentation have shown that they can outperform photogrammetry under conditions of reduced input data or lower image resolution. NeRFs are effective at rendering reflective, metallic and translucent surfaces, which are challenging for photogrammetry. However, they are more susceptible to noise and have problems capturing fine geometric details in high-resolution datasets. (Croce et al. 2024). Gaussian Splatting on the other hand, has been shown to offer real-time rendering capabilities and better handling of texture, brightness and depth effects, making it an effective method for visually convincing models, but with slightly lower accuracy in detail reconstruction. Both methods have potential for virtual and augmented reality applications and for scalable 3D modelling. However, challenges include inaccuracies in reconstructing features with limited viewpoints and high computational requirements for NeRFs (Basso et al. 2024).

In contrast to NeRFs and Gaussian Splatting the neural 3D reconstruction method DUSt3R offers a different approach for 3D reconstruction. Its pointmaps based approach allows for scene reconstruction even when camera parameters (intrinsics and extrinsics) are unknown. DUSt3R streamlines traditional multi-view stereo (MVS) workflows by bypassing the reliance on explicit camera calibration or prior pose estimation (Wang et al. 2023). This method has not yet been applied to cultural heritage documentation.

Our case study focuses on the mass digitization of medieval tombstones scattered across the landscapes of the Western Balkans, also known as Stećci. Of the approximately 60,000 known stećci, only 8% are decorated with various bas-relief decorations according to the current state of research, and inscriptions dedicated to the deceased have been documented on fewer than 400 tombstones. Despite their large number, the stećci seem to be disappearing from the landscape. The deteriorating condition is particularly evident in the severe weathering of certain tombstones, which is exacerbated by the predominant use of local limestone as the primary carving material. This choice of material combined with environmental factors has significantly degraded the quality of the iconography and inscriptions on these monuments, making them ideal candidates for mass digitization.

Previously, our approach was based on photogrammetry, but it quickly became clear that this approach may not be feasible due to the large number of these tombstones. Under ideal data

capture conditions, conventional photogrammetry still provides extremely robust and accurate results. However, its major drawback is the time and expertise required by technicians for each scan. While this may not be a problem for individual applications, the approach becomes impractical for mass digitization efforts, especially in outdoor environments where scalability and efficiency are critical. Neural rendering techniques could allow us to use a faster method of data acquisition, such as capturing video of the objects or using lower resolution and quality imagery, and still achieve reliable results.
In this paper, we compare the results of the mentioned neural rendering 3D reconstruction techniques and evaluate their effectiveness, quality and their potential applications for mass digitization.

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501. Pretty Pictures and Research Tool: Enhancing 3D Documentation of Historic Clinker Boats through Parametric Modeling

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Introduction
Photogrammetry and LiDAR have become standard tools for preserving the surface details of archaeological artefacts. However, these methods often fall short in capturing the underlying construction principles and material properties that define the essence of complex objects like historic clinker boats. This paper presents a novel approach that integrates reverse engineering and procedural reconstruction techniques to enhance 3D documentation in heritage.

Methods and Materials
Focusing on the Mjøsbåt project—a conservation initiative for early 20th-century clinker-built boats in Norway (Anno Museum, n.d.)—we demonstrate how overlaying photogrammetry scans with clean, parametric 3D models developed in SideFX Houdini can unveil the inherent construction principles of these vessels.
Our current prototype of a Houdini Digital Asset allows us to define sections based on the scanned geometry of a boat. These sections serve as visual guides to establish corner points for aligning the planks. The amount of overlap, bending, and other parameters of the planks can be adjusted to match the shape of the overlaid scan.
By considering the parameters of each single plank, our method preserves not just the visual appearance but also the construction methods themselves. This enables the generation of accurate 2D plots, scale models, and even assets for interactive applications.

Results and Discussion
Our approach provides a more comprehensive understanding of materiality that goes beyond surface-level aesthetics. We discuss how this method can aid in the documentation process of clinker boats, its advantages, and how it can complement common 3D reconstruction techniques based on point clouds. This includes the ability to produce variations of ship designs and compare different construction methods.
We'd like to emphasise the importance of moving beyond the binary of "pretty pictures or research tool" by demonstrating that aesthetic quality and research utility are not mutually exclusive but can be mutually reinforcing.
By focusing on construction methods, our approach not only replicates the artefact but also preserves the construction techniques, supporting the craft of boat building and acknowledging the UNESCO inscription of Nordic clinker boat traditions (UNESCO, n.d.).
Furthermore, we explore the potential applicability of our reverse engineering approach to other fields within archaeology—for instance, allowing the identification of missing parts and understanding assembly processes—with implications for future 3D documentation standards.

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326. Balancing Photorealism and Transparency: A FAIR Approach to 3D Digitisation for Cultural Heritage documentation and dissemination

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Introduction

In recent years, the application of 3D technologies to cultural heritage dissemination has deepened the intertwining between GLAM and the gaming industry. The pipelines borrowed from 3D authoring in gaming greatly enhance the potential for photorealism in Web3D rendering technologies. However, this comes at the cost of the scientific accuracy of 3D reconstructions, as these technologies require significant simplification of both geometry and textures.

Furthermore, despite the growing use of 3D technologies in archaeology and museums to study, disseminate, and enhance cultural heritage, the lack of a standardised and shared methodology raises issues of accessibility, transparency, and interoperability in the research domain, especially concerning the 3D data manipulation and authorial intervention performed to fix gaps due to acquisition conditions (ICOMOS General Assembly 2017).

Building on these premises, this article aims to address two complementary research questions:

RQ1: Is it possible to achieve an acceptable level of photorealism for the GLAM sector for Web3D applications using a FAIR approach?

RQ2: In the context of such a workflow, where dissemination potential and scientific value should be simultaneously pursued, how can transparency related to the reliability and authenticity of the data be improved?

This contribution introduces a defined pipeline designed to deliver photorealistic results while adhering to FAIR principles, emphasising reusability, sustainability, and openness to develop the digital twin of a temporary exhibition “The Other Renaissance” held in Bologna as part of the CHANGES project (Thematic Spoke 4: Virtual Technologies for Museums and Art Collections) (RQ1). The project focused on the digitisation of hundreds of complex artefacts, necessitating the development and implementation of a thorough methodology. This paper presents our approach, using the Teriaca Vase as a case study. The Vase, an elaborately decorated container historically used in apothecaries to store the medicinal antidote theriaca, was selected from the exhibition to illustrate the application of our methodology. Our framework incorporates a paradata-based approach (Apollonio and Giovannini 2015), providing a detailed example of its practical implementation. This method aims to enhance 3D object reconstructions by increasing their informational complexity, integrating metadata that conveys the certainty and quality of the data alongside geometric and texture details (RQ2).

Methods and Materials

Digitisation is inherently imperfect due to technological and data collection limitations, resulting in gaps or inaccuracies. In our specific case, the high number of cultural heritage objects (CHOs) to digitise (301), their variety in terms of shapes, surfaces, and scales and the constraints of the exhibition's limited timeframe and physical space were the main challenges to face. Addressing the issues due to these conditions involved a combination of automated processes and manual interventions, introducing some subjectivity and authorial actions. In this context, our research output provides a systematic taxonomy for data transparency, prioritising the preservation of three distinct versions of each 3D model derived from the raw acquisition data (RAW):

1. Processed Raw Data (RAWp): the first output from photogrammetry or scanning software for data processing, without interpolation or geometric corrections;
2. Digital Cultural Heritage Object (DCHO): a complete model after resolved geometry issues, gap filling, and interpolation during the 3D modelling phase using computer graphics software;
3. Optimised Digital Cultural Heritage Object (DCHOo): obtained during the optimisation phase to generate a further performant 3D model version designed for real-time interaction on web-based platforms (ATON framework was adopted).

Each stage in the pipeline, from acquisition to web-based publication, was carefully documented to ensure transparency and reproducibility (Barzaghi et al., 2024). Storing all derivative versions (RAWp, DCHO, and DCHOo) allows for direct comparison, offering a clear record of the authorial decisions and interventions made during the modelling process. The authorial aspect of reconstruction echoes the challenges of integrating missing portions of artefacts into virtual archaeological models, highlighting a shared methodology that can be adapted across domains to enhance reliability and applicability in diverse contexts. The developed pipeline achieved a level of photorealism consistent with the aim of dissemination and valorising cultural heritage. Starting from this premise, we propose a methodology to enhance data transparency further, making it suitable for documentation purposes as well.

Applying the process to the Teriaca (Figure 1) allowed for the creation of a lightweight and efficient 3D asset optimised for Web3D platforms. Polygon count was significantly reduced (from millions to thousands) while maintaining high local control over accuracy and topology. The subsequent UV mapping allowed for generating clear and readable 2D maps through baking. These maps aided in the controlled integration of missing parts in textures and geometry.

Both integrations have been stored and documented via a false-colour map associated with the same UV set so that it has been possible to subsequently deploy it as an alternative visualisation mode on the published asset. The colour map has been obtained by baking a vertex colour map associated with portions that have been filled during the mesh healing and repairing phase, and then enhanced during the integration of the same gaps in the textures, along with portions that were altered by low sampling in the texture projection during the digitisation of raw data.

Results

The digital twin pipeline was designed to produce outputs that meet the photorealistic requirements of a project with dissemination purposes. Efforts were made to utilise open formats and software at every step of the workflow aligning with FAIR principles. For the long-term preservation of 3D data, the team selected Zenodo as a temporary repository, given its adherence to Open Science principles.

The published digitised Teriaca DCHOo combines perceptual realism with low memory usage and quick Web3D loading, thanks to the optimisation of the geometry. It includes clear paradata to indicate integrated sections, enabling both casual users and specialists to explore the item and assess it before requesting raw data or the physical object for detailed study.

Discussion and conclusions

The proposed pipeline was tested for creating the Aldrovandi digital twin in the context of the CHANGES project. Paradata methodology will be further tested for future case studies within the same project. This approach may assess the integration of gaps for an extended ontology incorporating signed distances between the RAW and DCHOo meshes or other data visualised via false colour maps. Advanced acquisition techniques, (e.g., Gaussian splatting) will be explored to enhance the process further.

Figure 1: rendering of the Teriaca Vase - artefact preserved by the Museo Civico Archeologico of Bologna.

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233. Integrating Architectural Historiography and Digitalization: HBIM Documentation of San Nicola in Carcere's Evolution from Temple to Church

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Introduction

The church of San Nicola in Carcere in Rome serves as a prime example of the adaptive reuse of architectural spaces across centuries. Originally a Roman temple, it has undergone numerous transformations reflecting shifts in religious practices, societal norms, and architectural styles (Palombi 2006). Our research aims to leverage modern digital documentation techniques, specifically Heritage Building Information Modeling (HBIM), to explore the building's complex history by reconstructing its various building phases and therefore use HBIM as a comprehensive tool to understand, document and preserve architectural heritage.

Photorealism has often been the goal of digital reconstructions, but our research explores how HBIM contributes to deeper insights into architectural reuse and materiality. By combining expertise in architectural history and digitalization, we aim to create a model that not only represents the physical structure but also captures its historical transitions, providing a more extensive approach to digital heritage documentation.

Methods and Materials

The documentation of San Nicola in Carcere began with a thorough survey of the site using high-precision terrestrial laser scanning (TLS). The research team benefited from their extensive experience gained in previous projects, such as the documentation of the Aachen Cathedral World Heritage Site (Pritchard et al. 2023). This method allowed us to capture the intricate details of the building's structure, including its unique architectural elements and material textures. Devices such as the IMAGER 5016 of Z+F and FARO laser X330 scanners were employed, generating extensive point cloud data that serve as the foundation for our HBIM model. The integration of these datasets involved sophisticated registration techniques, ensuring the accuracy and alignment of scanned information across different scanning sessions. This process reflects the need for high-fidelity data capture, especially when dealing with heritage sites characterized by irregular geometries and material surfaces that have changed over centuries.

The HBIM model creation process was not merely about digitizing the current state of the building. It involved the integration of historical research, including archival documents, architectural drawings, and previous studies of the site's materiality. By combining photogrammetry and laser scanning data, we were able to produce a detailed 3D representation that serves as a virtual time capsule, illustrating various stages of the building's adaptation. Our workflow emphasizes interoperability and the use of openBIM standards, such as bSDD (buildingSMART Data Dictionary) and CIDOC-CRM (Conceptual Reference Model), to ensure the data can be integrated, shared, and preserved for future research (Argasiński and Kuroczyński 2023).

A significant challenge in this project was maintaining the balance between technical precision and historical interpretation. The collaboration between architectural historians and digitalization specialists was crucial in this regard. Historians provided insights into the building's past, identifying key periods of transformation and reuse, while digitalization experts focused on how to best represent these changes in a 3D model. This interdisciplinary approach allowed for a richer understanding of the site, moving beyond a purely visual model to one that encapsulates historical narratives.

Results

The HBIM model of San Nicola in Carcere has revealed several previously unnoticed details about the building's structure and materiality. By accurately mapping the surfaces and textures of the building, the model highlights areas where original Roman masonry has been integrated with medieval and modern elements. This visualization provides a more nuanced understanding of how the building was adapted and repurposed over time, illustrating not just architectural continuity but also transformation. The use of photorealistic textures combined with precise geometrical data allows us to present a digital model that can serve both as a research tool for specialists and as an educational resource for the public.

A key achievement of this project is the ability to demonstrate the practical benefits of using openBIM standards in heritage documentation. By adopting bSDD and CIDOC-CRM, the project ensures that the HBIM model is not just a static representation but a dynamic database that can be expanded with additional information over time. This interoperability is vital for heritage projects, where collaboration between different institutions and disciplines often requires a flexible approach to data sharing. The standardization also facilitates long-term preservation, ensuring that the model remains accessible and usable for future research.

Discussion

The creation of a detailed HBIM model for San Nicola in Carcere underscores the potential of combining advanced digital techniques with traditional historical research. Our approach challenges the conventional separation between 'science' and 'art' in digital heritage documentation, showing that photorealistic models can serve as robust research tools. The integration of high-precision scanning, historical analysis, and openBIM methodologies allows us to present a model that is not just visually appealing but also contextually rich. This aligns with the session's call to rethink how we document and present materiality in heritage, advocating for a more holistic approach that considers both physical appearance and historical significance.

One of the broader implications of our research is the potential for standardized digital heritage documentation practices. The heterogeneous landscape of digital heritage practices often results in competing approaches and variability in the quality of digital outputs. By demonstrating a workflow that emphasizes standardization and interoperability, we hope to contribute to a more cohesive approach to 3D heritage documentation. The use of openBIM frameworks, in particular, addresses common challenges related to data integration, long-term storage, and collaboration across disciplines.

Furthermore, our project highlights the importance of photorealism not as an end in itself but as a means to better understand the materiality and historical context of heritage sites. The debate over whether digital models should prioritize aesthetic appeal or serve as accurate research tools is ongoing. Our research suggests that these goals are not mutually exclusive; a well-constructed HBIM model can achieve both, offering a visually compelling representation that also functions as a precise and informative research tool. This approach reflects a growing appreciation for the nuances of materiality in heritage documentation, moving beyond simplistic binaries and towards a more integrated understanding of the past.

Conclusion
The HBIM project for San Nicola in Carcere demonstrates the potential of integrating architectural historiography with cutting-edge digitalization techniques. By utilizing high-precision laser scanning, openBIM standards, and a collaborative approach that bridges technical and historical expertise, we have created a model that offers new insights into the building's complex history of reuse. This approach not only enhances our understanding of the site but also provides a model for future heritage documentation projects that seek to balance technical accuracy with historical depth.

As digital tools and techniques continue to evolve, it is crucial to address the challenges of standardization, interoperability, and the sustainability of 3D data. Our project offers one possible solution, emphasizing the importance of openBIM frameworks and interdisciplinary collaboration. Ultimately, the goal is to ensure that digital heritage models are not just visually impressive but also academically robust, capable of serving as valuable resources for both researchers and the public.

Figure 1 Horizontal section of the texturized model of San Nicola in Carcere

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13. What You Don't See is What You Don't Get: Pitfalls of Effortless Photorealism in Archaeological Documentation

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Photorealistic and scientifically precise 3D capturing as a main documentation tool has become a standard already in some contexts of archaeological fieldwork. Tools and software are increasingly affordable and user-friendly, and simultaneously the public heritage agencies, museums and scientific collections are more and more capable of processing and storing this data. Things are looking good for the future of SfM photogrammetry, LiDAR and other 3D capture technologies, but some fundamental risks may be hidden beneath the sheen of the beautiful and precise pictures.

In this presentation I explore photorealistic 3D field documentation technologies from a critical perspective. What is easy, what is difficult? How much can we learn from digital materials, and what crucial sensory or contextual data might be overlooked? As we can efficiently make 360 degree digital twins of the fieldwork project with the click of a button, are we at risk of losing the ability to use our own human senses to recognize other relevant features? Using a material of some 2500 Finnish fieldwork reports between 2013 and 2022, I show what archaeologically significant phenomena are getting out of focus due to the blinding ease of "just scanning" everything frequently. Ultimately, I aim to establish a robust theoretical foundation for future discussions on how to effectively instruct and guide archaeological 3D documentation principles. By critically evaluating the balance between technological convenience and the nuanced understanding required in the field, this presentation seeks to contribute to a framework that ensures these powerful tools enhance, rather than diminish, archaeological insight.

266. Mobile GIS and Digital Data Collection Workflows and Training Tools in the Context of International Collaboration: Assessing the QField Cloud Platform

Ian Lindsay (Purdue University)*; Nicole Ningning Kong (Purdue University); Rajesh Kalyanam (Purdue University)

Mobile GIS and remote sensing tools have found increasing applications at many stages of the survey data pipeline, from uploading reference imagery, to dynamic site recording using spatially aware forms, to sharing real-time results with collaborators. The benefits of survey tools, as summarized in recent literature, range from increased efficiency in digital data entry; greater collaborative participation and engagement across the survey team; quicker rates of data visualization and analysis allowing for rapid responses in response to unfolding results and field conditions (e.g., Lindsay and Kong 2022; Wollrodt et al 2016). Recent how-to publications have covered a range of commercial, free open-source, and custom modules highlighting the range of mobile options, each representing an individual solution to wide range of field conditions, budgets, and skillsets on archaeological projects (Sobotkova et al 2021). In short, the past decade of experimentation with digital data capture modalities have not gravitated toward a consensus, one-size-fits-all solution when it comes to building a mobile GIS system, but rather reflects one of adaptive segmentation (Chyla and Buławka 2020). Underlying the fragmented landscape of mobile GIS technical approaches, however, are passionate debates in the user community about the merits of open-source versus commercial GIS packages that pivot on a variety of economic, technical, and ethical considerations. Among the consistent challenges is uneven access to technology, training, and funding among many archaeological communities (particularly in the Global South) to sustainably migrate from analog to digital workflows and participate fully in the growth of the discipline in these directions. At the same time, open-source projects have traditionally required a level of technical expertise as users are often required to wrangle several storage and computational resources together during deployment. These challenges have been a major roadblock to broader adoption of open-source solutions.

This paper will focus on some of these issues through a discussion of two popular data collection platforms, ArcGIS FieldMaps (formerly Collector for ArcGIS) and QField. It is by now well known that open-source options are no longer simply a budget-conscience alternative to commercial packages but have come to exceed commercial capabilities in some data collection and visualization tasks. For project teams distributed across several institutions or countries needing to work jointly on data editing, management, and analysis tasks, it is vital to develop a shared vocabulary about data ontologies, security, and interoperability; these issues are especially important when considering how different partners (e.g., project data managers and student volunteers) interact with the data at various stages in the pipeline (Kansa and Kansa 2021). Recent developments in WebGIS and cloud-based synchronization are providing solutions to configure how data is exposed at various levels in a collaborative team or to the public, including sharing levels, managing groups and organizational membership, and the use of read-only versus editable versions of feature layers. With these sorts of security and accessibility features, QField Cloud is beginning to close one of the remaining data management gaps with the often cost-prohibitive ArcGIS Online platform. But how well does it work? The technical affordances of QField Cloud as a cost-effective and scalable collaborative resource will therefore shape one part of our discussion.

In addition to questions of data security and financial accessibility are persistent concerns of technical training. As field-accessible geospatial datasets and cyberinfrastructure (CI) tools are becoming de rigueur in archaeology, training in the use of these technologies has not been a standard component of humanities curricula resulting in a growing gap in methods preparation. Therefore, the second part of our presentation will be a works-in-progress discussion of our attempts to address this gap through open access cybertraining tools, including modules on QField and QField Cloud. The development of these geospatial research and teaching modules is under the auspices of an ongoing NSF-sponsored project by the co-authors with combined backgrounds in archaeology, geography, data science, advanced CI, and technology pedagogy to empower social science scholars, including archaeology students and faculty, at institutions where geospatial and CI training are not readily available. We focus specifically on the effective split between static background instructional materials versus hands-on activities. Our training modules leverage both the Carpentries framework and its design principle of backward design. We will describe how this principle fits within the rubric of archaeological instruction and more broadly GIS.

One way to strengthen healthy GIS collaborations is through building capacity across teams, so that members are operating with a shared vision and framework for how GIS data is captured, managed, and accessed by team members who wish to do so. In the long run, broader training in these emerging tools can also help reduce colonial dependencies by fostering cultures of trust through more equitable participation in data capture, management, and sharing.

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241. MobileGIS Workflow: Towards a New Approach for Documenting Multi-Period Rural Sites in Tunisia

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MobileGIS, a mobile Geographic Information System with built-in GPS, is increasingly popular tool for field data collection across scientific disciplines. The GPS and mobile network connection enable precise positioning, crucial for archaeological field prospection. Collected data, stored in various formats, undergoes further processing through websites or GIS desktop programs connected to the internet and cloud services.

A notable advantage of mobileGIS is its role in the Volunteer Geographic Information, enabling collective data compilation through Crowd Data Collecting. This involvement of many people facilitates rapid mapping projects and engages students in archaeological projects.

Since the location of all archaeological artifacts is documented, they can be inventoried and brought from the field for the further analysis conducted by a specialist. Their spatial and chronological distribution supplemented by detailed study and documentation of surface features can help us in a better understanding of the function and general characteristics of archaeological sites.

Additionally, the combination of different types of surveys within one research project could potentially enable information about recently destroyed archaeological features to be retrieved. In effect, one can combine the results from different types of dataset on the documented material from the surface, visualize and analyze them in GIS, together with other types of data, thanks to this, they can be further studied and interpreted.

Despite the growing use of mobileGIS in archaeological fieldwork, existing literature lacks discussion on workflows for further artifact research and guidelines for dataset preparation, publication, and presentation. This project addresses these gaps by creating a workflow for full mobileGIS utilization in archaeological surface prospection.

The chosen example, site MR 3 located near the Roman city of Mustis in North Tunisia, is a newly-discovered rural settlement at risk due to a lack of protection.

The research is a part of the Polish-Tunisian AFRIPAL archaeological project, led by T. Waliszewski (FA, UW) and J. Hajji (INP). The project aims for a holistic approach, which includes gathering information about surface artifacts and documenting archaeological features and monument remains.

Rural settlements in North Africahave received limited scholarly attention, but recent projects have challenged this, providing nuanced insights into architectural typology and settlement patterns during the Roman and Byzantine periods. However, the continued function of these However, their long-lasting role as integral components of changing cultural landscape has received far less attention. Using mobileGIS to document on of such settlements might help us to fill this gap, exploring the long-term existence and functioning of rural sites and monuments in the modern built environment.

The presented research integrates mobileGIS to establish a comprehensive workflow for pre-field work preparation, fieldwork, and post-field work analysis, allowing results to be presented in an online map accessible to the general public.

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277. Mapping Memory: Mobile GIS and UAV-Assisted Prospection in the Huarmey and Culebras Valleys, Peru

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The CHULLPA project, a multidisciplinary initiative focused on the Middle Horizon (MH) in the northern coast of Peru, aims to elucidate the political, administrative, economic, and ideological transformations brought about by the expansion of the Wari state. A central theme of the project is understanding how ancestor worship played a role in forging new social and political structures. Castillo de Huarmey, a key Wari site on the northern Peruvian coast, serves as an important focal point of the project. Castillo de Huarmey is known for its rich funerary context, which provides crucial insights into the mortuary practices, social organization, and regional influence of the Wari state. This research contributes to these aims through detailed documentation of MH and Late Intermediate Period funerary sites in the Huarmey and Culebras valleys, assessing their spatial and material relationships to key regional centers like Castillo de Huarmey.

This paper presents the results of a pilot prospection program employing mobile GIS and UAVs to investigate funerary sites across the Huarmey and Culebras valleys, with a focus on their spatial and material relationships to Castillo de Huarmey. Seventeen funerary sites were selected across the Huarmey and Culebras valleys, representing diverse environmental settings: the coastal plains, mid-valley crossroads, and upper-valley regions. Prospection at six of these sites employed mobile GIS technology, including a customized Survey123 questionnaire tailored to the Peruvian context, which facilitated efficient, systematic surface data collection. UAVs supplemented this effort by generating high-resolution orthophotos, 3D models, and digital elevation models (DEMs) for all surveyed locations. These datasets enabled detailed site condition assessments and guided the planning of future excavation zones.

Preliminary analysis of the mass data collection reveals distinct variations in material culture across the environmental zones. Coastal sites exhibited abundant textile remains, including fishing nets, while sites located in the mid-valley showed a prevalence of organic materials. In contrast, the upper-valley sites yielded pottery with characteristics indicative of highland Andean origins, suggesting connections between coastal and mountainous regions during the MH. These observations provide early insights into how environmental factors influenced funerary practices and material culture distribution, and they underline the importance of funerary landscapes in understanding Wari-period social networks and inter-regional interactions.

The integration of mobile GIS with UAV-based mapping facilitated efficient, large-scale documentation of these highly disturbed archaeological sites, which otherwise pose significant challenges to traditional survey methods. This approach contributes to CHULLPA's broader goal of examining how ancestor veneration and funerary practices shaped social memory and power structures during the MH. Moreover, it highlights a replicable methodological framework that can be adapted for the study of other culturally complex and environmentally challenging mortuary landscapes worldwide.

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334. What's up in the hood? Digital surface survey of the Thracian landscape around the Neolithic site of Paradimi.

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In recent years, contemporary research projects involving surface surveys have been conducted in the region of Greek Thrace. This focus is primarily due to the limited research that has been conducted in the area, resulting in a significant research gap. As part of the Parex project, which aims to investigate the Neolithic site of Paradimi, an intensive digital surface survey using smartphones was conducted in the surrounding area in 2024. The primary objective of the intensive field survey is to identify new Neolithic sites, both contemporary and non-contemporary than the Neolithic settlement of Paradimi, in order to investigate the settlement pattern of the region. At the same time, the wider area was explored with the aim of locating primary resource sources that very likely supported human activity throughout the occupation of Paradimi tell.
The settlement of Paradimi stands as perhaps the most famous Neolithic settlement in Thrace. Recent results from the Mapfarm project, together with trench-excavation research carried out in the past, indicate that the site was occupied from the Early Neolithic period to the Early Bronze Age (Bakalakis and Sakelariou 1981, Sgouropoulos et al. 2024), with possible hiatus in occupation in the late phase of the Final Neolithic (Urem-Kotsou et al. in preparation). Despite the significant attention given to the Neolithic settlement, the wider area around the tell had not been systematically investigated.
The new intensive digital surface survey aims to identify and record archaeological remains in the area surrounding the Neolithic settlement, within a defined region characterized by its unique geomorphological features. The research focused on artifacts contemporary with the Paradimi settlement without, however, excluding from recording the finds from other periods. The intense agricultural activity, the presence of modern settlements, industrial facilities, and the road network necessitated an adaptation of the research methodology to accommodate the modern landscape changes.
To ensure the most comprehensive application of archaeological methodology for conducting the intensive surface survey under the conditions mentioned above, a digital documentation application was chosen utilizing the capabilities of mobile GIS, and in particular QField/QGIS. In the field, each member of the surface survey team recorded the archaeological finds and other relevant research data using the application on his/her smartphone. A customized digital data collection form was developed specifically for this archaeological survey, utilizing the QField application. Each recorded archaeological find included information relating to its type and material, chronological period, the field unit where it was found, the visibility of the field surface, and general comments. Additionally, there was the option to attach a photograph of the find. One of the main characteristics of the applied methodology was the ability to immediately record the spatial information of each find through the use of the smartphone's GNSS receiver.
The direct interaction of the application with QGIS made it possible to enrich the digital recording environment with the boundaries of agricultural fields instead of the use of grid, which appeared to be problematic due to the peculiarities of the area. Thus, the agricultural fields constituted the research units according to which the study area was subdivided. At the same time, the satellite image of the area was visible as a background in the digital environment of the application. In this way, the easy orientation of the walkers in the fields under-study was ensured, as well as the collection of archaeological finds per field.

One of the most significant benefits of this methodology is the capability of real-time updates to both the central QGIS project and the QField applications on individual user devices. As a result, field users/walkers are kept updated on the team's progress, enabling them to identify areas with a higher frequency of archaeological finds and those requiring further investigation. These capabilities allowed team members to divide in smaller groups and conduct the intensive surface survey at the same time, depending on the research needs.

The surface survey of the area surrounding the Neolithic settlement was completed in two six-day periods (spring and autumn), examining an area slightly less than 9 km2. Thanks to the high recording speed, intensive surface survey was applied to 321 agricultural fields, with the archaeological finds exceeding 19.100 records. The data of the findings collected during the surface survey are stored in the QGIS project in vector format, followed by the information recorded by the walkers while locating them in the field. In the next stage of the research, the appropriate GIS tools will be utilized in combination with the surface survey results in order to answer the research questions of the project.

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58. LET'S DIG WITH QFIELD! A mobile GIS for archaeological excavation.

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In recent years, mobile GIS systems have rapidly established themselves as essential digital tools, particularly for the real-time management and recording of archaeological data collected during field walking operations. Today, these systems play a pivotal role in shaping survey strategies and documentation practices in landscape archaeology research.
But mobile GIS technology is increasingly proving its versatility also in the effective management of archaeological excavations.
Historically, one of the main limitations to the use of mobile GIS in archaeological excavations was the positioning accuracy provided by mobile devices (such as tablets or smartphones). While the margin of error in the internal GPS antenna could be tolerated for ceramic surface surveys, stratigraphic excavations demand a much higher level of precision — often millimetric — to ensure accurate and comprehensive graphic documentation.
In this paper, we will explore how the F/OSS application QField has addressed these challenges, establishing itself as a versatile tool for the comprehensive management of archaeological excavations. By allowing connection to a DGNSS antenna via Bluetooth, QField provides the millimetric precision necessary for excavation operations. This capability allows for the direct collection and organization of stratigraphic and planimetric data in the field, reducing mapping errors and eliminating the need for off-field post processing and data mapping. This capability supports the creation of a true real-time excavation GIS, allowing for immediate visualization and query of the collected data throughout the establishment of a relational and spatial database where each context and its unique code are central to the data acquisition process.
Furthermore, we will examine the construction of this relational database underlying QField, focusing on the entities it comprises and their interrelationships. We will also analyze how data entry widgets have been designed and configured to facilitate efficient data input on the mobile app, improving both usability and field data visualization.
In conclusion, this paper will critically assess both the strengths and limitations of the developed system, which has already been field-tested in two distinct archaeological excavations—one in Italy and one in Greece. This analysis aims to provide insights into potential future enhancements that could make QField an even more intuitive and powerful tool for managing archaeological excavation data.

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423. "From the Mountains to the Plains": Surveying diverse cultural landscapes in central and northern Greece using the Qfield mobile phone application.

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This communication explores the contribution of mobile geospatial applications, such as Qfield, in archaeological fieldwork. It draws upon the results of two extensive surveys conducted in northern and central Greece, the Grevena Archaeological Project in Western Macedonia, and the second phase of the programme 'Long Time, No See: Land Reclamation and the Cultural Record of the Central-Western Plain of Thessaly', focusing on the Kambos region in Thessaly. Both aim at reconstructing aspects (e.g. settlement patterns) of the regional cultural landscape in the long term, which though were essentially different in terms of natural setting and historical trajectories.
The projects were designed from the outset to be multi- and interdisciplinary and have been carried out by a specialised international team in collaboration with the local archaeological services. Many of the members, such as the writers, worked together in both regions (Apostolou at al. 2024; Krahtopoulou et al. 2020; Orengo et al. 2015)
Grevena is a montane landscape situated between Epirus and (Western) Macedonia. It develops between the great Pindus Mountain range to west and the Vourinos mountains in the east, embracing a system of small river valleys in the middle. Various administrative and research limitations had resulted in under-studying this region in the past.
Conversely, Kambos is located in the heart of the country's most extensive lowland area, on the alluvial western part of the Thessalian plain, which has undergone significant land modification over the past century, with an impact on both the agricultural and the cultural landscape.
Based on the common objectives, the team members devoted part of the research to site definition and location analysis. A range of datasets from different multi-scale multi-temporal sources, both visual and archival, such as cartographic material, historical aerial and satellite photographs and Digital Surface Models (DSMs) derived from both satellite and UAV (drone) datasets', were integrated within a Geographical Information System (GIS) environment. Their features were analysed, and locations of archaeological interest were exported into a series of multi-line and multi-point vector layers comprising parts of the projects' geodatabases. These layers were also to assist the field validation of the desktop analysis results by implementing the mobile application version of QGIS, Qfield, along with additional vector point layers with attribute values tailored to the needs of each area and the specific research question of each project which were created to support data collection.
With the assistance of Qfield the team members managed to inspect by extensive survey 325 points of interest in the area of Kambos and 125 in Grevena. Of these, 145 and 92, respectively, were identified as archaeological sites. Using Qfield in both areas, it was feasible to navigate to the points of interest, access all available layers and their associated information, and collect new, accurately geolocated information in real time, therefore accelerating the whole process of the survey. On the other hand, the peculiarities of each case study required adaptation of the groundtruthing strategies, with subsequent adaptation of the field documentation of parameters such as site limits or visibility.

In this paper, we would like to provide an empirical and statistical overview of the two archaeological surveys in Greece and to showcase the adaptability of the QField tool in two diametrically dissimilar cases, in terms of natural setting and characteristics. Through this process, we explore matters of site visibility, geomorphology and long-term settlement models, contributing to building meaningful narratives of human activity and landscape evolution.

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305. Assessing site presence through radiocarbon density distributions: a new perpective on chronological modelling

Filippo Rizzitano (Sapienza University of Rome)*

Modelling C14 dates is an essential tool for constructing robust chronologies, yet its potential applications extend beyond basic temporal determination. Advancements in methodologies and the availability of extensive datasets have significantly enhanced our capacity to derive meaningful time series from aggregated radiocarbon data. Groundbreaking studies at the continental scale utilized summed radiocarbon dates from specific regions to model patterns of human activity, settlement dynamics, and population trends over time (Hinz et al. 2012; Shennan et al. 2013).
This study introduces an innovative method to calculate the probability of a site's presence or absence using the percentage density of Summed Probability Distributions (SPD) derived from C14 dates (Wright et al. 2020).
The research focuses on central and southern Italy during the Bronze Age, a period characterized by significant cultural variability and a wealth of available radiocarbon dates. This method allows the construction of phase maps based on the probability percentages derived from the radiocarbon dates of each site. For sites without direct dating, SPD analyses of associated cultural aspects enabled their inclusion in the chronological phases.
This approach allows for a more detailed and probabilistically robust analysis of the temporal distribution of sites. Furthermore, this method enhances the interoperability of archaeological datasets by integrating probabilistic analyses with computational modelling. This opens avenues for developing standardized frameworks in chronological modelling, contributing to a more unified understanding of archaeological contexts.

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200. Review of AI-Driven Chatbot Solutions for Remote Sensing in Archaeology

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This study reviews AI-powered chatbot solutions for remote sensing archaeology, emphasizing its capacity to transform data interpretation and accessibility. The study reviews methods that integrate large language models (LLMs), like those of GPT-4, with machine learning algorithms, such as convolutional neural networks (CNNs), to handle and evaluate vast remote sensing datasets. The incorporation of these AI technologies allows archaeologists to query and engage with satellite images, LiDAR, and multispectral data via intuitive, conversational interfaces. The literature review findings demonstrate that the utilization of AI chatbots markedly enhances the efficiency of data retrieval and analysis, rendering intricate geographical information more accessible to non-experts and facilitating real-time site detection and monitoring.

The combination of artificial intelligence and remote sensing has gained interest as archaeologists encounter the difficulty of analyzing extensive datasets generated by contemporary imaging technology. Conventional approaches, however efficacious, are resource-demanding and necessitate specialized training, hence constraining wider participation in archaeological data. AI-driven chatbots serve as a -recent- revolutionary approach by automating data processing and offering natural language interfaces for enhanced accessibility and interpretation [2]. Platforms like those of Google Earth Engine (GEE) have proven the viability of cloud-based geospatial analysis, so reinforcing the contribution of AI to the progression of archaeological research [1].

Although AI-driven chatbots provide significant advantages for remote sensing archaeology, certain issues must be resolved to guarantee their efficient deployment. A major concern is the dependability of LLMs in handling intricate and context-dependent inquiries. Despite being trained on extensive datasets, these models may occasionally yield erroneous or too generalized outputs, requiring thorough validation by specialists. The reliance on high-quality data for training these models raises concerns around biases and limitations in dataset representation, which can impact the performance and inclusivity of AI systems. The risk of over dependence on automated technologies may undermine researchers' critical analytical skills. Addressing these issues is emerging and it is essential for creating resilient, reliable systems that enhance rather than supplant conventional archaeological skills [3].

The incorporation of AI-driven chatbots into remote sensing processes has significant ramifications for computational applications and quantitative techniques in archaeology. These tools democratize access to advanced remote sensing technologies by simplifying data interaction, thereby facilitating broader engagement from researchers, heritage managers, and community stakeholders. This method promotes interdisciplinary collaboration, uniting archaeologists, computer scientists, and data analysts to create scalable solutions for heritage conservation. Furthermore, the capability of AI models to automate routine data processing and deliver real-time updates can improve the efficiency and precision of site monitoring, corresponding with contemporary requirements for proactive cultural heritage management.

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42. Topography Visualisation Toolbox: An open-source tool for visualising rock art and beyond

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The visualisation of carved surfaces can prove difficult using 3D meshes and traditional landscape archaeology methods due to their ephemeral nature and/or scale. This is particularly evident in Swedish rock art where carvings are millimetres deep. To help visualise carvings with various depths and states of erosion, as well as generate material that could be used in deep learning tasks requiring fewer computational resources than 3D data, we developed Topography Visualisation Toolbox (TVT; https://tvt.dh.gu.se). The primary tool in TVT generates a range of topographic visualisations from 3D meshes.

TVT uses tkinter and customtkinter for a user-friendly interface and is packaged as an executable file to provide easy access for users without coding knowledge. Users supply a directory containing at least one mesh file in ply, obj, or stl format and choose from processing options, such as downsampling, cleaning, scaling, etc. before running the visualisation tool. The underlying functions rely on open-source libraries like Open3D and scikit-learn to process the mesh into points that are used to generate several images with scikit-image and scipy.

As a first stage, the mesh is read in and converted to a point cloud. If the user has chosen to, this point cloud will be:

- cleaned of spatial outliers
- rotated either according to a matrix or automatically using a principal components analysis
- downsampled according to a user-selected value
- scaled according to a user-selected value

The resulting point cloud is used to calculate a mesh-grid based on its dimensions. The depth map and normal map are interpolated to this grid, with the depth map being used to generate further topographic visualisations. A topographic map is generated in much the same way as a local relief model where the smoothed depth map is subtracted from the original. Here we generate two variations on the topographic map, one with more focus on the areas of interest (e.g. carved areas) and one with more focus on the surface texture. From the topographic map, we also generate an enhanced topographic map using Contrast Limited Adaptive Histogram Equalization (CLAHE) and a blend between the enhanced topography and texture maps. All images derived using the topographic maps are saved in both greyscale and full colour plots.

As the tool was initially developed for rock art panels it has been widely used for visualising laser scans and photogrammetry models of both large panels and individual stelae. These visualisations allowed for training of deep learning models, discovery of new rock art motifs, and data dissemination to a wide audience. More recently the tool has been used for visualising other material, including modern gravestones to reconstruct erased inscriptions, graffiti in Saint Sophia Cathedral in Kyiv, and a rune stone in Väne-Åsaka.

TVT is under continuous development, and we aim to introduce new tools based on the outcomes of our deep learning tasks and the feedback gained from its use outside of rock art research.

190. Towards Image-Based Machine Learning Palaeographic Analysis in Greek Inscriptions

Matthew Evans (University of Leicester)*; Anastasia Eleftheriadou (Interdisciplinary Center for Archaeology and the Evolution of Human Behavior (ICArEHB))

Machine learning (ML) applications in the study of ancient scripts have already demonstrated considerable progress in areas such as transcription, restoration, and attribution (Luo et al., 2021; Assael et al., 2022). While these studies underscore the potential of ML methods to deepen our understanding of inscribed historical texts, they primarily concentrate on the textual content rather than the physical properties of the inscriptions, such as the shape and style of letter forms. This poster introduces a developing concept for an image-based machine learning application aimed at advancing palaeographic analysis of ancient Greek inscriptions, specifically focusing on the study of letter forms and shapes to gain insights into the inscriptions' dating and identification of hands.

The methodology involves the use of pre-trained convolutional neural network (CNN) algorithms, specifically ResNet and VGG, which will be fine-tuned on two-dimensional high-resolution images of ancient Greek inscriptions from Samos island and its surrounding region to detect subtle variations in letter forms, strokes, and stylistic details. Following data acquisition and standardisation, the images will be imported into a CNN model to automatically segment individual characters. Subsequently, the characters will be grouped by letter type, and additional parameters—such as carving width, orientation, depth, and curvature—will be extracted to identify potentially distinctive characteristics. This dataset will then be used as input for another CNN model with a multi-level classification structure. The first classification level will focus on form (letter allographs) to establish chronology based on predefined criteria found in the literature. The second classification level will analyse letter style to identify regional variations and/or individual letter cutters. The models will be evaluated using performance metrics, including confusion matrix, accuracy, loss, F1-score, and ROC-AUC curves.

The poster further explores potential challenges at each stage of this workflow, including data collection constraints, preprocessing complexities owing to the nature of the material, and the interpretation of results. The anticipated implications of this approach include (1) a digital workflow that could assist in the dating of inscriptions, utilising comparative analysis across a large corpus, and (2) the potential to identify distinct hands of individual lettercutters or epigraphic workshops, contributing to our understanding of the people and processes behind epigraphic practices and production. Currently, the identification of individual lettercutters and workshops relies predominantly on manual techniques—requiring direct access to inscriptions and a high degree of familiarity with an epigraphic corpus. An image-based ML approach, while dependent on high-resolution imaging, expands the accessibility of this technique to a broader range of researchers, works towards an objective methodology, and allows for the exploration of a variety of new historical inquiries.

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520. Automated detection of Holocene archaeological structures along the southern edge of the Nefud Desert, a comparison of proprietary and freely available satellite imagery.

Amy Hatton (Max Planck Institute for Geoanthropology)*

One of the most visible features of the archaeological record of the Arabian Peninsula are the numerous stone structures built during the Holocene. In recent years the use of remote sensing in Saudi Arabia has received renewed interest due to the availability of high-resolution imagery from free platforms such as Bing Aerial and Google Satellite imagery (Kennedy 2011, 201). On the Arabian Peninsula there are thousands of structures, ranging in size from small 1-2m wide cairns to monumental structures such as kites that can be kilometers long. While remotely sensed imagery has been used to identify archaeological remains in Arabia (Harrower et al. 2013), there are few examples of automated detection of structures in the region. I have manually surveyed satellite imagery, to identify archaeological structures, across five study areas along the margins of the southern Nefud desert, totaling an area of 2496 km2. In total this resulted in 781 structures, which fall into 12 different classes, that have been used to train a semantic segmentation model.

Automated detection of archaeological structures is a difficult task as training datasets are often small. I have also experienced issues due to the unbalanced classes, both in the number of training examples of each class and in the proportion of background vs structure pixels within the images used for training. There are also significant size differences between structures in the dataset, ranging from 1m to ~300m in length. In order to improve the amount of training data I used image augmentation techniques, and to account for the class imbalance I have used Intersection Over Union (IOU) and the F1 score to assess the models.

In order to use a reproducible methodology, training data was exported as images and masks from QGIS using a script following Casini et al. (2023). The images and masks were used to train a Fully-Convolutional Network model with a ResNet-50 backbone. I have created a model which is trained on data collected for Bing Aerial Imagery, and will compare it to models using thumbnails of Google Satellite imagery as well Very High Resolution (VHR) imagery from Worldview 2 and Worldview 3 (both 50cm). I will also compare the FCN ResNet50 model to a Mask R-CNN model to assess which architecture works best for this case study.

These comparisons will allow for an understanding of how great an effect different image resolutions have on detection of stone structures (with resolutions ranging from 50cm to ~4m), as well as understanding which model architectures work best for this area and structure types. Remote sensing is an invaluable methodology that has allowed for documentation of thousands of stone structures across the Arabian Peninsula, especially through large scale projects such as EAMENA (Bewley et al. 2016). While remote sensing allows for rapid and efficient documentation of structures, especially when paired with DL methods, there is still a prohibitive cost to buying VHR satellite imagery. I aim to quantify the gain in detection rates that VHR imagery offers when compared to freely available satellite imagery. Stone structures offer a record of human demography and landscape use over the past 10,000 years. By better understanding detection rates of stone structures in different satellite imagery sources we can conduct more well-informed remote sensing studies. Allowing us in turn, to learn more about how humans were using the landscape, and how this has changed over time.

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313. Automating the identification of frost-related features in archaeological micromorphology using deep learning

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In archaeology, understanding how a site is formed and what is associated with past human occupations is crucial. Soil micromorphology plays a fundamental role in this regard, as it allows reconstructing both the depositional and post-depositional processes that shape the archaeological record. By analyzing undisturbed sediments under the microscope, archaeologists can identify the original geometry of the deposits and microstructural features, offering insights into past environments and human activities (Karkanas and Goldberg 2018). Frost-related features are key indicators of past environmental conditions and influence soil and sedimentary structures, leaving distinct features such as platy, lenticular, and granular microstructures, cappings on aggregates and grains, and associated porosity (Vliet-Lanoë 2010). However, identifying frost-related features from photomicrographs is often time-consuming, expert-dependent, and prone to reproducibility issues. To address these challenges, we applied deep learning techniques, specifically convolutional neural networks (CNNs), to automate and accelerate the classification of frost-related sedimentary structures. We used photomicrographs of micromorphological thin sections of sediment blocks from archaeological sites with frost-related features. Transfer learning was implemented to fine-tune the model, and its performance was evaluated using a 10-fold cross validation.

This approach represents an advancement in archaeological micromorphology, providing an objective and efficient method for identifying frost-related features. By enhancing reproducibility and reducing manual labor, this work shows the potential of deep learning in identifying complex sedimentary features and impacting our ability to reconstruct past environments. Broad application of CNNs in archaeology could lead to the development of a standardized and reproducible method of analysis, advancing both micromorphological analysis and computer-aided archaeological interpretations.

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287. Using ChatGPT For Simplified Processing Of Magnetometric Data In Archaeology

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This paper demonstrates the capabilities of ChatGPT in processing magnetometry data for archaeological research. By using only natural language queries (in Russian), without traditional programming or specialized software, this study explores the potential of ChatGPT to assist non-specialists in data analysis. Leveraging ChatGPT's natural language understanding and data visualization capabilities, magnetometric data from an archaeological site in Uzbekistan was analyzed. The goal is to demonstrate the possibilities of simplified data processing while acknowledging that this approach does not replace specialized geophysical expertise.

Introduction

Research at the archaeological site of Karatepa was conducted to study buried kilns using non-invasive geophysical methods. Karatepa, located near the city of Termez in southern Uzbekistan, is an ancient Buddhist monastic complex known for its historical richness and cultural significance (Ставиский, 1972).

Typically, data processing in geophysical research requires programming skills and specialized software, which can be a barrier for non-specialists. This study explores how ChatGPT can simplify data processing and visualization, reducing the need for extensive programming knowledge or specialized software. Using only natural language prompts, magnetometric data from a single site, divided into two 40 by 40-meter squares during fieldwork, was analyzed and visualized.

Data and Methodology

To measure the magnetic field, a Geometrics G-864 magnetometer with two sensors and a recording frequency of 50 Hz was used. The distance between the sensors was 50 centimeters. The number of measurements in one square was 77,470, and in the other 64,022. The data were saved in two files, “kiln_1” and “kiln_2”, in.csv format with a comma delimiter, containing three columns - X and Y coordinates (in meters) and Mag values (in nT).

After uploading the files, the following request was made:

“I have two files of cesium magnetometer data, where X and Y are coordinates (in meters), and Mag is the magnetic field (in nT). I need to merge the data, shifting Y in the second file by 40 meters. Plot a magnetic field map so that kiln_1 is at the bottom (0-40 meters) and kiln_2 is at the top (40-80 meters). Remove duplicate coordinates by averaging the Mag values. The scales of the X and Y axes should be equal, and the map should be in grayscale.”

ChatGPT then merged the data from both files, shifting the Y-coordinates of the second file by 40 meters to align the datasets, and created a map in.png format (Fig. 1).

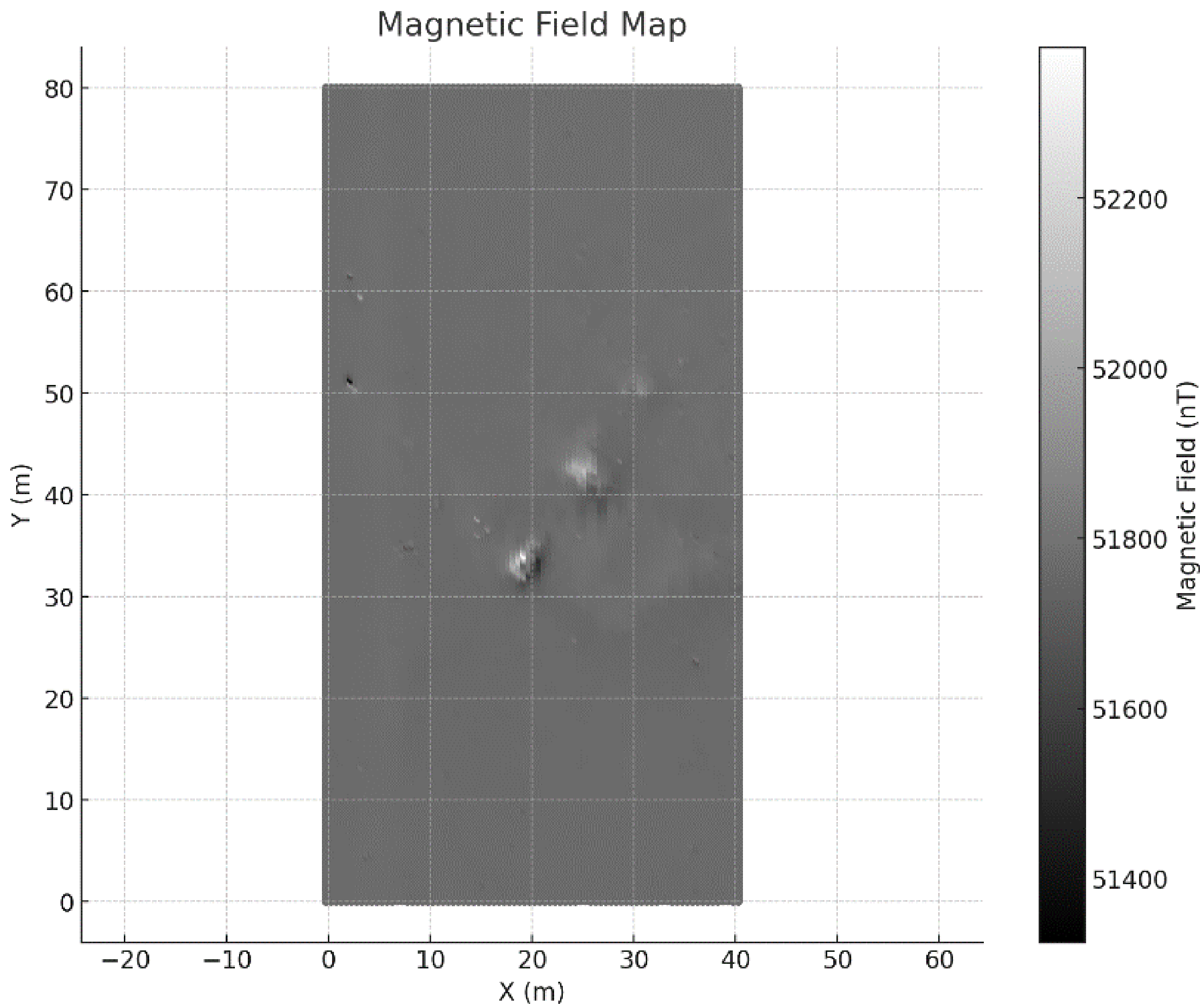

Figure 1: Magnetic field map after merging datasets (initial visualization)

The next request was: “It is necessary to remove values that strongly deviate from the general background, both maximum and minimum”. Outliers, representing extreme values deviating from the overall dataset, were detected and removed using the interquartile range (IQR) method. A map in.png format was provided for download (Fig. 2).

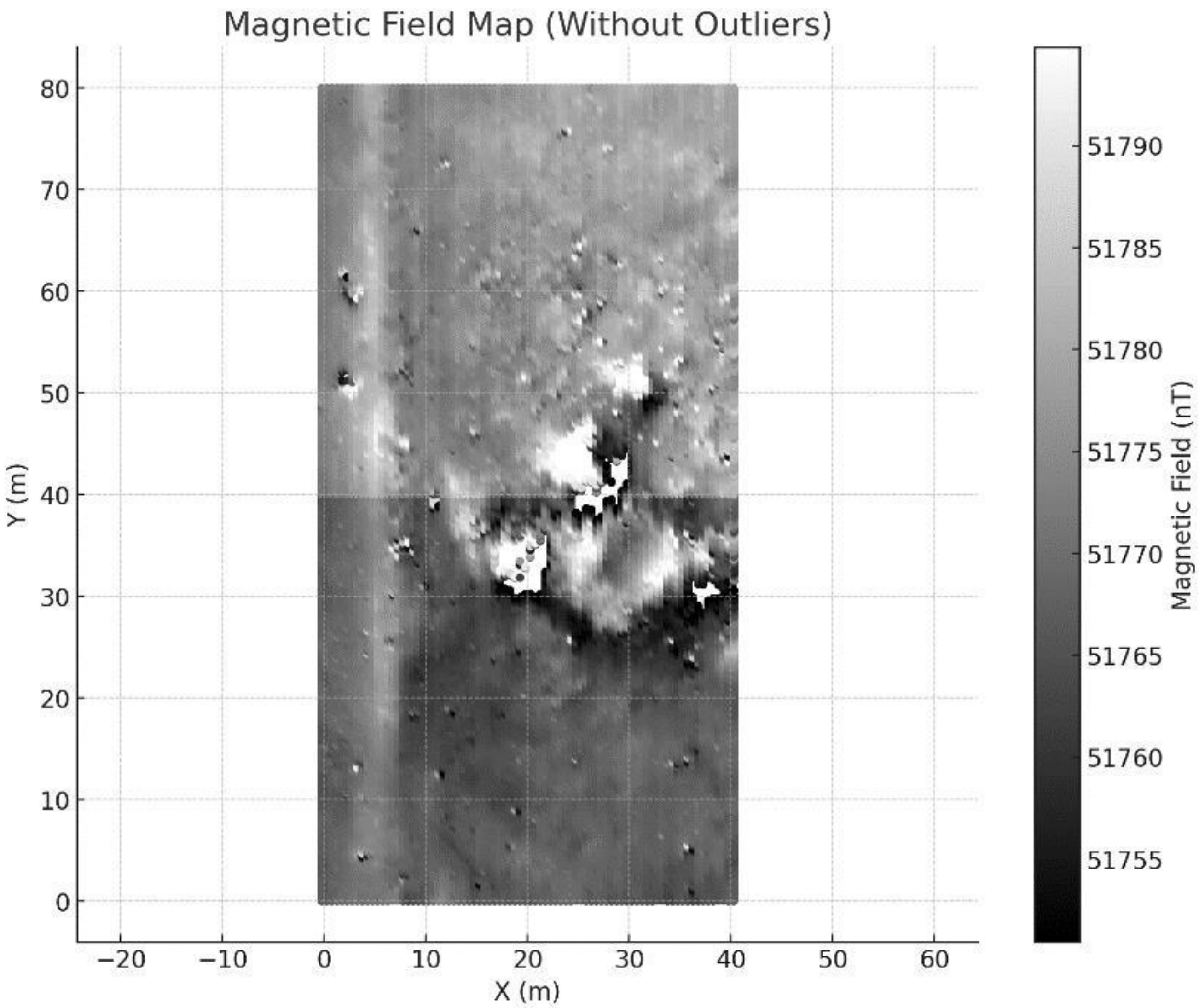

Figure 2: Magnetic field map after outlier removal

The third request was: “After removing values that strongly deviated from the general background, empty values appeared. It is necessary to fill them!” The cleaned data were interpolated to create a continuous magnetic field map of the area. ChatGPT created a visualization in grayscale. After filling the gaps, the request was made: “Destagger to remove jitter” (Fig. 3).

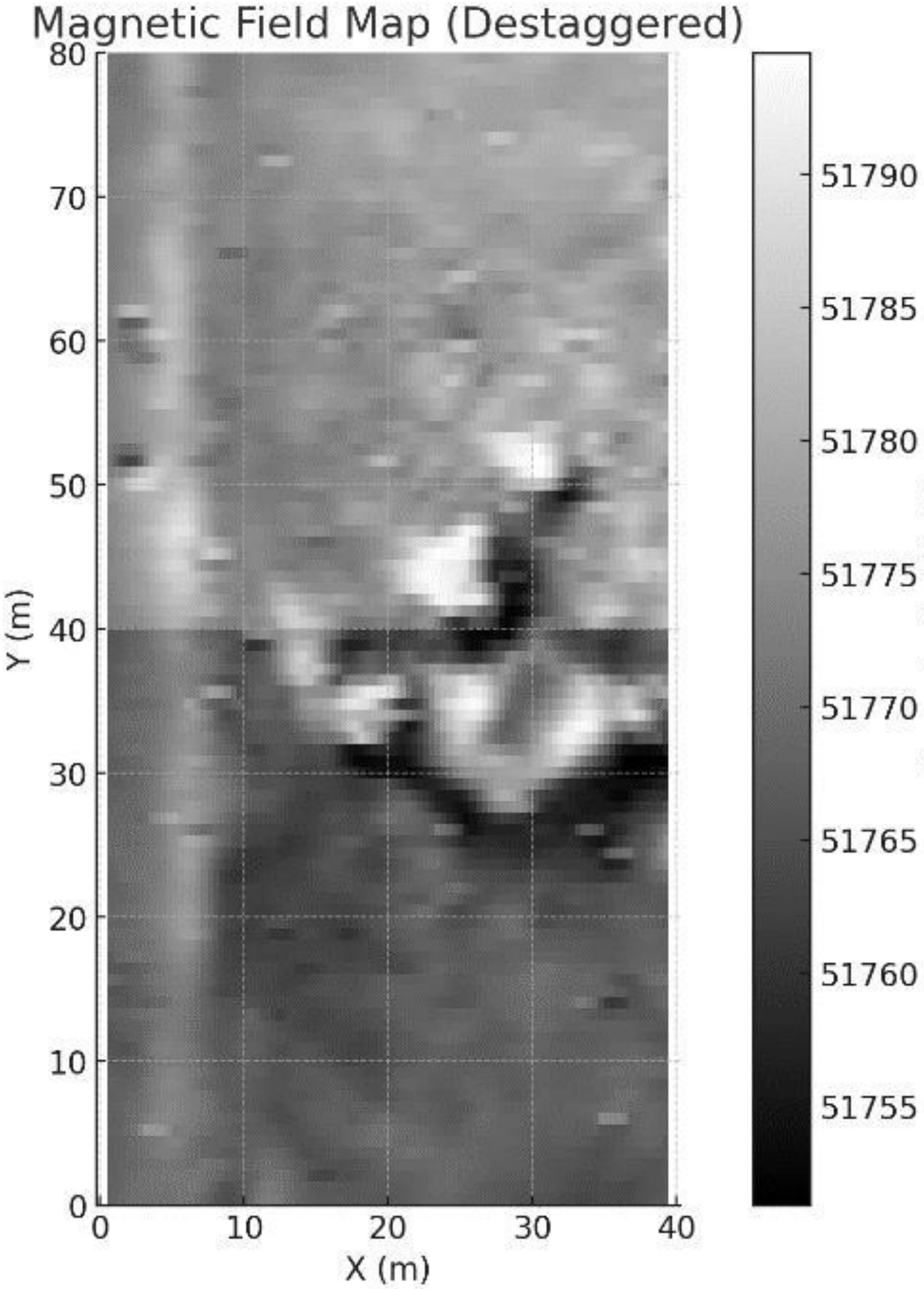

Figure 3: Interpolated Magnetic Field Map with Smoothing and Contrast Enhancement

A color gradient was observed on the consolidated map, which led to the following request: "Since the map was built from the data of two files, there is a color gradient between the top and bottom map, fix this." ChatGPT proposed a correction by aligning the datasets to minimize discrepancies, resulting in a unified and consistent map.

The final request was: "Color inversion." The map was inverted (Fig. 4).

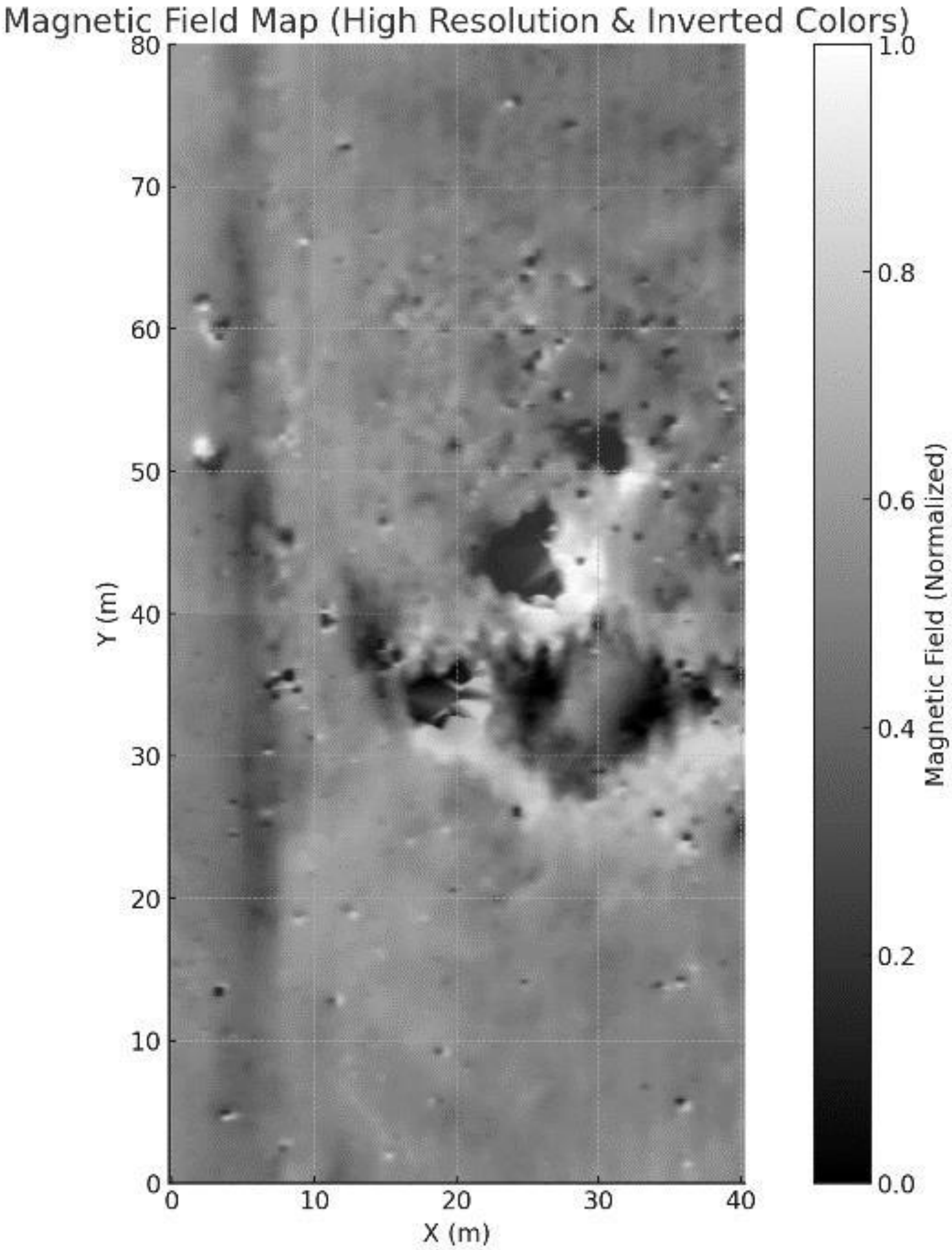

Figure 4: Final high-resolution magnetic field map with gradient correction and color inversion

Results and Discussion

The processed maps revealed magnetic anomalies that could correspond to buried kiln structures or other archaeological features. Using ChatGPT allowed for data analysis based on natural language prompts, highlighting the potential of AI to bridge the gap between advanced data analysis and researchers lacking programming skills.

The high-resolution visualization allowed for better identification of archaeological features, which is crucial for planning excavations.

Conclusion

This case study demonstrates how ChatGPT can facilitate magnetometry data analysis in archaeology without the need for specialized software or programming skills. While this approach is useful for preliminary analysis and simplifying workflows for non-specialists, it should not be considered a replacement for professional data processing by geophysicists. ChatGPT's ability to perform basic data processing tasks and visualization can serve as a helpful starting point, but a full and thorough analysis still benefits from expert intervention and the use of specialized tools.

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193. With R for Reuse: Data Reuse for the Diachronic Analysis of the Reuse of the Megalithic Landscape in Gipuzkoa (Northeast of the Iberian Peninsula)

IZASKUN EGUILEGOR (GPAC/UPV-EHU)*

Since the discovery of one of the earliest megaliths in the Historical Province of Gipuzkoa (northern Basque Country, Spain), specifically the dolmen of Jentillari (Giant Stone), the research conducted has predominantly focused on prehistory (Altuna et al., 2002). Although in recent decades' various archaeologists have shown interest in the reuse of megaliths in later historical periods, the analysis and collection of this information have been notably scarce. Furthermore, to this day, contemporary materials that are frequently found both on the surface and during excavations are not adequately recorded. In many cases, although they are collected, the documentation is minimal, and their characterization presents a considerable challenge.
The research lines presented in this poster are based on the doctoral research of the same author. This work aims to study the evolution and reuse of the megalithic landscape of Gipuzkoa, emphasizing on the research of Bergson's multitemporality (Hamillakis 2015, 150-155; Olivier 2013, 121-122; Olsen 2013, 2). In addition to that, it focuses on the interrelations between communities and on education as an essential element for social transformation. In this context, data collection must be carried out methodologically and from a transdisciplinary perspective. Furthermore, the study should not only incorporate previously presented data but, above all, establish a systematization of new data that, to date, has been overlooked.
For the data collection process, the research is structured around three different phases. 1) Identifying potential and cost-effective sources of information for the analysis of the megalith itself and its reuse. Archaeology serves as the foundation of the research, analysing the following sources: a) Archaeological maps of Gipuzkoa; b) Reports from annual interventions; c) Fieldwork reports; d) Fieldwork itself; e) Analysis of materials stored in the provincial repository associated with each megalith; f) Scientific articles on megalithic in Gipuzkoa; g) Diaries of researchers from the early 20th century. Additionally, other sources such as ethnographic and cartographic materials are analysed. 2) Systematization of related data using various tools: a) Google Sheet and PostGis for record-keeping; b) QGIS for cartographic documentation; c) AutoCAD and Photoshop for systematic drawing; d) Blender for virtual reconstructions. 3) The final phase, which is actually part of the entire process and provides another type of source, involves citizen participation and, consequently, the systematization of public archaeology. For this purpose, various tools are employed: a) QGIS for social mapping; b) Google Sheet and PostGis for recording responses; c) Canva for illustrating and sharing archaeological information.

In relation to the aforementioned, the following lines focus on the presentation of the process of data collection in a systematic and methodological manner. Addressing the theme of reuse, it is argued that a proper understanding of data reuse is fundamental, for analysing the reuse of these megalithic spaces. The importance of this is to understand that information is often classified multiple times due to the lack of open, accessible, and inclusive data analysis systems (Huggett 2018, 28). For this reason, we aim to establish concrete processes to reach society openly from public archaeology. The primary objective of this research is to create an open database that facilitates the understanding of the megalithic landscape as an identity element in the 21st century. Thus, the aim is to integrate various elements and scientific disciplines that are effective in exploring the multiple relationships of information, with particular emphasis on improving the systematization of archaeological records.

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144. From Deultum to DigiDeultum: Upgrading the Historical Narrative by Connecting Diverse Sources

Lily Grozdanova (Sofia University "St. Kliment Ohridski")*; Dilyana Boteva-Boyanova (Sofia University "St. Kliment Ohridski"); Nikolay Dimitrov (NAIM – BAS); Hristina Ivanova-Anaplioti (University of Verona)

The project BNSF КП-06-H80/7, 08.12.2023 “Upgrading the Historical Narrative: From Deultum to DigiDeultum” poses the fundamental question: Has digital humanities, particularly the study of Antiquity, reached the level of synthesising new research directions, methods, and ultimately – upgraded knowledge?

The project explores whether there is a fundamental shift in the reconstruction of historical narrative by combining traditional historical and archaeological methods with digital humanities and archaeological sciences to study and reconsider the Roman colony of Deultum. According to the FAIR principles, the team is digitising and processing both the research results by newly acquired data and data gathered through more than 40 years of archaeological study on the site, as well as the multitype source material recovered there.

The proposed poster concentrates on the options for combined analyses of various source materials through innovative approaches, aiming to find the cross-sections of the data they provide and identify out-of-the-box concepts that can bring us to the possibly upgraded knowledge for Deultum. It will represent the state of results in developing and implementing a multitype source DB based on the data model and freeware of the Corpus Nummorum scientific product. A special accent is placed on the numismatic data in a digital interdisciplinary perspective and its potential to address both spatial and temporal concepts, such as:

- Reconstruction of the individual spaces – correlate and interpret the coin finds with other grave goods.
- Identification of iconographic spaces by tracing designs from numismatic objects appearing on other materials.
- Explain why the coinage produced by the local mint still does not seem to dominate any of the finds from the different areas of the colony itself. Haven't the archaeological excavations found the respective stratigraphic layers yet?
- What is the time span of the numismatic data from the site, and how can it be interpreted?
- Refining the chronologising role of coin finds within an archaeological site.

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365. Modeling Roman Equid Archaeofaunal Data: Within or Beyond the RomAniDat Initiative

Dominika Schmidtová (Masaryk University)*; Anthony King (University of Winchester); Michal Smíšek (Masaryk University); Maike Groot (Freie Universität Berlin); Věra Klontza (Masaryk University); Ricardo Fernandes (Max Planck Institute for Geoanthropology)

This poster presents the use of archaeofaunal data on Equids to explore their roles and contexts in the ancient world animal-human environment. Currently we are focusing on already published data from Roman Italy, Britain, and the Netherlands. By analysing horse remains in archaeological contexts, we investigate their association with specific site types (e.g., military contexts), study the ratio with other animal taxa in faunal assemblages or identify chronological patterns in the changing NISP of various taxa in relation to historical events.

The Equid dataset is part of the Romanidat initiative (Schmidtová et al. 2023), a network of archaeozoologists, archaeologists, and historians committed to harmonizing heterogeneous data collections. The first published dataset on Roman Italy was focussed mainly on three main consumed domestic taxa (Bos, Ovis/Capra, Sus), while other species were not included. Despite varying research questions and focus of regional datasets, such as those from the Netherlands (Groot et al. 2024) and Britain (King et al, under review), Romanidat ensures consistency in key data attributes, including site type, coordinates, and chronology. These shared standards enable integrated processing, spatio-temporal modeling, and comparative analysis across diverse datasets.

Romanidat is hosted on the Pandora platform, which supports collaborative data management and advanced spatio-temporal modeling. In this poster, we will showcase examples of large-scale modeling of Equids archaeofaunal data within the Roman Empire, demonstrating how shared frameworks and current archaeological knowledge can produce meaningful insights across diverse research communities.

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356. Historical Cartographies as a Metaphor to Access Linked Open Data

Bianca La Manna (University of Genova)*

This research aims to design a web application that allows the unstructured data, i.e. the digitized historical cartographies, to provide the semantic framework for accessing Linked Open Data (LOD). This result was possible thanks to the combination of Semantic Web standards, tools for image annotation, and JavaScript libraries for building interactive maps.

The first challenge was to provide a semantic framework for any historical place, e.g. places that could be represented in historical cartography, but do not exist in reality, such as Atlantis. Starting from the comparison of the semantic representation of the concept of place according to the main ontologies (DCMI; CIDOC-CRM; geoSPARQL; CRMgeo), it came out that most of these semantic tools provided a spatial description of place based on the concept of Euclidean space. This was due to the introduction in recent years of GIS technology and spatially referenced data which brought a predominance of a mathematical representation of space that influenced the Knowledge Organization Systems (KOSs). For archaeological, historical, and philological research, however, a geo-semantic approach is preferable, in which places are defined by discursive and cultural information.

We propose a data model that describes the concept of Place as a cultural construction and combines the existing ontologies in a single conceptual model based on four classes (Place, Location, Geometry, and Space), according to their level of objectivity, and their different relation with the concept of Time.

We demonstrated that with very few data requirements, it is possible to build a web application that uses historical cartographies as a metaphor to gather and access cultural data dynamically and semantically. The georeferencing of digitized historical cartographies has been performed without the use of proper GIS software to have the minimum technological requirements. This was possible, thanks to standards like the Geographic Annotation of IIIF Manifest, and the shared effort between open-source tools, like AllMaps and Leaflet;

We designed an interactive map that can present various kinds of data to the user with the most suitable visualization. The interactive map was built overlaying the raster image of historical cartography on a digital-born map. The latter provides the coordinates for each point on the image, making it possible to interact with it or to place external data directly on the historical cartography. It supports the traditional methods for visual comparison of cartographies, such as side-to-side visualization.

Finally, the maps' metadata have been enrichment and integrated with LOD, to reuse what is already available on the web to provide more contextual information about places.

The pilot interactive map opens up a plethora of future possibilities in the field of research on historical places, gathering in one user-friendly visualization metadata and enriched data on specific subjects; a compared visualization of diachronic and synchronic representations of the same place; the location of any kind of additional information on a historical map, e.g. archaeological collection as well as textual and contextual information.

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445. A customizable data collection App at your fingertips: the example of the survey between Eretria and Amarynthos

Chloé Chezeaux (UNIL/ Swiss School of Archaeology in Greece)*

Since 2021, an extensive survey has been undertaken in the plain linking the present-day municipalities of Eretria and Amarynthos (Evia, Greece), with the objective of gaining greater insight into the integration of the Artemis sanctuary into the wider ancient landscape. The program encompasses an area of more than 17 km^2, with data gathered during extensive research conducted in the Eretria hinterland in the 2000s. However, this region, which is poised to become one of the most well-documented in the Greek world, is facing several significant challenges. In addition to forest fires and frequent looting, the rapid urbanization of recent decades has irreversibly compromised the archaeological heritage. Therefore, systematic and accelerated fieldwork is essential to safeguard the last surface traces of ancient occupation, which are at risk of disappearing.
As part of my PHD, I am combining data from past and recent surveys with advanced remote sensing methods to produce an up-to-date, exhaustive and detailed archaeological map of the sites on the Eretrian plain. This map will make it possible to trace the evolution of settlement patterns over the long term, analyze the parallel development of Amarynthos and Eretria, and study the overall connectivity of the plain, thus offering a renewed understanding of this complex territory.
To achieve these objectives, the use of Geographic Information Systems (GIS) quickly became essential. Better still, the ability to transport this tool directly into the field proved to be a practical and innovative solution. Thanks to a data collection database specially designed for the needs of the survey (via ESRI's 123 Survey app), fully configurable and shareable in real time, a substantial volume of data could be entered directly in the field and instantly saved on the server (fig. 1). Equipped with tablets, the survey teams have real-time access to their geographical position, to the various data on the GIS (old maps, topographical maps, units already surveyed) and above all to anomalies identified upstream by Lidar remote sensing, thus optimizing searches and facilitating rapid data recording. The data is then processed almost instantaneously in ArcGIS Pro for more detailed spatial analysis. The data may be used to create distribution maps based on the quantity of material found in the field, as well as to determine areas of human activity.
The utilization of an accessible tool like 123 survey database, from its design to its sharing and modification capabilities, enables archaeologists to exert comprehensive control over their data, while simultaneously allowing them to direct their attention towards the straightforward and efficacious processing and utilization of said data.

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187. Adapting to the Field: Digital Recording Practices in International Commercial Archaeology

Quentin Drillat (Éveha International)*; Antoine Darchambeau (Éveha International)

International commercial archaeology presents a complex landscape for digital field recording, due to a large number and variety of contexts, practices, teams and contractors requirements. It appears almost impossible to set up a single, standardized protocol for data collection in that context. However, because data and reports often need to be produced within short deadlines, with team members dispersed all over the world, the interest of digital field data collection is widely recognized, as it fastens and optimizes work from the field.

Part of the Eveha Group, Eveha International, a company providing heritage and archaeological management services in 32 countries so far, has conducted projects from extensive 40 square kilometers surveys to smaller-scale rescue excavations during which it faced challenges related to the adaptability of digital field collection practices. The company addresses these challenges through a multifaceted approach that balances standardization with adaptability. This poster explores Eveha International's practices, highlighting the importance of adaptability and diverse technology adoption in ensuring efficient and adaptable data collection across a range of contexts and project requirements.

Eveha International recognizes the importance of attribute data standardization for research and reuse purposes. As much as possible, Eveha International utilizes standardized glossaries and data structures to enhance consistency across projects. Yet, flexibility remains crucial to adapt to diverse contexts, teams and contractors. For attribute data collection, Eveha International utilizes mobile Geographic Information Systems (GIS) with standardized and customizable forms to capture qualitative information, while surveying equipment (GNSS and/or Total Stations) ensures accurate measurements. Mobile applications like QField (opengis.ch) and ArcGIS Survey123 (ESRI) facilitate direct integration of GPS/GNSS and archaeological data. Originally, the Eveha Group policy was to use open source software. Thus, QGIS, and its mobile application QField, have first been favored by Eveha International for its field projects. However, the widespread adoption of ESRI softwares in the archaeological community led the company to also use ArcGIS Survey123 to produce data that collaborating teams and contractors could easily work with. This flexible approach enables leveraging the most appropriate technology for each project. Data acquired onsite is integrated into a central multi-relational online database, such as PostgreSQL/PostGIS or ArcGIS online, to ensure data integrity and real-time data synchronization among team members. Depending on project requirements, photogrammetric surveys and UAV flights capture additional spatial information, generating 3D models and orthomosaics, later integrated to GIS projects. While digital tools offer many advantages, some archaeological drawings are still done manually by Eveha International team members. A balance between digital and manual drawing techniques is adopted in the field, a decision made after carefully considering the resources needed to acquire equipment and train team members against the time required to digitize hand drawings after fieldwork campaigns

Eveha International's multifaceted approach to digital field recording demonstrates the importance of adaptability in international commercial archaeology. Despite its apparent rigidity, field data collection enables archaeologists working in such contexts to efficiently produce high-quality data when standardized digital practices are combined with a flexible technology toolbox and open communication strategies.

306. Documentation for Challenging Palaeolithic Excavations: Digital Solutions at MSA site of Got10 (Southern Ethiopia)

Francesco Lucchini (Sapienza University of Rome)*

Excavating Palaeolithic sites in Africa may present several challenges, including political instability, limited excavation time, logistical constraints, and environmental factors such as erosion, which strongly affect the state of preservation. This is particularly true for open-air sites, which require not only traditional site documentation - e.g., documenting the position and extension of archaeological layers - but also detailed surveys of physical changes due to erosion over time. These complexities demand adaptable and efficient approaches to field documentation, especially in remote and demanding contexts. Here, we present a study focused on the Got10 site, a Middle Stone Age (MSA) open-air occupation located in a modern savannah environment in southern Ethiopia (Fusco et al. in press). Got10 is particularly relevant for addressing the mentioned issues, as its preservation is strongly affected by yearly erosional phenomena. To manage this complexity, we have developed an integrated documentation workflow specifically tailored to the site's conditions. The workflow incorporates the use of mobile devices for quick and precise data collection. In recent years, several studies have highlighted the advantages of such tools for field documentation, such as those by Montagnetti and Guarino 2021 and Paukkonen 2023. These devices offer portability and user-friendliness, making them invaluable for both excavation and survey tasks. These tools ensure efficient data recording even under logistical constraints, while digital models captured in the field support detailed analyses during post-excavation processes. This poster will detail the design and implementation of our data collection methods, demonstrating their practicality and effectiveness in the challenging yet archaeologically significant environment of the Got10 site.

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34. Exploring Ancient Egyptian Water Management: New Insights from Remote Sensing Techniques at the Wadi al-Garawi Dam (Helwan, Egypt)

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This communication presents preliminary research on the monumental masonry-faced earthen dam called Sadd el-Kafara, located in Wadi al-Garawi in Egypt’s Eastern Desert, in order to explore its role in ancient Egyptian water management. Our study examines the dam’s construction methods, operational function, and its relationship with the surrounding landscape and settlements, proposing hypotheses on its purpose to be refined as research progresses.

Using advanced remote sensing, particularly Google Earth image analysis and photogrammetry, we have created a detailed 3D model of the dam and estimated its theoretical reservoir capacity. Our findings reinforce earlier hypotheses, including those by Georg Schweinfurth (1895), suggesting that the dam’s primary function was floodwater control rather than long-term storage. This supports evidence that Wadi al-Garawi operates as an intermittent watercourse, likely carrying significant water flows only during torrential rain. At peak capacity, the reservoir would extend approximately 1,600 meters from the dam and flood up to 15 hectares, sufficient to manage seasonal floodwaters in this arid region.

The 3D model enabled comprehensive geometric analysis, including a hypothetical outline of the development of the dam’s missing sections and an estimation of its core and outer stone composition. A basic reconstruction of the dam’s morphology provides insights into its volume, layout, and the likely number of ashlars used based on preserved block dimensions. Integrating this model with topographical data from the wadi allowed us to approximate the flood zones the dam could control, offering valuable insights into its operational impact on surrounding areas.

Our findings support the hypothesis that Wadi al-Garawi Dam primarily served as a flood-control structure, likely designed to mitigate torrential rain impacts and regulate flow toward the Nile Valley. This control function suggests the potential existence of a broader hydraulic network within Wadi al-Garawi and its tributaries, providing insights into regional water management strategies in ancient Egypt. The prospect that Wadi al-Garawi Dam was part of a broader hydraulic system underscores the need to investigate similar structures within Wadi al-Garawi and surrounding areas. Remote sensing analysis identified previously unknown settlements, suggesting a socio-environmental context where communities may have benefited from or relied on the dam’s regulatory role. The presence of these settlements further clarifies the dam's strategic integration with its environment, suggesting a complex relationship between its hydraulic function and the needs of the local population.

The implications of this research extend beyond the specific case of Wadi al-Garawi Dam, offering broader insights into ancient Egyptian water management strategies and socio-environmental contexts, as well as sophisticated engineering practices of ancient Egyptian society. Our findings highlight advanced hydraulic engineering and environmental adaptation skills characteristic of this society, reflecting the technical expertise required to construct and maintain such a monumental structure. This study underscores the importance of advanced remote sensing and photogrammetry in archaeological research, especially in areas facing modern development that threaten archaeological heritage. By showcasing the benefits of these methods, we advocate for their ongoing application in archaeology to protect and enhance our understanding of ancient engineering and water management practices amid present-day challenges.

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355. SODa – Sammlungen, Objekte, Datenkompetenzen (Collections, Objects, Data Literacy)

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SODa – Sammlungen, Objekte, Datenkompetenzen (Collections, Objects, Data Literacy) is a collaborative project focused on establishing a Data Literacy Center for academic collections in Germany. With over 1,200 collections spanning nearly all scientific disciplines, Germany's academic landscape holds an unparalleled resource of knowledge and data. These collections serve as critical infrastructures for research, teaching, and knowledge transfer, while preserving valuable cultural and scientific heritage. The German Council of Science and Humanities has emphasized their extraordinary importance for science and has emphatically called for them to be expanded as research infrastructures. However, their potential can only be fully realized through effective digitization and innovative digital methods.

SODa addresses these challenges by fostering data literacy and building digital infrastructure to advance the digitization, accessibility, and usability of academic collections. It acts as a networking, learning, and research platform, promoting interdisciplinary collaboration, sharing of best practices, and the development of sustainable research infrastructures. SODa integrates expertise from research, teaching, and collection management to provide essential data competencies tailored to the diverse needs of collection managers, researchers, and technical staff.

SODa enables the exploration, discussion, and refinement of standards, good practices, and innovative methods in collection-based research data management, analysis, and reuse. The project emphasizes a holistic approach to the digital cultural shift, offering tools and training designed to unlock the potential of academic collections. These include personal consultations, workshops, summer schools, and freely accessible open educational resources. Additionally, SODa's Semantic Co-Working Space (SCS) provides targeted support and digital tools for digitization projects, enabling high-quality, sustainable, and standard-compliant digitization of collection data.

A key focus of SODa is advancing the research data lifecycle, including cataloging, digitization, long-term preservation, and data reuse. By leveraging innovative digital methods such as 2D and 3D object visualization, machine learning, and structured data analysis, SODa fosters new avenues for research and enhances traditional methodologies. Provenance research, restoration documentation, and data-driven object analysis are central to its efforts.

Through its partnerships with Humboldt-Universität zu Berlin, Friedrich-Alexander-Universität Erlangen-Nürnberg, the Germanisches Nationalmuseum Nürnberg, and the IGSD - Interessengemeinschaft für semantische Datenverarbeitung e.V., SODa strengthens interdisciplinary collaboration and contributes to national and international research initiatives, including the National Research Data Infrastructure (NFDI).

By addressing gaps in digital infrastructure and expertise, SODa ensures that academic collections remain dynamic resources for innovation, contributing to the advancement of Germany's research landscape and fostering international connectivity. Its diverse portfolio of activities and resources establishes SODa as a cornerstone for developing sustainable, interdisciplinary solutions for the digitization and utilization of academic collections.

The Federal Ministry of Education and Research (BMBF) is funding the development of SODa from 15.11.2023 to 14.11.2026.

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111. LiDAR and its integration with other Remote Sensing techniques for Iron Age Archaeology in the Valencian region (Spain).

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This poster focuses on the utility and limitations of open-source LiDAR datasets published by the Spanish National Geographic Institute (IGN) for the Valencian region. We emphasise the necessity of integrating these datasets with other proximal and more remote sensing techniques to gain a deeper understanding of Iron Age communities in the Valencian territory.

Since the IGN released its LiDAR datasets covering Spain, several archaeological studies using this data have been published (Cerrillo and Lopez 2020). However, the central region of the Valencian territory has not been extensively studied using this technology. Although a few promising works have emerged in the mentioned region for Iberian Iron Age studies (1st millennium BC), such as those by Grau Mira (2016), most of these works rely on the already processed Digital Terrain Model (DTM) provided by the Spanish National Institute. We argue for the potential benefits of processing and filtering raw point clouds for specific archaeological targets to achieve better data control, and the use of deep learning to fully exploit the information contained within these datasets at a higher analytical level.

Additionally, the Valencian territory, like many Mediterranean areas, has a complex and varied topography, with dense low vegetation that can obstruct LiDAR points (Fontana 2024). Combined with the intense land occupation and transformation since prehistoric times, characterising the archaeological landscape in a minimally invasive manner can be complicated using only low-resolution LiDAR data.

Therefore, we believe it is important to evaluate the strengths of the open-source LiDAR coverages as well as their limitations. Additionally, we stress the importance of integrating these datasets with information from various sources, such as multi-temporal aerial and satellite imagery and localised geophysical studies, to help provide a more complete picture.

226. A command-line interface for chronological network modelling in R

Gilles Geeraerts (Université libre de Bruxelles)*; Joe Roe (University of Bern); Eythan Levy (Bern University)

Chronological networks (Levy et al. 2021) are a robust new approach to formally modelling complex chronologies drawn from archaeological and historic data. The method has been implemented in the software ChronoLog (https://chrono.ulb.be/), which provides a graphical user interface for interactively building and evaluating chronological network models. Here we introduce a new implementation of chronological networks in the R statistical programming language. The chronologr package ports the ChronoLog's chronological network data structure and core algorithms from Java to R. These include the functional ity to translate user-provided temporal contraints and relations to a graph format, check its logical consistency, and (if consistent) 'tighten' it to give the narrowest possible temporal constraints (i.e. date ranges) on the chronology. Since we had an existing reference implementation in Java, and most of the underlying
graph algorithms needed to implement these functions are available in R through the igraph library (Csardi and Nepusz 2006), this part of the implementation is relatively straightforward.

A more challenging aspect of bringing chronological networks to R was adapting ChronoLog's graphical interface to a scripted command line. This required us to rethink the UI patterns used for data import, model construction, and querying of the output, as those that worked well in a graphical environment did not naturally translate to a scripted one. We also faced the challenge of translating ChronoLog's underlying object-oriented application programming interface (API) to better fit R's functional idiom.

In particular, a major strength of the ChronoLog GUI is that it facilitates iterative model building by giving the user instant feedback on how changes to the network and temporal constraints affect the 'tightened' chronology. Bringing this to the R interface was one of our key aims, which we approached by implementing a simple domain-specific language (DSL) for building chronological network models. This consists of a set of declarative functions by which users can progressively construct a model, as an alternative to simply providing its specification as input data. In this way, the R script itself serves as a human-readable description of the model, allowing for easier reproduction and, crucially, for the user to iteratively adjust the model in response to feedback from the consistency check and tightening procedures. The syntax of these functions are closely modelled on existing 'tidy'-style DSLs in ggplot2 and other popular R packages (Wickham 2014, ch. 15), which provides a familiar interface for a large number of R users and facilitates the integration of chronologr into data analysis pipelines using other packages.

455. 3D Scanning And 3D Printing: For Precise Data Collection In Archaeology

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Introduction: The rapid development of digital tools and technologies has set a new standard for research capabilities in the field of cultural heritage (Chetverikov, Hlotov, and Bakuła 2024, 4131; Wachowiak and Karas 2009, 141). 3D scanners and 3D printers have opened new opportunities for scholars and cultural heritage institutions by enabling the creation of accurate replicas of artifacts, thereby facilitating more in-depth research without being detrimental to the original items (Wachowiak and Karas 2009, 142). This study aims to replicate an artifact with the combined use of a handheld 3D laser scanner and a 3D printer, providing an opportunity to closely examine the object and better understand its function, all while preserving the fragile integrity of the original artifact (Chetverikov, Hlotov, and Bakuła 2024, 4131; Wachowiak and Karas 2009, 143).

Content: The goal of this study is to fully recreate a replica of the artifact, using innovative tools such as 3D scanning and 3D printing.

Methodology:
3D Scanning of Artifact:
Utilizing the Artec Spider 3D Scanner, a high-resolution handheld 3D laser scanning (e.g., structured light/photogrammetry) to capture the detailed surface geometry of the fragmented artifact.
Processing scans by using specialized software (e.g., Artec Studio 18 Professional, and Agisoft Metashape) to generate accurate digital models.

Data Post-Processing:
- Cleaning and optimizing raw 3D scan data by removing noise, correcting texture distortion, aligning multiple angles (scans) to create a single scan per fragment, and filling in gaps (holes) to generate models suitable for analysis and printing.
- Fully reassembling all fragments of the artifact and refining the digital model for enhanced detail preservation and artifact integrity, and maintaining accuracy by using the Blender 3.4.0 software.

3D Printing of Artifact:
- Employing Flashforge Creator 3 (3D printer) which uses FDM (Fused Deposition Modeling) and SLA (Stereolithography) technologies to create high-fidelity 3D prints of the now fully reassembled artifact.

- Materials included PLA, resin, and other archaeologically suitable printing materials to simulate the artifact's original properties.
Verified dimensional accuracy (1:1 scale) and surface quality of printed replicas.

Use in Comparative Analysis:
- Leveraged 3D-printed replicas to perform hands-on experimental archaeology and comparative studies.

- Provided a 1:1 scaled 3D printed replica using the white filament and a triangle infill for educational use, facilitating a non-invasive interaction and research with the artifact (Wachowiak and Karas 2009, 144).

Results: The replica was printed to scale (1:1), and took approximately a little bit over 13 hours to recreate. The copy had 152 layers, 70 for support, and 82 layers for the artifact itself. The quality of printing was excellent, and the supports were easy to remove. Yet, the texture of the 3D printed object was not smooth where supports were removed (and thus the supports were connected to the underside of the bowl for this reason exactly). The stippling created by the lines of the printer's nozzle could still be seen and felt. Similarly, it was also possible to see where one of the eight fragments was not fully aligned with the artifact, in which, for future printing, it is easily fixable by returning to Blender 3.4.0 and re-aligning the single fragment.

Conclusion: The integration of 3D scanning and 3D printing proved to be highly effective for the precise data collection and analysis of the artifact. Using the Artec Spider handheld laser scanner and a turntable setup allowed for the easy capture of individual fragments, ensuring that each piece was accurately digitized. The process of cleaning, filling holes, and aligning double scans was streamlined by the intuitive Artec Studio Professional software, which facilitated a smooth workflow. However, the most time-consuming aspect involved the alignment of the fragments in Blender 3.4.0 to recreate the complete artifact. While the process itself was straightforward, it required patience and precision to ensure all eight fragments fit together correctly. This step highlighted the importance of meticulous attention to detail, as misalignment in one fragment affected the final print-ed result. Despite the challenges, the 3D printing process, using the FlashForge 3D Creator, yielded a high-quality model. Nevertheless, limitations of the 3D printing technology became apparent, as the printed replica could not fully replicate the color, material, texture, or density of the original artifact. Although the printed object cannot be considered an exact replica in all respects, its creation serves as a valuable tool for further research, preservation, and accessibility. This process exemplifies how 3D scanning and 3D printing can enhance archaeological practices, offering a tangible representation of cultural artifacts that can aid in understanding their function and significance (Tucci et al. 2017, 692).

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141. Digital Insights into Ancient Artefacts: Investigating Ceramic Vessels for Perfumed Oil from Ancient Thrace

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This study outlines an interdisciplinary approach to the digitization and visualization of high-value archaeological artefacts, specifically focusing on closed ceramic vessels from the 5th and 4th century BC, including Greek lekythoi and askoi from Ancient Thrace, currently housed in the National Archaeological Museum’s collection in Sofia. Traditionally used as funerary oil containers, these vessels were constructed from multiple skillfully joined components. In some cases, hidden internal reservoirs were crafted to store perfumed oils, adding another layer of complexity that is not visible from the outside. Decorated with black and red figural, floral, and geometric designs, as well as polychromy and gold, these vessels hold substantial cultural and heritage value, representing complex manufacturing and artistic techniques of the time.

The study aims to uncover details of their construction, usage, and decoration, offering valuable insights into ancient manufacturing and artistic techniques. The research methodology employs advanced technologies, such as the use of micro-computed tomography for volumetric scanning of the artefacts, 360-degree macro-photogrammetry to digitise their outside envelope, and 3D visualisation and modelling to demonstrate the acquired results. Each technology contributes distinct yet complementary insights into both the internal and external features of these vessels. Micro-computed tomography allows for high-resolution volumetric scanning, which provides critical data on the internal structures of these closed forms, enabling analysis of wall thickness, construction techniques, and potential residues that might reveal the vessels' original contents or past usage. It is also instrumental in identifying hidden fractures, porosity in the clay, and potential restoration needs without compromising the artefact’s integrity.

In parallel, 360-degree macro-photogrammetry focuses on capturing the vessel's exterior with fine detail, allowing for the documentation of surface features, such as intricate painted decorations, inscriptions, and wear patterns. When decorations are partially preserved, this method can assist in their full digital reconstruction. The study further integrates these findings into 3D visualization and modelling, making it possible to simulate the original appearance, structural details, and manufacturing methods of the vessels. This approach not only supports scholarly analysis but also enhances public accessibility and appreciation of these artefacts through interactive digital collections.

The data collected through these technologies will contribute to the creation of a comprehensive database for scientific analysis and public presentation, promoting greater awareness and appreciation of these significant archaeological artefacts.

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