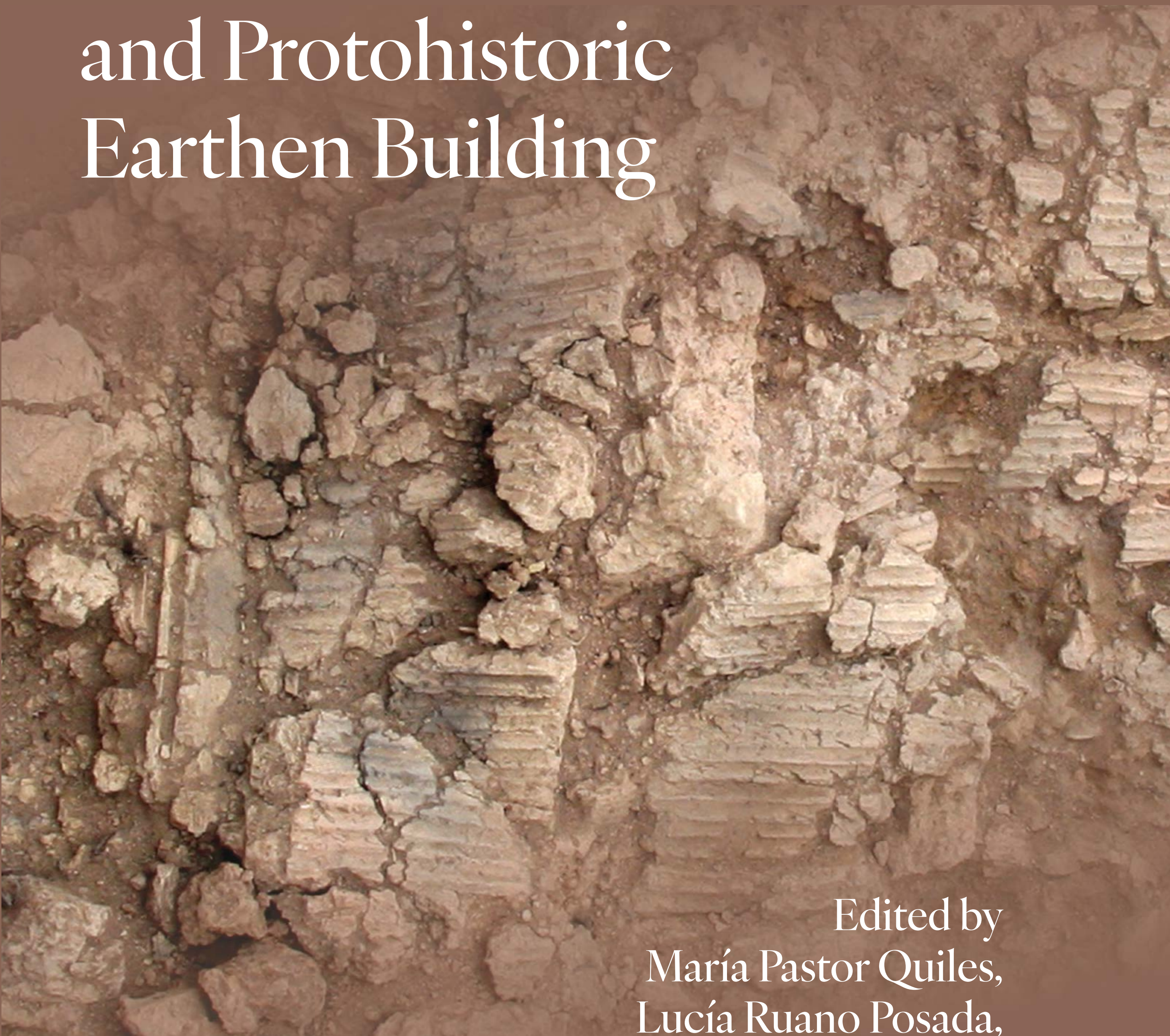
Productive and Social Practices in Prehistoric and Protohistoric Earthen Building



Edited by
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Cover: Fallen wall of reed-impressed daub from room A11 at Early Iron Age Sant Jaume d'Alcanar, Catalonia (© Marta Mateu, David Garcia i Rubert and Sonia Carbonell Pastor).

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María Pastor Quiles, Lucía Ruano Posada,
Alejandra Sánchez-Polo and Marta Mateu

Soil: Earthen architecture as an archaeological research topic

Earth: one of the four natural elements which, for the ancient Greeks, functioned as philosophical principles organising both the world and humanity. Earth, soil or matter represent the common topoi from which all things develop—the space where basic, elementary and subsistence principles unfold. From this perspective, earth emerges as a material employed in the manufacture of a diverse range of objects, from idols and fine ceramics to more 'rudimentary' items such as loom weights or ovens. It is also used to provide shelter, whether through excavation to create dwellings and silos for crop storage, or by kneading the material—even minimally—to enhance the technical properties required for the construction of earthen walls.

In any case, the concept of constructing with raw earth and other natural materials has, since Classical Antiquity, carried profound negative connotations, as already expressed by Vitruvius (Vitr. *De Arch.*, 2.1.8). Perhaps initiated by the ruling classes, these perceptions associate such techniques with the primitive, the unsophisticated, poverty, structural fragility or even dirt. This duality is manifest even in the ostentatious domestic architecture of Roman Pompeii: houses were built from 'humble' materials, such as earth, yet shielded by rich stuccos, bestowing an air of elegance and sophistication upon the structure and, by extension, its inhabitants (Constantini *et al.* 2025; Vaserman *et al.* 2025). Such prejudices permeate both historiography and popular culture. One might consider the well-known children's tale of 'The Three Little Pigs', with roots dating back at least to the 19th century, in which construction choices using natural materials, such as straw and wood, are unable to endure. The 'superior' alternative is presented as brick and tile: materials derived from earth, yet crucially fired rather than raw. Contemporary ethnographic and ethnohistorical research (González Ruibal 1998; Hadjri *et al.* 2007; Kraus 2012; Kulshreshtha *et al.* 2020; Marsh and Kulshreshtha 2021; Ben Chariff *et al.* 2023) demonstrates that these prejudices continue to underpin the resistance of many societies to perceiving earthen construction as a desirable housing solution. This also affects the continuity and recovery of local building traditions based on available natural resources, reuse and, above all, adaptation to the bioclimatic conditions of each region.

This ideological bias has not only shaped public perception—perpetuating the myth of fragility in contrast to the 'noble' nature of stone or brick—but has also permeated the very foundations of academia. Consequently, it dictates which remains are deemed worthy of preservation and analysis and which are not. Crucially, albeit perhaps more indirectly, it also determines who ultimately studies these marginalised and undervalued archaeological vestiges.

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Stabilizers: State-of-art, advances and issues in its archaeological application

Thus, within the field of research into earthen construction, and its archaeological study in particular, the widespread negative connotations of the material as something 'folk', domestic, minor or 'secondary' appear to have influenced its status as a research topic. It is not uncommon to encounter such perceptions, manifesting as either doubt or direct negative feedback, when announcing the choice of mud as an object of study. This stands in contrast to more 'glamorous' fields, whether focused on material studies such as ceramics or metals, or those associated with construction, such as urbanism, to name but a few. This reflects the shared experience of many of us dedicated to this line of inquiry and profoundly impacts the study of these materials. As has been argued for decades, and as the authors of this text have asserted in various scientific forums (Pastor 2017; 2025; Ruano Posada and Sánchez-Polo 2023; Mateu *et al.* 2013; Mateu 2025; Ruano Posada *et al.* 2025; Sánchez-Polo *et al*. 2025a; 2025b), we repeatedly observe that remains of render, daub with impressions, hand-shaped pieces or even adobes are neither correctly excavated nor recovered. Frequently, they simply disappear, while those remains that are collected often go unstudied, left abandoned in museums with almost no adequate conservation measures.

The study of these remains as a distinct field of specialisation has a relatively short history. Within the European context, the pioneering work of Claire-Anne de Chazelles since the 1980s (Chazelles and Poupet 1985) must be highlighted; her research subsequently encompassed various prehistoric and protohistoric periods across the continent and the Mediterranean, including the Iberian Peninsula and sites such as Empúries. In the Iberian Peninsula, it is M. Carme Belarte who has contributed most significantly to the study of earthen construction remains, focusing on the Iberian Northeast and the Protohistoric period since the early 1990s (Belarte 1993, 2002). Her work aligns with additional early investigations into this subject (i.e. Romero 1992; Miret 1992; Asensio 1995; Sánchez 1997), alongside other initial studies by Elena García and Carmen Lara regarding prehistoric mud remains (García and Lara 1999, 2007). From the early 2000s, Magdalena Gómez—a contributor to this volume—focused on domestic spaces and Neolithic earthen remains in the Spanish Levant (Gómez 2008). In Portugal, Patrícia Bruno addressed prehistoric earthen construction evidence across various sites in several works (i.e. Bruno *et al.* 2010). Shortly thereafter, in Germany, Franziska Knoll and Mechthild Klamm published a seminal, comprehensive volume on the study of earthen construction in archaeology (2015). In Spain, these efforts have been followed by further research, including our own (Mateu 2011, 2016; Pastor 2021; Ruano Posada 2021; Ruano Posada and Sánchez-Polo 2023), and the recent publication of significant works in this field (Rodríguez and Jiménez 2022; Carranza *et al.* 2025).

Simultaneously, the early years of the new millennium saw the first symposia on earthen construction in Montpellier (France), bringing together specialists in architecture, archaeology, engineering, ethnology and history—the first of which was directed by C.-A. de Chazelles, A. Klein and M. Lieutaud. These conferences have continued ever since (2001, 2005, 2008, 2016, 2019), expanding their geographical scope and publishing through the series *Échanges transdisciplisaires sur les constructions en terre crue* (for instance, the first by Chazelles and Klein, 2003). Researchers from the French sphere, including Émilie Leal and Marylise Onfray, have continued to contribute to the knowledge of past earthen construction, as evidenced by the recent publication of the volume *La terre crue en contexte funéraire* (Leal *et al.* 2025) and through other published scientific meetings (Onfray *et al.* 2023).

A new momentum in this field of research has been generated through sessions at major international archaeological congresses. Notable among these was the session organised by Serena Love and Corisande Fenwick at the 2014 Annual Meeting of the European Association of Archaeologists (EAA) in Turkey, titled 'The archaeology of architecture: technology and practice'. This EAA session specialised in earthen architecture was followed by others, such as those held in Maastricht in 2017 ('Earthen Architectures from the Neolithic to the Iron Age: Detection of structures and characterisation of building techniques') and in Barcelona in 2018 ('Earthen architecture and habitation sites: building ways of life in Prehistory'). These were succeeded by the 2023 session—the proceedings of which are published here—as well as those held in Rome in 2024 and those that continue to be convened to the present day.

Further progress in the generation of knowledge regarding these remains has been driven by archaeometric and micromorphological analyses. From various perspectives, these are contributing to an understanding of the operational sequences and gestures (*chaînes opératoires*) of earthen materials and structures—ranging from construction techniques to maintenance processes and post-depositional alterations, among others. Within the fields of geoarchaeology and micromorphology, the work of Wendy Matthews, Cécilia Cammas and Julia Wattez from the mid-1990s onwards is particularly noteworthy. Currently, numerous other research projects are being conducted globally, specialising in different chrono-cultural periods (Mateu 2025). We also highlight the ongoing dynamism of the work and teams led by Marta Lorenzon in the Mediterranean basin and other regions, Maud Devolder in the Aegean — a contributor to this volume—Jana Anvari in Europe (Mancini *et al.* 2026) and Annick Daneels in Mexico. Daneels also coordinated a session at the UISPP in 2018 on earthen construction, which was published by Archaeopress alongside Maria Torras (Daneels and Torras 2021).

It is unsurprising that, since the inception of earthen construction studies in archaeology, interaction with other disciplines has been essential for understanding these remains. This serves, on one hand, to better comprehend building techniques and structures and, on the other, to unify and refine the terminology employed. As previously noted, the Montpellier symposia were established for this purpose; however, international organisations and networks formed since the late 20th century have also been instrumental. These bodies organise congresses on earthen architecture and heritage that have increasingly incorporated archaeological data and challenges into their discourse (i.e. ICOMOS-TERRA, CRAterre-Grains d'Isère, the PROTERRA Ibero-American Network-SIACOT or the NGO Adobe in Action-Earth USA).

Among these disciplines, the study of traditional architecture has been a primary contributor. A notable example is the *Diccionario de la construcción con tierra* (2003) by J. de Hoz, L. Maldonado and F. Vela, which has proved vital in clarifying construction concepts that are seldom encountered in their entirety within archaeology, where buildings are typically found in a state of ruin. In this regard, Camilla Mileto, F. Vegas and their team at the Universitat Politècnica de València have spent over two decades studying vernacular architecture, with a particular devotion to earthen structures. As part of the COREMANS initiative—led by the Spanish Cultural Heritage Institute—this team has defined specific 'intervention criteria for earthen architecture' while developing an extensive compendium of earthen construction methods throughout the Iberian Peninsula (Mileto and Vegas 2017). Furthermore, they have fostered a prolific school of thought through the supervision of doctoral theses, such as those by F. J. Gómez on traditional adobe construction and S. Manzano on Iberian archaeological sites featuring *in situ* earthen architecture. These works document various construction methods, structural pathologies and the general state of conservation.

Regarding terminology, international groups have put forward several proposals, such as the *Glosario Internacional sobre Terminología en Técnicas de Construcción de Tierra* by the PROTERRA Ibero-American Network, which is available on their website[1]. Within archaeology, the quadrilingual glossary by Franziska Knoll, María Pastor, Claire-Anne de Chazelles and Louise Cooke (2019) has become indispensable. This work specialises in earthen architecture and focuses on distinguishing between construction techniques

[1] https://redproterra.org/es/terminologia/

and typologies; it reflects the diverse range of earthen building remains encountered by the four authors, whose research has spanned a vast geographical and chronological scope.

It is perhaps no mere coincidence that we—the female researchers whose work we seek to render visible through this text—are dedicated to this field in a higher proportion than our male counterparts, who still constitute the majority in the scientific and archaeological professions. As stated in the opening of the book *Arquitectura con arquitectas* (Garrido *et al.* 2023: 11): 'visibility is the prior and necessary step to achieving recognition'. The study of earthen construction and mud materials is one of those subjects where women researchers predominate, much like other fields such as conservation and restoration—which are, in a sense, associated with the 'care' of material culture—or gender studies themselves. We are aware that gendered associations, both conscious and unconscious, operate in the assignment and selection of areas of work and study. Consequently, women remain underrepresented in the historical and archaeological study of economics, politics, the military and the theoretical developments of the discipline—intellectual and philosophical spheres with long-established trajectories that remain markedly masculinised. This disparity also persists due to the continued dichotomy between the 'field' and the 'lab'—'*arqueología de bota*' and '*de bata*', in Spanish. This separates those—generally men—who largely direct and work on excavations from those—predominantly women—who lead the laboratories. The latter often find themselves relegated to the 'backroom' tasks of processing, studying, mending and classifying materials following excavation, or working with instrumental analytical techniques—the Archaeological Sciences.

It is hardly surprising that a material which has received scant attention—and is associated with the secondary, the domestic and even maintenance activities—should be a field developed especially by women. Following this pattern of dichotomous narratives, the archaeology of architecture is a discipline firmly established in academia, boasting several specialised journals such as the CSIC's *Arqueología de la Arquitectura*, founded in 2002, or the volume *Archeotecture* published in 2003 (Ayán *et al.* 2003). A defining feature of this subdiscipline is its focus on standing buildings, whether fully or partially preserved, which are typically constructed of stone. Consequently, it is generally monumental buildings that receive attention in the analysis of wall stratigraphy and the reconstruction of their 'biographies'. While it is true that—with rare exceptions, such as some presented in this very monograph—archaeological earthen architecture often lacks the large wall surfaces required for this type of architectural analysis, it has also been an academically neglected field until recently. This is due, in part, to its relegation to the domestic sphere, which usually falls outside the scope of buildings studied by the archaeology of architecture. In this way, research into past earthen architecture remains largely invisible. Being little known and thus poorly recognised, it falls on the 'feminine' side of the traditional gender divide that still permeates our societies across all spheres, from the personal to the professional and scientific. Furthermore, within research, masculinised environments tend to reproduce these patterns, whereas the presence of women fosters the inclusion of other women, as various studies have indicated (Bowman and Ulm 2009; Maliniak *et al.* 2013; Piper *et al.* 2016; Mateo and Pastor 2022; Pastor and Mateo 2022).

Gradually, research into earthen architecture in archaeology is gaining ground in new spheres and becoming consolidated across different parts of the world, building links and networks while fostering the transfer of knowledge. In many cases, these lines of research have emerged from a secondary position, a fact that is important to acknowledge, as it also serves as a strength by encouraging necessary multi- and interdisciplinary synergy and dynamism.

Parallel to this, recent decades have seen a renewed interest in these techniques and materials within contemporary architecture. This shift is driven by the rise of bio-construction, the use of recyclable and low-impact materials and the pursuit of more sustainable and socially responsible models of habitability. Far from being a mere nostalgic revival, this resurgence is underpinned by technical experimentation, innovation and a dialogue between traditional wisdom and modern scientific knowledge. It once again places earth and other natural materials at the heart of the debate on construction in a context of climate crisis, resource depletion and the questioning of dominant industrial models. This convergence between past and present further reinforces the social and scientific relevance of archaeological studies on earthen architecture, demonstrating its potential not only as an object of historical analysis but also as a source of inspiration for addressing the challenges of the future.

Water: The monograph origin

This volume has been slowly conceived over the past two years, although it truly began in 2022 when we proposed a session for the 30th EAA Annual Meeting in Belfast (2023), titled 'Using Earthen Architecture as an Excuse: Productive and Social Practices in Prehistoric and Protohistoric Building'. What started as an initial idea to discuss construction techniques and social processes in European building practices evolved into a continuous eight-hour dialogue featuring 23 presentations focused on ten different countries. Just over 25% of these were presented by male researchers, reflecting the aforementioned trend that earthen architecture in archaeology is particularly, though not exclusively, linked to female scholars.

The papers collected here span various periods of Later Prehistory and Protohistory across diverse geographic contexts and they remain heterogeneous in both their approach and the methodologies employed. This volume offers a contemporary overview of the state of archaeological research into the earthen construction practised across different global territories millennia ago, focusing analysis on the productive and social aspects of building. It reflects the still nascent state of knowledge regarding these architectural manifestations of past communities across the various fields addressed. Significant obstacles remain, such as persistent terminological issues and the challenges of classifying construction techniques, as well as substantial gaps in the study of the historical development of these building forms. However, works such as those gathered here provide a valuable contribution to progressively reversing these difficulties and building a new, more comprehensive framework of knowledge regarding this essential reality of human societies, from the first stable settlements to the present day. Today, earthen construction continues to hold immense historical, heritage, scientific and cultural value; furthermore, given the complex environmental crisis in which we are immersed, it possesses undeniable public importance due to its eminently sustainable nature (Moriset *et al.* 2021).

Sun: Article presentation

This volume does not intend to be a mere accumulation of case studies, but rather a proposal that reflects the complexity of earthen architecture as both a social and technological phenomenon. The contributions are organised according to an analytical logic that transitions from the micro-scale of construction remains to the social dimension of the landscape. This analytical framework fosters a cross-cutting perspective on the issues facing Prehistoric and Protohistoric communities, moving beyond geographical dispersion to focus on the methodological challenges common to the archaeology of earthen construction. This approach should not be viewed as a series of isolated compartments; on the contrary, the thematic axes presented here are fluid and permeable categories, where archaeometric analyses, *chaînes opératoires* and social interpretations are constantly interwoven within the reality of the archaeological record.

Macroscopic analysis of construction remains and their contexts. This initial axis brings together research focused on the macroscopic identification and characterisation of earthen structures, following a chronological sequence that traces the evolution of technical solutions across the Mediterranean and the Iberian Peninsula. **Maud Devolder**'s work at the Palace of Malia (Crete) analyses the use of mudbrick since the Middle and Late Bronze Age, establishing macroscopic criteria for identifying superstructures that have long since disappeared. In a similar vein, **Laerke Recht and Kataryna Zeman-Wiśniewska** examine how Late Bronze Age excavated architecture in Cyprus integrates the geological substrate as a foundation for earthen structures, thereby enhancing thermal sustainability.

Moving towards the transition between the Late Bronze Age and the Early Iron Age, **Alejandra Sánchez-Polo and Lucía Ruano Posada** document the shift from wattle-and-daub dwellings to the widespread adoption of mudbrick in the northern Iberian Meseta; they analyse macroscopic manufacturing traces and the processes of technical experimentation between local traditions and external innovations. Finally, the study by **Marta Mateu, David Garcia i Rubert and Sonia Carbonell Pastor** on Sant Jaume d'Alcanar serves as a transitional node: by starting from the macroscopic analysis of linings and pavements exceptionally preserved by fire, the text theoretically bridges into microanalysis. This approach demonstrates that integrating stratigraphic study with micromorphology is essential for deepening our understanding of the *chaîne opératoire* and the cultural attribution of construction techniques.

Archaeometric analysis: microstratigraphy and physico-chemical characterisation. This second axis focuses on the application of archaeometry to overcome the limitations of the macroscopic record, enabling a profound reading of the composition and formation of earthen structures. The section begins chronologically with the work of **Magdalena Gómez Puche and Ana Polo-Díaz**, who present the first combined (macroscopic and micromorphological) analyses of Early Neolithic mortars in the Iberian Peninsula (Mas d'Is and Los Cascajos). Their research reveals an early technical variability in earthen "recipes", highlighting the use of cereal processing by-products as stabilisers and contributing to the study of the earliest uses of lime in Prehistoric domestic structures.

Across a broad temporal scale covering much of the Balearic Bronze Age, **M. Mercè Bergadà *et al.*** apply microstratigraphic analysis to Naveta I at Closos de Can Gaià (Mallorca). This study allows for the precise differentiation of technical evolution—from wattle-and-daub to cob ball modelling—and the identification of occupation surfaces invisible to the naked eye, which are fundamental to understanding the articulation of domestic space. Finally, the section expands towards a different geographical and methodological scale with the work of **Gianni Gallello *et al.*** on the geoglyphs of Acre (Brazil). Through the analysis of rare earth elements (REE), this study demonstrates the potential of geochemistry to distinguish between natural deposits and anthropogenic construction horizons in monumental earthen structures where the material record is extremely scarce, providing a vital tool for the characterisation of built landscapes.

Theoretical approaches and social experimentation. This third axis brings together research that transcends the *in situ* analysis of archaeological remains to explore construction logic through the lenses of geometry and social interaction. On one hand, **Luis Miguel Carranza *et al.*** propose a geometric and mechanical approach to earthen roofing in Western Asia during antiquity, examining the technical viability of self-supporting domes and vaults constructed without centring (falsework). Their work underscores the vital importance of understanding the physical logic of the material to correctly interpret mudbrick and brick remains within monumental contexts.

On the other hand, the volume incorporates the perspective of experimental archaeology and social interaction through the work of **Antje Wilton and Kenan Hochuli**. Through an analysis of the reconstruction of a Mesolithic hut, the authors explore how coordination and shared learning during the building process generate social dynamics that can be traced within the archaeological record. This section, therefore, bridges the abstraction of architectural design with the reality of collective effort, providing tools to understand construction as a living, coordinated process.

Heritage, sustainability and transfer. As the conclusion to this volume, the contribution by **Marialucia Amadio *et al.*** presents the EARTHERITAGE project, which proposes a dialogue between the documentation of the archaeological record and its potential transfer to contemporary conservation needs. The study focuses on the analysis of Cypriot Bronze Age materials through an approach that integrates archaeology and geoarchaeology with technical experimentation. The objective of this research is not only to deepen our knowledge of past construction solutions but also to use them as an empirical basis for developing preservation strategies that are both sustainable and compatible with original raw materials. By linking the study of unfired earth with sustainability and contemporary architecture, this work provides technical responses to current climate crisis challenges and the management of tangible heritage in the Mediterranean, synthesising the volume's ambition to connect the memory of building practices with the challenges of the present day.

Conclusions

With this volume, we aim to highlight the fact that earthen architecture has been, and remains, a profoundly widespread constructive reality, both geographically and historically. Despite long-standing prejudices and its traditional invisibility in archaeological research, we now possess the frameworks and tools necessary to extract a wealth of information from this fragile materiality. Consequently, this book is born to reclaim the scientific status of unfired earth, underlining its potential to articulate complex discourses on social organisation and technical specialisation in the past. It is a call for its necessary incorporation into current research strategies, recognising in this materiality a record that allows us to begin reading complex social and technical processes where, previously, only mud and dust were perceived.

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Macroscopic Evidence for the Use of Adobes at Minoan Malia (Bronze Age Crete)

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Abstract: The Bronze Age site of Malia, on the north coast of Crete, has yielded extensive evidence for the use of adobes (or Minoan 'mudbricks'). This can be explained both by the ready availability of suitable raw materials in the immediate vicinity of the settlement and by the care taken by the excavators to protect the mudbrick walls. A review is offered of the evidence pertaining to the mudbrick walls and installations identified on the site. This reassessment provides the basis for outlining patterns in mudbrick wall construction, identifying the clues that point to disintegrated mudbrick superstructures, and discussing the organisation of mudbrick production and related building projects.

Keywords: Minoan mudbrick, Bronze Age Crete, Malia Palace, earthen architecture, building process.

Résumé: Malia, site de l'Âge du Bronze égéen situé sur la côte nord de la Crète, a livré de nombreuses preuves de l'utilisation d'adobes (ou 'briques crues') minoennes. Cet usage est souvent mis en relation avec l'abondance des matières premières disponibles dans les environs immédiats du site ainsi qu'avec le soin apporté par les fouilleurs à la protection des murs. Cette contribution propose une synthèse des données relatives aux murs et installations en briques crues mis au jour à Malia, afin de mettre en évidence les principaux traits de l'architecture en terre sur le site, de définir les critères permettant d'identifier les superstructures en briques crues aujourd'hui désintégrées, et d'aborder la question de l'organisation de la production des briques ainsi que celle des projets de construction.

Mots-clés: Briques minoennes, Crète de l'âge du Bronze, Palais de Malia, architecture en terre, processus de construction.

Introduction

The Bronze Age site of Malia is located on the north coast of Crete, on a fertile plain bordered to the north by the sea and to the south by the foothills of the Selena mountain range (Figure 1a). This topographical setting provided the inhabitants of the 3rd- and 2nd-millennium BC settlement with abundant agricultural resources, as well as privileged access to maritime and terrestrial exchange networks, the outcomes of which are reflected in a rich material culture and in major socio-political and urban developments that align with broader island-wise trajectories throughout the Early, Middle and Late Bronze Age (Devolder 2019a; Driessen 2010) (Table 1). The immediate surroundings of the site also supplied essential building materials: the hard, light grey to dark grey-blue limestone forming the geological substrate of the plain; the *terra rossa* produced by the erosion of this limestone; and the sandstone formed from consolidated aeolian dunes, quarried in regular blocks along the Malia shoreline (Devolder and Lorenzon 2019; Devolder *et al.* 2024: 11, fig. 4c; Dimou *et al.* 2000; Guest-Papamanoli 1989; Müller-Celka 2020).

Adobe, commonly referred to as mudbrick in the archaeological literature on Bronze Age Crete, was a key building component at Minoan Malia. Its prominence can be explained both by the availability of suitable illite-muscovite clay beds on the plain, which provided convenient sources of raw material, and by the care taken by the excavators to protect mudbrick walls immediately after excavation (Demargne and Gallet de Santerre 1953: 42–43, pl. XIX 4; Devolder and Lorenzon 2019: 100–101;

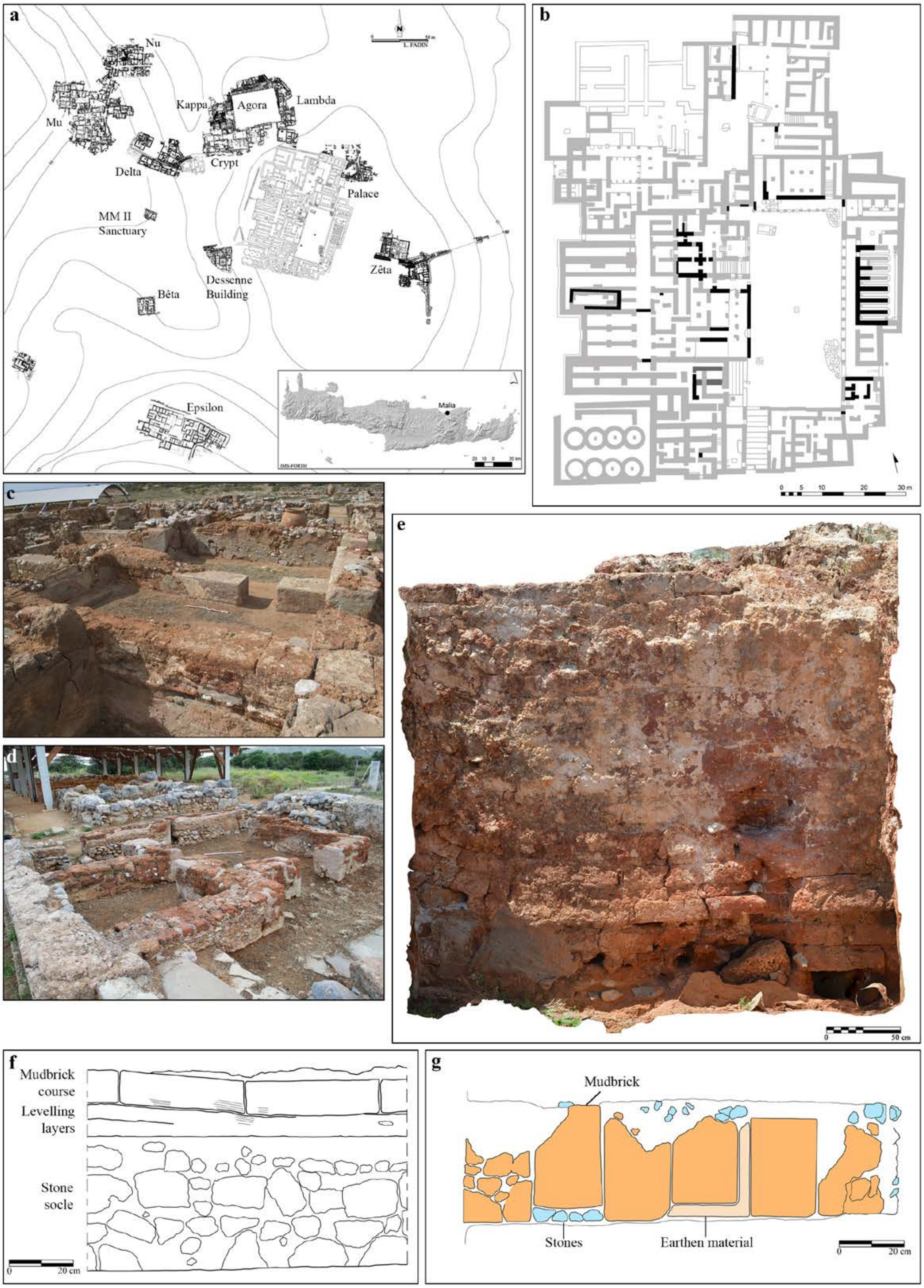

Figure 1. a) Location of Malia in Crete (EFA/L. Fadin and IMS-FORTH/M. Devolder); b) schematic plan of the Palace with preserved mudbrick walls shown in black (EFA/M. Devolder, after E. Andersen); c–d) views of Neopalatial mudbrick walls in the Palace (EFA/M. Devolder); e) view of Prepalatial mudbrick walls in the Palace (EFA/M. Devolder); f) elevation and g) plan of Protopalatial walls in the Eastern Magazines of the Palace (EFA/M. Devolder).

Table 1. Chronological framework and occupation patterns at Malia throughout the Early, Middle and Late Bronze Age (EBA, MBA and LBA).

Period		Phase	Relative dates (c.)	Occupation patterns at Malia
Neolithic		Final Neolithic I–IV	4500–3100 BC	Sporadic traces of occupation on the plain
EBA	**Prepalatial**	Early Minoan I	3100–2650 BC	Sporadic traces of occupation on the site
		Early Minoan IIA	2650–2450 BC	
		Early Minoan IIB	2450–2200 BC	Increased occupation of the site
		Early Minoan III	2200–2050 BC	Sporadic traces of occupation on the site
MBA		Middle Minoan IA	2050–1900 BC	
	Protopalatial	Middle Minoan IB	1900–1800 BC	First Palace and Protopalatial 'grands ensembles' until a major destruction on the site *c.* 1700 BC
		Middle Minoan IIA	1800–1750 BC	
		Middle Minoan IIB	1750–1700 BC	
	Neopalatial	Middle Minoan IIIA	1700–1640 BC	Ongoing but currently less well documented occupation of the site
		Middle Minoan IIIB	1640–1600 BC	
LBA		Late Minoan IA	1600–1510 BC	Second Palace (destroyed *c.* 1530 BC?)
		Late Minoan IB	1510–1430 BC	Ongoing but currently less well documented occupation of the site
	Final Palatial	Late Minoan II	1430–1390 BC	
		Late Minoan IIIA1	1390–1360 BC	'Mycenaean' occupation of several structures on the site
	Postpalatial	Late Minoan IIIA2	1360–1330 BC	
		Late Minoan IIIB	1330–1190 BC	

Pelon 1980: 6, 198–200; Schmid 1990: 930–939; Schmid and Treuil 2017: 125–128, 289–290). This situation has given Malia an ambivalent status: it is regarded as both a model for Minoan earthen architecture and as an exception within the island's built environment, where mudbrick walls are less well preserved or where stone was favoured over earth.

The objectives of this contribution are to examine the characteristics of earthen architecture at Malia, outline patterns in mudbrick wall construction, identify the clues that point to disintegrated mudbrick superstructures and discuss the organisation of mudbrick production and related building projects. To do so, it processes evidence produced by a macroscopic study of earthen remains from the Palace and by a review and analysis of bibliographic and archival sources for the Palace and other buildings on the site. Focusing first on mudbrick walls in the Palace, the Mu Quarter, the Delta Quarter, the Zêta Quarter and documented remains elsewhere on the site, it then proceeds to revise data related to less well-preserved mudbrick installations that took the form of partitions for compartments, fire-related structures or platforms of debated function. The results of our reassessment of the data are then synthesised and set in perspective to highlight broader patterns of earthen architecture construction throughout the Bronze Age at Malia.

Mudbrick walls

The Palace

The Malia Palace was constructed towards the end of the Middle Minoan IA phase (*c.* 1900 BC), although it incorporates earlier mudbrick walls dating to the Early Minoan IIB phase (*c.* 2450–2200 BC) (Figure 1b). The monumental complex survived several destructive events throughout the Middle and Late Bronze Age and was ultimately destroyed by fire toward the end of the 16th century BC, in the Late Minoan IA phase (Devolder 2025; Devolder *et al.* 2023). The standing remains, although they span a period of almost 900 years, mostly belong to a major building project undertaken at the transition between the 17th and 16th centuries BC and destroyed towards the end of the 16th century BC. The excavation daybooks and early publications contain frequent references to destruction layers that include mudbricks or masses of earth interpreted as the decayed remains of mudbrick structures (Charbonneaux 1928: 349–350, 354; Chapouthier and Charbonneaux 1928; Chapouthier and Joly 1936; Hazzidakis 1915: 118–119, fig. 6). The walls now forming the four wings around the Central Court illustrate the diversity of building components and masonry types employed in the construction of the Late Bronze Age Palace. These include entire sets of rooms as well as individual walls built of mudbrick. Features related to bricklaying, together with mudbrick dimensions and their macro- and microscopic composition, indicate that different teams of mudbrick builders were assigned to specific areas of the Palace. These teams acquired raw materials, processed them to produce the mudbricks and then assembled them into walls (Devolder and Lorenzon 2019: 107–114).

Despite these variations, the mudbrick walls of the Malia Palace display a series of recurring constructional features (Devolder and Lorenzon 2019: 69–81). Mudbrick courses are consistently set atop a stone socle built of two-faced small boulders and rubble-stone masonry, whose primary function is to prevent moisture from rising into the earthen superstructure through capillarity (Figure 1f). These stone socles occur on both exterior and interior walls and range in height from 0.15 to 0.58 m. Only in rare cases—typically for partitions that divide space or limit access—is the stone socle omitted, with mudbricks instead resting on a stone foundation that barely emerges, if at all, above floor level. The stone socle is generally capped with a 4–12 cm-thick levelling layer of earthen building material, its surface carefully flattened to receive the mudbrick courses (Devolder and Lorenzon 2019: figs. 3, 4, 7–9) (Figure 1f). In several walls, small stones are inserted into this layer as wedges, reinforcing the earthen material as it is being compacted. Where mudbrick walls survive to sufficient height, additional intermediary layers of earthen building material—6–16 cm thick and often containing stone wedges—are preserved between mudbrick courses. These layers served to level the masonry before the subsequent mudbrick courses were laid.

In most parts of the Late Bronze Age Palace, mudbricks were laid in header bond—that is, with their shortest sides forming the wall faces (Figure 1c–g). Running bond, in which mudbricks are laid as stretchers, appears only in partition walls. In the Middle Bronze Age walls preserved in the Eastern Magazines, the bricks are set in header bond, but the individual bricks within each course are horizontally offset (Devolder and Lorenzon 2019: fig. 11) (Figure 1g). This arrangement allowed builders to construct walls wider than the length of a single brick, while the addition of earthen building material between bricks enhanced cohesion within each course. A single example of English bond—alternating courses of headers and stretchers—is attested in Early Bronze Age walls later incorporated into the Palace (Devolder and Lorenzon 2019: fig. 11) (Figure 1e). A similar arrangement may also be present in some heavily restored Neopalatial walls in Area VI (pers. obs.).

A macroscopic study of the mudbricks used in the Malia Palace has shown that their fabric ranges widely in composition, from fine to coarse (Devolder and Lorenzon 2019: 92, fig. 26). Mudbricks with

Figure 2. a) Detail of mud coating incorporating straw in the Palace (EFA/M. Devolder); b) general view of the Mu Quarter (EFA/J.-C. Poursat [R3274]); c) plan of the Mu Quarter (EFA/M. Schmid); d) mudbrick partition next to the lustral basin in House Delta Alpha (EFA/unknown author [R5294]) and e) mudbrick platform in House Zêta Bêta (EFA/unknown author).

a homogeneous, fine macro-fabric are typically reddish in colour and were produced from screened sediments with a maximum gravel size of 1.5 cm. These sediments were mixed with large quantities of *Posidonia oceanica* seagrass (Guest-Papamanoli 1978: 6; Lorenzon 2021; Veropoulidou and Devolder 2024) and contain very few other inclusions. At the opposite end of the spectrum are mudbricks with a heterogeneous, coarse macro-fabric. These are more varied in colour and were made from unscreened sediments, resulting in numerous large inclusions such as gravel, obsidian, bone, shell, plaster or ceramic fragments. Notably, these coarser mudbricks contain much smaller amounts of seagrass temper. Coarse mudbricks also show a greater degree of erosion, suggesting that they have performed less well over time than those produced with a finer macro-fabric (Devolder and Lorenzon 2019: 92).

There is no evidence for the use of timber within the mudbrick walls of the Malia Palace. The scarcity of indications for any mudbrick-timber association may simply reflect the limited preservation of the walls, which rarely survive more than 80 cm in height; any timber framework positioned higher in the elevation would no longer be preserved. It is nevertheless noteworthy that the Early Minoan IIB walls incorporated into the later Palace, which are preserved to a height of 1.93 m, show no traces whatsoever of timber elements (Devolder and Lorenzon 2019: 81–83) (Figure 1e).

Several of the Palace's mudbrick walls still preserve remains of the protective revetment that once covered them. In many cases, only the primary mud-coating layer—3 to 10 cm thick and coarse in texture—survives. This initial layer typically contains large quantities of straw in stalks 2 to 10 cm long, which helped drain excess water and prevented cracking caused by shrinkage during drying (Figure 2a) (Devolder and Lorenzon 2019: 94). Its composition closely matches that of the coarse mud plaster used to regularise the faces of irregular stone walls, a practice well attested at other sites as well (Devolder 2009: 71; Shaw 2009: 141–143). This coarse coating was usually covered with layers of finer mud or lime plaster, which required regular upkeep (Devolder and Lorenzon 2019: 94–95, fig. 28).

The Mu Quarter

The Mu Quarter is one of the most emblematic buildings in Minoan Crete, owing largely to its destruction by fire—likely triggered by an earthquake (Devolder 2019b: 79–81)—at the end of the Middle Minoan IIB phase (*c.* 1700 BC). This event baked the mudbrick walls and secured their exceptional state of preservation (Poursat *et al.* 1978: 20–21; Schmid and Treuil 2017: 12) (Figure 2b). The complex is composed of two major structures, Buildings A and B, around and against which several smaller or only partially excavated buildings (C, D and E), as well as a number of workshops, were constructed (Figure 2c). Architectural study of the ruin suggests the following sequence: Building C (possibly), the earliest part of Building A and perhaps Building D were built first, already during the Middle Minoan II phase. Building A was then extended southwards, and finally, Building B was added (Schmid and Treuil 2017: 10–12).

With the exception of a few underground walls built entirely of small boulders and rubble stones, as well as several exceptional façade walls constructed of carefully cut ashlar blocks, the preserved walls of the Mu Quarter are composed of mudbrick courses set on a low stone socle, with only rare examples of mudbrick partitions lacking a socle (Schmid and Treuil 2017: plan 6). In many walls—particularly in Buildings D and E and in areas built directly on the deeper bedrock in the south-eastern sector of Building A—only the stone socle survives (Schmid and Treuil 2017: plan 6). The complex layout of the Mu Quarter was therefore supported primarily by mudbrick walls, and the boldest reconstructions propose that the structures originally reached three to four storeys (Schmid and Treuil 2017: 250–253).

Where mudbrick courses are preserved, it is possible to identify recurrent building patterns, which shed light both on production organisation and on the builders' capacity to adapt to the structural requirements of the complex. The stone socles—typically 0.40–0.60 m high but reaching up to 1.70 m high in areas built on lower natural ground—are constructed of hard limestone small boulders, rubble stones and occasional conglomerate elements arranged in two-faced masonry. In exterior walls, larger blocks were used, some described as roughly worked (Schmid and Treuil 2017: 144, 146). Unless resting on earlier structures, these socles were founded directly on bedrock, a recurrent practice at Bronze Age Malia (Devolder 2019b: 64–65, fig. 12). Mudbricks were laid either as stretchers or headers across the wall thickness, with one recorded instance of English bond. Notably, the architectural study identifies a shift in brick orientation: stretchers dominate the earliest phase of Building A, whereas headers appear in the later phase of Building A and in Building B. This change made the construction of thicker walls during the later building stages of the Mu Quarter possible (Schmid and Treuil 2017: 147).

The use of a timber framework in the walls of the Mu Quarter, composed of longitudinal (round or roughly finished) and transversal (generally squared) elements, is best attested in the fully preserved stone walls of the underground rooms in Area V of Building B. Schmid and Treuil (2017: 148, 151) argue, however, that similar timber elements were also incorporated into the mudbrick walls, positioned both above the stone socle and at the top of the mudbrick elevation. Together with the vertical timber elements framing doors and windows, horizontal elements would have formed a robust, load-bearing structural framework for the buildings of the Mu Quarter. The publication does report limited evidence for such timber components—specifically in the west wall of room III 2 and in the stringer wall of staircase III C (Schmid and Treuil 2017: 147, fig. 232, 234). Yet even well-preserved mudbrick walls do not always show clear traces of former timber elements, making their original presence difficult to ascertain.

Macroscopic observation of the mudbricks in the Mu Quarter, as described by the authors of its architectural study, indicates the presence of mineral temper naturally occurring in the procured soil, along with *Posidonia oceanica* seagrass deliberately added as vegetal temper (Schmid and Treuil 2017: 137). Their macro-fabric can, however, be more accurately characterised as homogeneous, following the typology developed for the Malia Palace (pers. obs.; Devolder and Lorenzon 2019: 92), a feature that reflects the care invested in mudbrick production. The dimensions of the bricks suggest the use of up to six mould templates (Schmid and Treuil 2017: 137, fig. 224). Notably, only one of these templates is shared by walls from different phases in the Mu Quarter's building sequence, whereas multiple mould sizes appear within a single construction episode. This points to segmented mudbrick production, echoing similar observations made for the Late Bronze Age Palace (Devolder and Lorenzon 2019: 110).

The Delta Quarter

Evidence for the use of mudbrick in the Delta Quarter, an ensemble of Neopalatial houses built in some cases atop Protopalatial structures which may have formed part of larger domestic units, is limited both in preservation and publication (Bradfer-Burdet and Pomadère 2011; Driessen 2010). Only a small number of walls still retained mudbricks at the time of their discovery in the first half of the 20th century.

Preserved mudbrick courses are visible in several walls of House Delta Bêta, notably along the east wall of corridor 1 and the south wall of the narrow room 13, as well as in a few fragmentary remains to the south (Bradfer-Burdet and Pomadère 2011: fig. 9.3; Demargne and Gallet de Santerre 1953: 48, 50). In the wall east of room 1, the mudbricks—measuring *c.* 0.55 × 0.40 × 0.15 m—are laid as headers on a roughly 0.25 m-high rubble-stone socle. These bricks fill the full thickness of the wall, which was constructed in two segments north and south of a pre-existing cut-sandstone pillar (Bradfer-Burdet and Pomadère 2011: 105, fig. 9.3, 9.5, 9.6, 9.9). South of space 3, the bricklaying is less clearly preserved; however, where the bricks are best visible, stretchers can be identified filling the width of the walls (Bradfer-Burdet and Pomadère 2011: fig. 9.7, 9.8).

The walls surrounding the lustral basin (space 7) in House Delta Alpha were narrow partitions, approximately 0.33 m wide, constructed of mudbricks set on a stone socle; only the head of the staircase wall incorporated a cut sandstone block (Demargne and Gallet de Santerre 1953: 46, pl. XIX.2, LXIII, LXVI). The excavators, noting the slightness of these earthen walls, suggested that they were not intended to be load-bearing. They also reported substantial quantities of charcoal on the floor of the lustral basin—particularly in its north-western part—which may have come from the timber framework typically set on the staircase wall in similar rooms (Pelon 1980: 119–120; Pernier and Banti 1951: 129, fig. 74). The earthen walls of the lustral basin were decorated with white plaster, bordered in their lower and middle sections by red bands (Demargne and Gallet de Santerre 1953: 46).

In several areas of the Delta Quarter, mudbricks were also used to form small partitions that closed off or subdivided interior spaces. These partitions were identified extending northward from the west wall of the lustral basin between spaces 4 and 7 in House Delta Alpha, as well as in rooms 2 and 3 of House Delta Gamma (Figure 2d) (Demargne and Gallet de Santerre 1953: 46, 52, pl. XIX.2, LXIII). Although no description of the bricklaying technique is provided, the excavators record a thickness of 0.08 m for the partition continuing the lustral basin's west wall, an unusually narrow dimension that suggests the mudbricks were set upright.

The Zêta Quarter

Houses Alpha, Bêta and Gamma of the Zêta Quarter were constructed in the Neopalatial period over earlier Protopalatial remains. At least two of these houses yielded some of the few deposits on the site that attest to a violent fire destruction during the Late Minoan IB phase (Demargne and Gallet de Santerre 1953: 84–85; Deshayes and Dessenne 1959: 55–60; Driessen 2010: 565). This fire contributed significantly to the preservation of their mudbrick walls.

In House Zêta Alpha, collapsed remains indicate that both the superstructure of the ground-floor walls and the upper-storey walls were built of mudbricks (space 25, storerooms 26–28), sometimes fallen directly onto the burnt remains of the roof and ceiling (Demargne and Gallet de Santerre 1953: 76, 77 n. 4). Owing to the intensity of the fire destruction, the quantity of published mudbrick debris from this building is even greater. Here, abundant evidence points to a mudbrick superstructure set on a stone socle in both interior and exterior walls, as well as to the use of mudbrick partitions (Demargne and Deshayes 1959: 8, 10, 15, 19, 23). Most of the mudbrick remains were found in association with the staircase east of room I, in the Minoan hall VII, and west of room X. No mudbrick remains are reported in the publication of House Zêta Gamma, though it remains entirely possible that many of the little-preserved stone walls once served as socles for now-lost earthen elevations (Deshayes and Dessenne 1959: 27–38). Although standing mudbrick walls are insufficiently preserved to discern construction patterns within the Zêta Quarter, the widespread use of mudbrick in both exterior and inner walls—on ground and upper floors alike—is strongly suggested by the collapsed remains and supported by stratigraphic evidence (Demargne and Gallet de Santerre 1953: 76, 77 n. 4; Deshayes and Dessenne 1959: 8, 19, 23).

Other documented examples of mudbrick walls on the site

Across other areas of the site—in Quarters Alpha, Bêta, Gamma, Epsilon, Nu, Thêta, the Dessenne Building, the Haghia Varvara House, the buildings around the Agora and the *Abords Nord-Est* of the Palace—the presence of earthen walls is inferred primarily from collapsed mudbrick fragments and from low stone socles constructed in two-faced small-boulder and rubble-stone masonry (Amouretti 1970: 27, 54–55, 73; Darcque *et al.* 2014: 30, 33, 38–39, 56, 124, 150, fig. 19; Deshayes and Dessenne 1959: 27–38, 94, 96–97, 99–100, 107, 110, 113; Devolder 2012–2013: esp. 61; 2019b: 36, 39–40; Pelon 1966: 555–

556, fig. 2–5, 11; 1970: 40, 115; van Effenterre and van Effenterre 1969: 8–12, 14, 18, 43, 68, 81, 83, pl. XXVII.3; 1976: 13–14, pl. X.2). These socles, typically 0.40–0.60 m wide and 0.20–0.50 m high (preserved), are sometimes described by excavators as *murettes* and are generally interpreted as the base for an earthen superstructure.

While this superstructure is occasionally identified explicitly as mudbrick, it is often referred to more broadly as an earthen wall. Unfortunately, no stratigraphic evidence is available to determine whether the disintegrated or burnt mudbricks derive from the earthen superstructure of the ground-floor walls or from the collapse of upper-storey walls. The abundance of mudbrick fragments across the site suggests the existence of upper mudbrick storeys, particularly given the mass of collapsed debris documented in these buildings. Some excavators, however, do not exclude the possible use of rammed earth or *pisé* (where earth is compacted and dried in a timber formwork) or wattle and daub (clay applied over wattlework) in the Haghia Varvara House and in the structures surrounding the Agora and beneath them (Pelon 1966: 555–556; Perello 2015; van Effenterre and van Effenterre 1969: 77; 1976: 13). The proposed use of these techniques is based primarily on the absence of identifiable mudbrick fragments within the collapsed debris excavated in these rooms (Pelon 1966: 555–556; van Effenterre and van Effenterre 1969: 73, 81). This lack of evidence may simply reflect the disintegration of mudbrick walls rather than the presence of alternative building techniques. It is worth recalling here that only a single possible instance of Minoan *pisé* has been reported in the literature, from House N at Palaikastro (Sackett *et al.* 1965: 259, fig. 1). Unfortunately, it is now disintegrated (pers. observation in 2004).

Mudbrick installations

Most of the mudbrick installations that were found during excavations in the early 20th century have now disappeared, and preserved specimens of mudbrick partitions and platforms have been documented only for the Delta, Zêta and Epsilon Quarters and in the Palace. Nevertheless, it is reasonable to suggest that such features once occurred more widely across the site.

In House Delta Alpha, one—perhaps originally several—mudbrick partitions blocked the openings between the vertical timber supports set on stone bases that separate court 8 from space 10. These partitions created small compartments in which cooking and pouring vessels were recovered (Demargne and Gallet de Santerre 1953: 46–47, XX.5, LXIII). In House Zêta Bêta, a small mudbrick partition (0.50 × 0.33 × 0.10 m) located to the south-west of room II formed a cupboard for cooking and pouring vessels. This installation was topped by a window that provided light to the inner room III (Deshayes and Dessenne 1959: 15, pl. III.3). Finally, in level III of the Epsilon Quarter, dated to the early Late Bronze Age, two mudbrick installations delimited small hearths (Deshayes and Dessenne 1959: 73, 75), while the thorough excavations conducted by Olivier Pelon in the complex Pre- to Postpalatial sequence in the eastern part of the same Quarter yielded additional evidence for mudbrick installations, three of which functioned as possible ovens and one as a basin (Pelon 1970: 73, 75–76, 116, 146, plans I, II, pl. V.4, VI.3, IX.4–5).

In addition to these exceptional instances of preserved mudbrick partitions, several mudbrick platforms have been identified in different buildings across the site. In the Neopalatial levels of Houses Delta Bêta (corridor 14), Delta Gamma (room 2) and Zêta Bêta (central room XVII) (Figure 2e), in the *Maison de la Cave au Pilier* east of the Agora (room β)[1] and in space XVII 1 of the Palace[2], rectangular mudbrick platforms

[1] In this house the platform is composed of 'flat fired bricks' each measuring 0.275 × 0.315 × 0.06 m (van Effenterre and van Effenterre 1969: 119). These dimensions and description do not exclude the possibility that the platform is made of terracotta plaques similar to those (two specimens) found in space 6.21 in the Court-centred Building at Sissi, one of which was located near a stone base for a vertical support (Devolder 2018: 165; Devolder and Wolf 2022: 221–226, fig. 6.2.11, 13b, 14a, 14d).

[2] In his description of this installation, Pelon (1980: 212, n. 1) indicates that one of the mudbricks is 0.07 m thick, which is thin for mudbricks on the site. This may suggest that they are not mudbricks but terracotta plaques.

were discovered (Chapouthier and Demargne 1962: 7, pl. XIV, 1; Demargne and Gallet de Santerre 1953: 51, 52, pl. XXV.1 and 3, LXVII; Deshayes and Dessenne 1959: 12–13, pl. III 2, plan II; Pelon 1980: 211–212, plan 12; van Effenterre and van Effenterre 1969: 119, fig. 11, pl. LXII 1–3). In every instance, these platforms were situated adjacent to a paved surface and/or a circular stone base. Although often interpreted as hearths, they remain ambiguous. They recall Middle Bronze Age platforms found in room I 12 of the Mu Quarter and in room 2 of the MM II Sanctuary. The Mu Quarter example consists of coated mudbricks with a hollow that may preserve traces of ashes, while the MM II Sanctuary one is described as clay turned into mudbrick with a hollow bearing clear traces of fire (Poursat 1966: 521, 523, fig. 5, 10; Schmid and Treuil 2017: 32, fig. 35, 36). Among Neopalatial examples, however, burning is securely attested only on the Zêta Bêta platform (Deshayes and Dessenne 1959: 12). As a result, the function of these rectangular mudbrick platforms remains debated. Some scholars have proposed that they represent a rectangular variant of the long-attested circular hearths on the site (Chapouthier and Demargne 1962: 13–17, pl. XX.2–3). Others, noting their rarity and the modest dimensions of certain specimens, suggest instead a ritual function (Demargne and Gallet de Santerre 1953: 51; Poursat 1966: 523; Schmid and Treuil 2017: 32, 278–279).

Discussion

No unequivocal evidence supports the use of rammed earth or wattle and daub at Malia. On the basis of current data, it therefore appears reasonable to conclude that earthen walls at the site were constructed exclusively of mudbricks. The earliest preserved mudbrick walls date to the Early Minoan IIB phase of the Prepalatial period; these were later incorporated into the walls of the later, Middle and Late Bronze Age phases of the Palace (Devolder 2016: 154, fig. 3, 9; Devolder and Lorenzon 2019: 81-82, fig. 12, 14–16) (Figure 1e). Notably, these earliest examples are also the best preserved on the site. Possible indications of earlier use come from disintegrated mudbrick layers and mudbrick fragments recovered from securely dated Early Minoan IIA and Early Minoan IIA-B contexts beneath the Palace and in the *Abords Nord-Est* (Darcque *et al.* 2014: 30, 33, fig. 9; Devolder and Caloi in prep.). The latest preserved evidence is less straightforward, but it appears to include Postpalatial mudbrick walls in the Epsilon Quarter (Pelon 1970: 40, 115)[3].

Despite this diachronic breadth, the mudbrick remains recorded during excavations—or still standing in the Minoan settlement and reviewed here—are relatively few. It is only in comparison with other Bronze Age Cretan sites that Malia stands out (Shaw 2009: 128–132). Nevertheless, recurring references to the accumulation of red earth in destruction or abandonment layers within rooms strongly suggest that many of the low, small-boulder and rubble-stone walls now visible on the site originally supported a mudbrick superstructure. The most reliable indicators that such walls functioned as stone socles are the preserved levelling layers and the small stone wedges that once capped the stone masonry (Figure 1f). It is also noteworthy that the socles associated with preserved mudbrick courses are almost exclusively built in two-faced small-boulder and rubble-stone masonry. This criterion allows us to exclude from the category of mudbrick walls the low interior walls built in one-faced masonry of large or small boulders and rubble stones (e.g., the walls of the MM II Sanctuary: Poursat 1966: fig. 4). Following these criteria, the number of ground-floor walls that would originally have been constructed of mudbrick significantly increases, thereby reinforcing the view that mudbrick architecture was extensively employed at Malia. Although mudbrick seems to have been preferred for interior ground-floor walls, a few—albeit rare—examples of exterior mudbrick walls are attested, in House Zêta Alpha and possibly in the Palace[4].

[3] Driessen and Farnoux (1994: 63) report that 'almost no mudbrick [is] used' in the LM IIIA2-B phases in the Postpalatial Nu Quarter.

[4] In the Palace, the wall to the south of the South-East Entrance is made of mudbricks but it is unclear if the passage there was covered, and the mudbrick wall to the north of the Central Court was protected by the cover of the North Portico there (Pelon 1980: 72-75, 148-150).

Mudbrick was also used for most, if not all, upper-storey walls, reducing the weight borne by the lower storeys—an observation already mentioned several times in connection with collapsed masses of earth and mudbrick debris. Further support for this interpretation comes from the limited quantity of stones visible on the modern surface of the archaeological zone and collected in *traphous* (the stone heaps produced during field clearing), implying that upper walls were not primarily built of stone.

An important question in Minoan architectural studies concerns the load-bearing capacity of mudbrick walls (Shaw 2009: 128). This issue becomes particularly challenging when considering the Malia Palace and the Mu Quarter, whose proposed reconstructions suggest that they were composed of several storeys (Darcque *et al.* 2014: plan XVIc, XVIIa–b; Schmid and Treuil 2017: fig. 392–399). Yet evidence from different areas of the site shows that builders took deliberate measures to enhance the structural performance of mudbrick walls. In the extension of Building A and in Building B in the Mu Quarter, as well as in the Eastern Magazines of the Palace, individual mudbricks were positioned carefully to increase wall thickness and thereby improve load-bearing capacity (Figs. 1b, 1f–g, 2c). By contrast, non-load-bearing partitions and installations were built using mudbricks set upright or as stretchers. The careful founding of stone socles on bedrock, sometimes deep below floor level, provides further indication that mudbrick walls were anchored with the same attention as those constructed in other masonry techniques. It is tempting to assume that their load-bearing capacity was reinforced by timber elements. However, direct evidence for timber frameworks is largely absent, even in the best-preserved examples. The published architectural study of the Mu Quarter offers only limited information on this matter. It is suggested that timber elements inserted in the walls and combined with the timber frames of doors and windows could have created a structural framework enabling mudbrick walls to support one or two upper storeys (Schmid and Treuil 2017: 148, 151). Nevertheless, it must be emphasised that documented evidence for such timber reinforcement is surprisingly scarce—not only in the Mu Quarter, but throughout the site.

Conclusion

The available data demonstrate that mudbrick was the sole material used for earthen walls at Malia, with evidence extending from the early Prepalatial to the Postpalatial period. Although surviving examples are few, architectural clues reveal that mudbrick superstructures were once widespread, particularly atop the characteristic stone socles. Measures such as increased wall thickness and well-founded socles indicate that builders tried to improve the structural performance of mudbrick walls for multi-storey architecture, even though firm evidence for timber frameworks remains minimal.

The recurring patterns in masonry features, bricklaying practices and the macroscopic composition of the mudbricks at Malia point to a consistent building tradition and attest to the builders' well-developed understanding of effective construction techniques. Throughout this review, the segmented nature of mudbrick production has been emphasised. It is reflected in the noticeable variation in mudbrick dimensions and composition even within a single building phase, or sometimes within a single construction episode. Such variability suggests that different parts of the same structure may have been entrusted to separate building teams whose levels of expertise differed. There is little indication at Malia for the mass production of mudbricks or the large-scale, standardised construction of mudbrick walls. Instead, the evidence points to a more localised, small-team mode of production, resulting in a built environment that is cohesive in technique yet far from uniform in its material execution.

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Production, Storage and Sustainability: The Use of Earthen and Sunken Architecture at Late Bronze Age Erimi-*Pitharka*, Cyprus

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Abstract: Cyprus has a long history of earthen architecture, including the carving of the bedrock to create subterranean and semi-subterranean spaces and installations, sometimes featuring mudbrick superstructures. This practice can be detected from as early as the Neolithic period and continues in various forms throughout the prehistoric and protohistoric periods. The calcareous bedrock that characterises much of Cyprus was easily carved and integrated into earthen architecture, surfaces and sunken features, such as pits, vats and emplacements for vessels. Fully subterranean 'caves' were modified for living, storage and workshop facilities, while the bedrock was cut to create semi-subterranean rooms and building sectors. Engaging with the local environment in this manner provided a cost-effective and sustainable means of managing temperature, wind and light. This chapter uses the Late Bronze Age site of Erimi-*Pitharka* in south-central Cyprus as a case study to explore the strategy of modifying and adapting the local bedrock (known as *kafkalla*) for use-surfaces, parts of walls and semi-subterranean rooms, permanent installations and fully subterranean spaces.

Keywords: Cyprus, Late Bronze Age, *kafkalla*, earthen and sunken architecture, *hyposkafon.*

Zusammenfassung: In Zypern gibt es eine lange Geschichte der Bearbeitung von anstehendem Gestein, um unterirdische und halb-unterirdische Räume und Anlagen zu schaffen. Diese Praxis lässt sich bis ins Neolithikum zurückverfolgen und setzte sich in verschiedenen Formen in der Vor- und Frühgeschichte fort. Der kalkhaltige anstehendes Gestein, der weite Teile Zyperns prägt, ließ sich leicht bearbeiten und in die Architektur, in Oberflächen und in unterirdische Grundlagen wie Gruben, Zisternen und Gefäßstandorte integrieren. Völlig unterirdische 'Höhlen' wurden zu Wohn-, Lager- und Werkstätten umgebaut, und das anstehende Gestein wurde so bearbeitet, dass ganze Räume und Gebäudeteile halb unterirdisch angelegt wurden. Die Einbettung in die lokale Umgebung war ein kostengünstiges und nachhaltiges Mittel zur Kontrolle von Temperatur, Wind und Licht. In diesem Kapitel wird die spätbronzezeitliche Siedlung Erimi-*Pitharka* in Südzypern als Fallstudie verwendet, um die Strategie der Modifikation und Anpassung des lokalen Felsgesteins (bekannt als *kafkalla*) für Nutzflächen, Teile von Mauern und halbunterirdische Räume, für feste Installationen und für vollständig unterirdische Räume zu untersuchen.

Stichworte: Zypern, Spätbronzezeit, *kafkalla*, versenkten Architektur, *hyposkafon.*

Introduction

The use of sunken architecture and installations has a long history in Cyprus, with evidence of bedrock-carving dating as early as the Aceramic Neolithic period. Both naturally occurring hollows and cuts, and artificially modified bedrock were used for a variety of purposes. At the Late Bronze Age site of

Erimi-*Pitharka*, the soft calcareous bedrock was modified or incorporated into features and architecture to create surfaces, semi-subterranean and subterranean spaces, and a range of installations related to workshops and storage of agricultural produce.

This chapter uses Erimi-*Pitharka* as a case study to explore the use of earthen and sunken architecture and installations in Cyprus. It specifically aims to analyse these architectural features and installations, discussing how they reflect sustainable storage and production practices. Drawing on the results of the first two seasons of new excavations conducted by the University of Graz in collaboration with Cardinal Stefan Wyszynski University, in Warsaw (2022–2023), along with earlier work by the Department of Antiquities, Cyprus, this analysis demonstrates how this strategic use of bedrock provided a cost-effective and sustainable foundation for earthen architecture. This technique facilitated the regulation of temperature, light and wind, thus maintaining optimal working conditions and a stable environment for stored produce.

Erimi-*Pitharka*: excavation history and the Kouris Valley

The site of Erimi-*Pitharka* (hereafter Pitharka) is located within the modern village of Erimi, in the Kouris Valley, in the district of Limassol, Cyprus (Figure 1a). Before the construction of the modern dam at Alassa, the Kouris River was part of a major drainage system of rivers and their tributaries, originating in the Troodos Mountains and discharging into Episkopi Bay. The area where Pitharka is located is characterised by a hilly landscape, with the site on top of one of those hills, with strategic access to the river for both water supply and the transport of people and goods. As for the geology of the area between the modern villages of Ypsonas, Erimi and Episkopi, the so-called Episkopi Chalks dominate the region. These consist of alternating layers of hard and soft cream-white chalk, sandy chalk and some marl, along with reef limestone attested in a few places. These chalk formations are bounded by alluvial plains and outcrop deposits (Greitzer and Constantinos 1969: 27–28). Locally known as *kafkalla*, these deposits constitute the bedrock at Pitharka.

The area of Erimi and the neighbouring village, Episkopi, is archaeologically very rich, with sites from Sotira to Erimi dating from the Ceramic Neolithic to the Roman and Byzantine periods. Pitharka itself dates to the Cypriot Late Bronze Age, more precisely the Late Cypriot IIC – Late Cypriot IIIA period (LC IIC–IIIA, 13th and first half of 12th century BC)[1]. At this time, urbanisation was well on its way, and Cyprus was intensely engaged in international relations and trade networks across the entire Eastern Mediterranean, with copper as one of the prime exports. These relations are perhaps most visible in the material culture, particularly the presence of highly mobile ceramic vessels. Several large—especially coastal—sites have been identified as ‘first tier’ centres, including Enkomi, Kition, Hala Sultan Tekke, Palaepaphos and Kalavasos-*Ayios Dhimitrios* (Knapp 2013: 355), where ceramics and other goods from the Aegean, Egypt, the Levant and Anatolia are abundant. These centres are typically estimated at 10–25 ha, if not more. In this scheme, Pitharka is a regional ‘second tier’ centre. Its exact extent is difficult to determine due to modern overbuilding and questions about the contemporaneity of all remains, but a cautious estimate based on excavated and surveyed areas places it at approximately 8 ha. Its primary functions appear to have been agricultural production and storage, likely maintaining close ties with the nearest major centre, Alassa, *c.* 8 km to the north in direct line, and with nearby and contemporary Episkopi-*Bamboula*, as well as potential connections with Kalavasos-*Ayios Dhimitrios* and even Palaepaphos.

[1] We here follow the chronology of Knapp (2013: 27, Table 2)–in simplified form, this means Aceramic Neolithic *c.* 8500/8400–5200 BCE, Ceramic Neolithic *c.* 5200/5000–4500/4000 BCE, Chalcolithic *c.* 4000/3900–2500/2400 BCE, Prehistoric Bronze Age (Philia/EC-MC II) *c.* 2400–1700 BCE, Protohistoric Bronze Age (MC III-LC IIIA) *c.* 1750/1700–1125/1100 BCE, Early Iron Age (LC IIB) *c.* 1125/1100–1050 BCE.

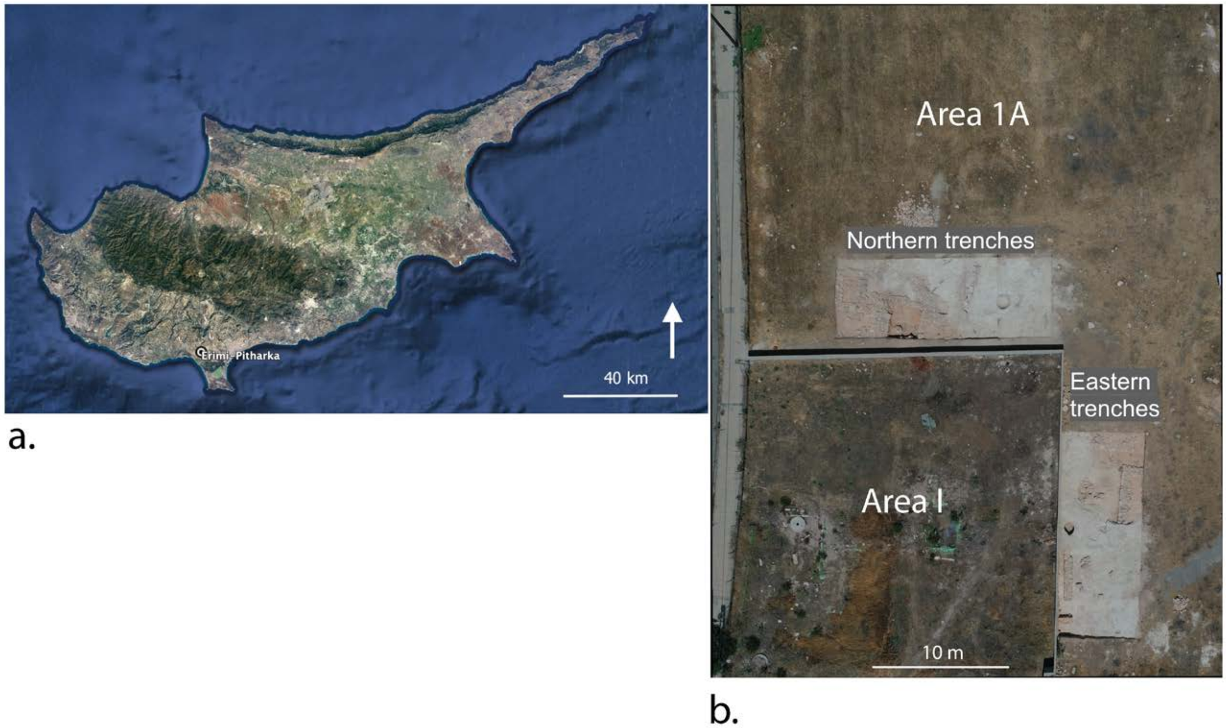

Figure 1. a) Location of Erimi-*Pitharka* on Cyprus. Adapted from Google Earth. b) Area I and Area 1A. The eastern and northern trenches of the new excavations are visible outside the modern cement wall (Area 1A), while the area inside the wall contains the earlier Department of Antiquities excavations (Area I, now backfilled). The light grey–almost white–visible across most of the area of the excavated trenches is the *kafkalla*-bedrock, while the light orange-red patches designate deteriorated mudbrick debris within the interior of rooms. Drone photo from the end of the 2022 excavation season. Photograph by A. Villani.

Due to modern building activities in the village of Erimi, rescue excavations were carried out at Pitharka by the Department of Antiquities of Cyprus between 2002–2004 and 2007–2012, followed by conservation work. In recent years, further rescue excavations have been developed both by the Department and the municipality. Since 2022, new excavations have been conducted by the University of Graz in collaboration with Cardinal Stefan Wyszynski University, in Warsaw. The initial excavations by the department were focused on a subterranean chamber (Vassiliou and Stylianou 2004; see more detailed description below), while work between 2007–2012 covered four areas of the site, with excavations headed by Katerina Papanikolaou from Limassol Archaeological Museum (Flourentzos 2010; Papanikolaou 2012). These identified: an extensive building in Area I, interpreted as the administrative centre of the site, along with evidence of production and storage facilities; Area II, near the slope of the river, contained many retaining walls and workshop installations carved into the bedrock, but also a large building associated with thick walls, thought to represent a tower, ideally placed for overlooking the river; Area III, where more retaining walls were documented following the natural terraces; and Area IV, which offered further workshop-related features along with stone-built walls of a building.

The new excavations conducted in 2022–2023 by the Graz/Warsaw team focused on the extended Area I, labelled Area 1A (see Recht *et al.* 2024 for a report on the first two excavation campaigns)[2]. Trenches

[2] Further examples of sunken architecture at Pitharka were discovered during the 2024 season, see Recht *et al.* 2025. and add this reference in the bibliography: Recht, Lærke, Katarzyna Zeman-Wiśniewska, Brigid Clark, and Mari Yamasaki. 2025. 'Excavations

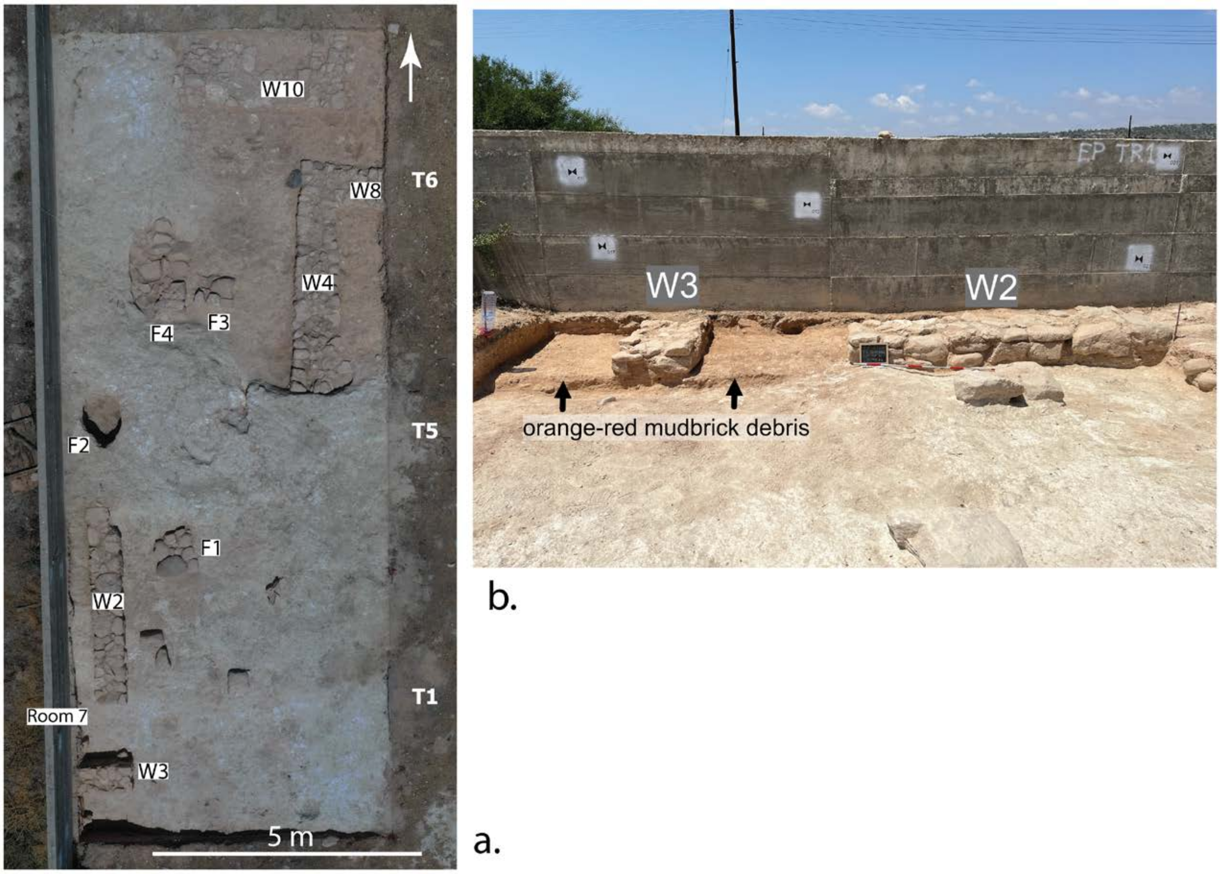

Figure 2. a) Eastern trenches of Area 1A, as seen at the end of the 2022 excavations season. Note the clear carving of the bedrock associated with W4, F2, F3 and F4. b) View of Walls 3 and 2, from the east. Photographs by A. Villani and M. Schutti.

were laid down immediately to the east and north of the previously excavated area, just outside a modern cement wall that surrounds Area I. In the eastern sector, Trenches 1, 5 and 6—each measuring 5 × 6 m—were placed in a row from south to north (Figures 1b, 2a, 2b). Here, the walls and other features suggest interior and exterior or semi-open spaces most likely used for production and possibly storage. In the western section of Trenches 1 and 5, two walls (W2 and W3) connect directly to Room 7 from the earlier excavations, thus clearly demonstrating the continuation of the building. Additionally, the corners and ends of two other rooms have been identified in the northern and eastern part of Trench 6 (W4, W8 and W10), but are not yet fully exposed. Installations in these trenches include a circular pit and several stone features—perhaps platforms—that seem to be related to the production activities of the site (F2, F3 and F4).

In the northern sector, Trenches 3, 2, 4/4A, 7/7A and 8/8A are placed from east to west. Trenches 3 and 2 are 6 × 4 m, and the remaining ones 7 × 4 m (Figures 1b and 3a). The eastern part consists of a large pithos embedded into the *kafkalla* within what appears to be an open or semi-open space. Immediately to the west lie the lowest one-two courses of a badly preserved wall and corresponding parallel terracotta drain (T2 and T3 in Figure 2a, shown without the preservation covers in Figure 1b). These remains are

at Late Bronze Age Erimi-Pitharka, Cyprus: The 2024 Season'. Internet Archaeology, no. 69 (March). https://doi.org/10.11141/ia.69.1.

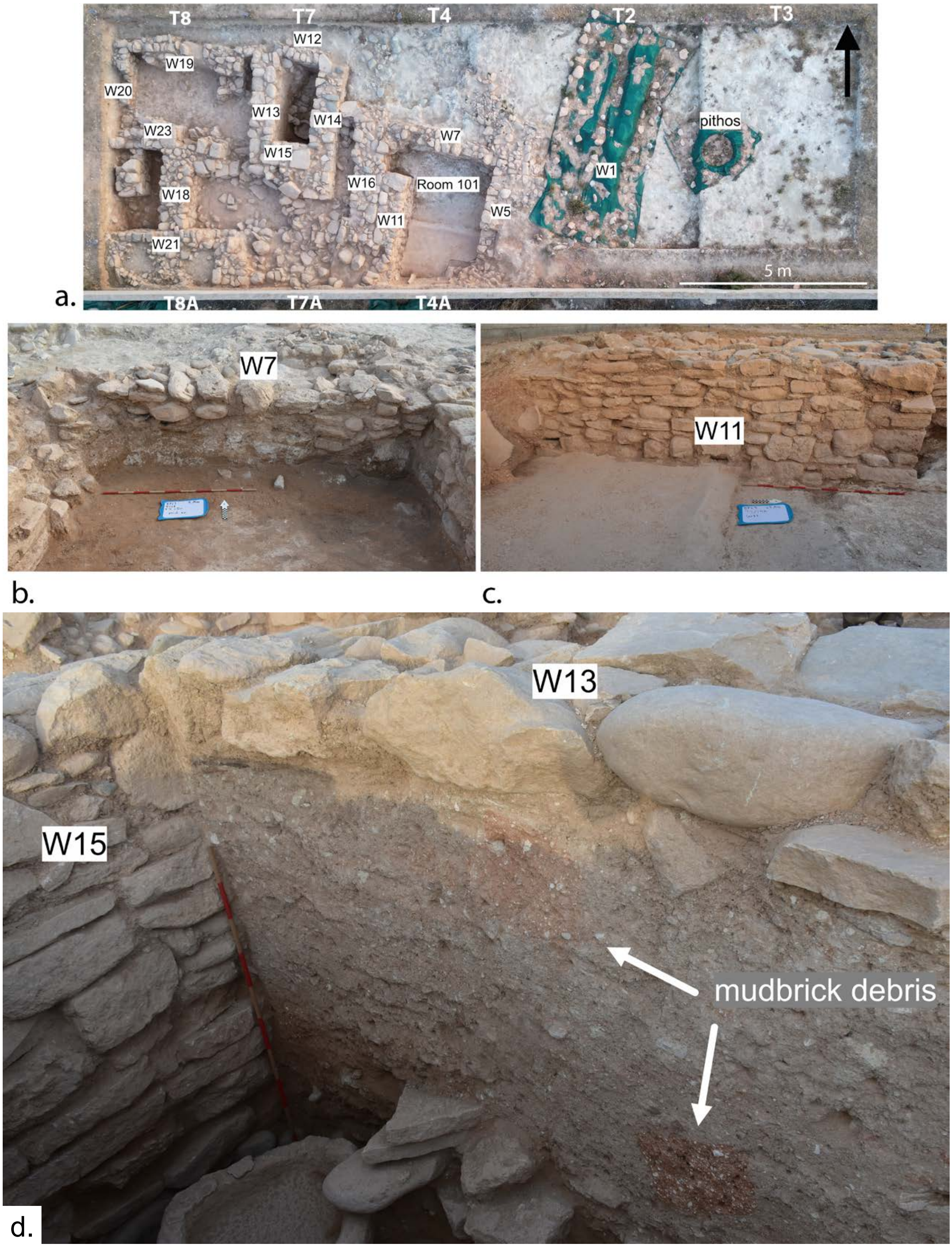

Figure 3. a) Northern trenches of Area 1A, as seen at the end of the 2023 excavation season. b) Wall 7, from the south, interior of Room 101 during excavation. c) Wall 11, from the east, interior of Room 101 at the end of excavation. d) Mudbrick lump within the debris. Photographs by L. Recht.

all very close to the modern surface, and as a result much disturbed. However, in Trenches 4/4A, 7/7A and 8/8A, the Bronze Age levels are better preserved and contain a sequence of rooms, a corridor and exterior spaces. Several phases can be detected in some rooms and spatial arrangements, and all rooms are semi-subterranean, deliberately sunk into the bedrock at different levels. The exact function of each room is challenging to determine with certainty due to the general clearing of content and disturbance, but Room 101 in Trench 4/4A has a very well-made plaster floor with a small 'step' running from east to west (Figure 3). Above this had been a mudbrick installation of unclear shape and function, associated with additional but less well-preserved plaster floors. The interior of the room had burnt down, but the space suggests some sort of manufacture related to liquids, at least in its initial stage of use (for view of the different stratigraphic stages of Room 101, see Recht *et al.* 2024, fig. 4). Similarly, the bottom of Room 106 contained a circular stone basin that may also have been used for production purposes. The other rooms were not as well-preserved and have not been fully excavated, as the bedrock has not yet been reached to establish their precise depth.

As is typical for Bronze Age Cyprus, the walls at Pitharka were constructed using a dry stone wall technique and a mudbrick superstructure. Although the mudbrick material is not the focus of this paper, it can be noted that it has almost entirely deteriorated in nearly all cases, surviving only as collapsed red-orange debris containing many small-to-large white and grey inclusions. Several rooms have distinct orange-red coloured soil in the interior as a result of such collapse (Figures 1b, 2a, 2b and 3a). Since they do not maintain their original shape, the precise measurements of the original bricks are therefore unidentifiable; however, occasional mudbrick 'lumps' or concentrations can be detected, suggesting a rectangular section of roughly 15 × 20 cm (Figure 3d). Given the elaborate use of the limestone-rich *kafkalla* bedrock at Pitharka, it is likely that a crushed version of this contributed to the light-hued inclusions macroscopically visible in the debris, pending confirmation via micromorphological analysis.

There is a great variety in the construction quality, along with extensive reuse, altered use, reinforcement and even dismantling of walls, but those best preserved are well constructed, with a width of 40–80 cm, featuring two rows of large stones for the facades with smaller ones as 'fill' in between. The stones are primarily field stones—some of which are cut, but not to the extent of the ashlar masonry found at some main centres—with large stones frequently used for doorways and corners. These field stones are supplemented by basalt and river-worn stones. Furthermore, broken or disused objects have been incorporated into the wall fabric, including large pithos fragments, a gaming stone, a pivot stone and a broken stone mortar (see Recht *et al.* 2024: section 5). The stone walls are combined with utilisation of the *kafkalla* as structural support, as part of lower walls (Figure 3b), as sub-floor surfaces (Figure 3c) and through excavation into the bedrock to create semi-subterranean spaces (Figures 2 and 3). Some of the walls only have three to five courses of stones due to the proximity of ancient surfaces to the modern ground level, but those in sunken spaces reach up to nine courses (Wall 11, Room 101; Figure 3c) or even 12 (Wall 14, Room 106).

The large building of Area I/1A appears to have been peacefully abandoned, and most spaces were cleared of especially light and highly mobile materials, leaving behind mainly broken and/or large and heavy objects. The abundance of stone tools (grinding slabs, handstones, pestles), along with a stone press and numerous sherds of pithoi and other large vessels, confirms the impression of Pitharka as a site specialising in storage and agricultural production, especially grain, olive oil and wine. These pithos sherds are supplemented by several large parts of pithoi that represent various sizes and shapes, suitable for both long- and short-term storage.

While imported vessels and sherds are present, they constitute a very small percentage of the complete ceramic assemblage (Clark and Recht 2025). It is clear that Pitharka was not a main international trade hub dealing in luxury goods, like Enkomi or Hala Sultan Tekke. Although close to the coast, it is also not a harbour; however, Pitharka was located directly on the Kouris River—now dried up in Erimi due to a dam further north—and through this, would have had direct connection to both Alassa to the north and the sea to the south.

Use of sunken architecture and the *hyposkafon* technique on Cyprus

Creating partly subterranean buildings by carving the earth or bedrock-cutting for wall foundations or emplacements for large vessels is sometimes described as the *hyposkafon* technique (Kanta 2014: 113). This term has been used by Kanta when describing such spaces at Pyla-*Kokkinokremos*, another Late Bronze Age site on Cyprus. At Pyla-*Kokkinokremos,* the *hyposkafon* technique was recognised in several parts of the site. In Complex I, such spaces were probably used for manufacturing activities. For instance, Room 45 features a wall built directly on the bedrock, and possibly other constructions, since some small holes and pits are visible in the bedrock, which might have supported a shed to cover a working area. Additionally, a drainage channel was also present (Kanta 2014: 86–87). Similar areas were found in Complex G, where spaces 15A-C are also described as *hyposkafon*, again featuring two possible sheds (nos. 29 and 30) and a generally industrial character (Kanta 2014: 16, 41). Another example is Room 10, with walls built on bedrock ledges, full of large vases which had fallen on their sides (Bretschneider *et al.* 2015: 15). The excavators of Pyla-*Kokkinokremos* suggest that the *hyposkafon* technique itself might have been imported from Crete (Bretschneider *et al*. 2015: 34), but it seems that similar workspaces and sunken architecture were already known and used on Cyprus in much earlier periods.

Moving closer to Pitharka, it is worth noting examples of sunken areas at Erimi-*Laonin tou Porakou*, a nearby Middle Bronze Age site. The top of the hill on which the site is located was a workshop area of *c.* 30 × 30 m, with household and funerary clusters on lower terraces (Bombardieri and Muti 2018: 27). This workshop area, largely interpreted as an open space, was dedicated to textile production. The bedrock was carved to create a system of basins of different depths connected with channels, while postholes provide evidence for sheds and other structures (Bombardieri and Muti 2018: 30; Bombardieri *et al.* 2015: 112–116, 119–121, Fig. 1, 3, 4, 6). Moreover, many pithoi and other vessels were sunken into the floors using plaster emplacements, sometimes secured with stones (Bombardieri *et al.* 2015: 114, 121–122, Fig. 8, 9). Similar rock-cut features have also been identified at Early Cypriot Sotira-*Kaminoudhia* (Swiny *et al.* 2003: 11–12).

At Erimi-*Laonin tou Porakou,* constructions were built directly on the bedrock, with the bottom part of the walls made of roughly dressed blocks and slabs arranged in several irregular courses, supporting a mudbrick superstructure coated with plaster (Bombardieri *et al.* 2015: 114; Amadio 2024: 2). A recent geoarchaeological study of the site's earthen building materials provides detailed comparanda for Pitharka (Amadio 2024). Analysis confirms the extensive use of mould-made mudbricks of consistent size (*c*. 40 × 14 × 12 cm), laid in techniques such as running bond and Flemish bond (Amadio 2024: 5–6). The study identifies distinct mudbrick 'recipes': calcareous yellow mudbricks (the most common type), high-calcareous white mudbricks and low-calcareous red earthen materials used for roofing. These were produced using locally sourced sediments—within a 2 km radius—and deliberately tempered with organic (i.e. chopped straw) and inorganic aggregates to improve their properties (Amadio 2024: 6–8, 11–12). This evidence points to organised craft production and a developed understanding of material properties. The construction of the large workshop complex—requiring both the carving of the bedrock and the mass production of mudbricks—suggests a supra-household level of labour organisation and technological knowledge (Amadio 2024: 13–14).

Such sunken architecture, using carved bedrock as the basis for the wall foundations and creating semi-sunken houses, is also known from the nearby Chalcolithic site of Erimi-*Pamboula* (Dikaios 1961; Bolger 1988). Indeed, this could be considered a characteristic building technique in the Kouris Valley, as suggested by Amadio (2023: 40–41). At Erimi-*Pamboula,* the bedrock was carved to construct houses, whereas at Erimi-*Laonin tou Porakou* this technique was applied to the workshop area. Amadio argues that this practice was linked to permanence and planning, particularly in the design and delimitation of working spaces (Amadio 2023: 142–143).

However, other regions in Cyprus also provide examples of sunken architecture and the use of the *hyposkafon* technique, as already noted for Pyla-*Kokkinokremos* in the eastern part of the island. The case of Structure 10 at Ayios Tychonas-*Klimonas* (Aceramic Neolithic A) offers a well-documented example of such construction, where a semi-subterranean circular building was built using exclusively earthen materials without stone foundations (Mylona *et al.* 2023: 4–5). The walls were constructed using the cob technique, involving the superimposition of earthen lumps or layers prepared with plant temper (Mylona *et al*. 2023: 9–10). The exclusive use of earth—despite the local availability of stone—may signal a cultural preference rather than a purely utilitarian choice (Mylona *et al*. 2023: 14).

In the early phase of the Aceramic Neolithic of Parekklisia-*Shillourokambos,* postholes and enclosure trenches were dug into the bedrock (Guilaine and Briois 2006: 164–165, figs. 3–4). During the same period, the inhabitants of Kalavasos-*Tenta* were also cutting into the limestone bedrock, creating ditches and pits (Todd 1987: 4950). Ceramic Neolithic Ayios Epiktitos-*Vrysi* is an especially interesting example of a site located on a headland *c.* 14 m above sea level, with semi-subterranean houses built in hollows 4–6 m deep, with stone foundations and *pisé* (rammed earth) superstructures (Mantzourani 2003: 3839; Peltenburg 1982: 11). Other Ceramic Neolithic sites in Cyprus also had subterranean hollows, most probably used for storage (usually *c.* 4 m deep), for example, at Philia *Drakos* A and Kalavasos-*Kokkinoya* (Knapp 2013: 171). The latter is well known for its subterranean dwellings and other sunken and underground features of unknown purpose—but not related to everyday activities (Clarke 2009).

It has been suggested that sunken architecture ('pit dwellings') is especially characteristic of the Early Chalcolithic on Cyprus (Clarke *et al.* 2007: 124–126; Steel 2004: 84). An example of that is the site of Kalavassos-*Ayious*, with numerous pits (including bell-shaped pits for grain storage), shallow depressions and a tunnel complex (Todd and Croft 2004: 9–10). At Kissonerga-*Mylouthkia,* Pit 300/Building 200 is an interesting case of a development, transitioning from an early subterranean pit dwelling to a round house with stone walls (Peltenburg *et al.* 2003: 119–121, figs. 40–42). In a later phase of the Chalcolithic, Souskiou-*Laona,* in the western part of the island, also had several semi-sunken houses with stone foundations and evidence of a possible daub superstructure (Peltenburg 2019: 7677). Another site worth noting is Politiko-*Troullia*, a Middle Bronze Age village in the foothills of the Troodos Mountains. Some of the houses in Areas A–G were founded on or cut into the siltstone bedrock, and modified bedrock was discovered in the courtyard in Area O-Z. Whilst the site provided examples of mudbrick structures, these were not sunken (Falconer and Fall 2013: 103, 105–106, fig. 7, 8).

Ethnographic studies of 20th-century abandoned villages in Cyprus provide direct analogies for understanding the life cycle and disappearance of prehistoric earthen architecture. Mudbrick construction, common in areas with suitable soils like the Dhiarizos Valley, was an affordable technique often undertaken at the household level (Villani 2025: 17). However, these structures are ephemeral, and Villani (2025: 25) suggests they can vanish within 50–70 years if not subject to regular maintenance. This rapid degradation largely explains the low archaeological visibility of such architecture across Cyprus.

Ethnographic data from Cyprus and the wider region also provide parallels for sunken storage spaces. In historical times, grain was often stored in subterranean containers, like *voufes* (cavity, hollow) used in Cyprus and the Dodecanese, up to 2.5 m deep wells outside the edge of the village. Even deeper underground pits were used to store grain in Palestine. In both regions, such systems functioned until the mid-20th century. Also interesting is a tradition known from the Judean hills, where jar-shaped underground containers were used, filled with grain, with chaff on top and sealed with clay, similar to the so-called *metamir*, 1 to 3 m deep bell-shaped pits built and used by Bedouins in the Negev area (Currid and Navon 1989: 68).

The *hyposkafon* technique has also been used since at least the Bronze Age on Cyprus to carve installations for wine and olive oil presses. Such presses and their associated rock-cut features have been discussed in detail by Hadjisavvas (1992; 2020). Importantly for the Kouris Valley region, this includes some of the earliest evidence of a wine press at Alassa-*Paliotaverna*, contemporaneous with Pitharka. Here, alongside the extensive use of the *hyposkafon* technique throughout the site, Building III had a sophisticated wine press that included a sherd floor, channels and pit cut into the bedrock, and a weight stone (Hadjisavvas 2017: 260–264). Furthermore, sunken installations related to wine or olive oil presses have also been detected at Erimi-*Kafkalla*, immediately north of Pitharka, although these likely date to a later period (Hadjisavvas 2020: 62–64).

Sunken architecture and features at Erimi-*Pitharka*

At Pitharka, the *kafkalla* (bedrock) was carved and modified for three main types of features or architecture: 1) for use-surfaces, parts of walls and creating semi-subterranean rooms; 2) for permanent installations; and 3) for fully subterranean spaces.

Surfaces, walls and rooms

Examples of the use of the bedrock as a fairly even surface, perhaps having been deliberately levelled, are most clearly identifiable in the southern part of the eastern trenches of Area 1A (Figure 2a). Here, in Trench 1 and roughly the southern half of Trench 5, there is a space of at least 7 × 5 m—which has not been fully excavated to the south and east. The associated use-surface consists of the bedrock, likely artificially cut to form a relatively level area. Due to the nature of the surface and the lack of walls forming rooms, it seems probable that this area was an open space. However, that it was in use in some way is suggested by three stone features (F1, Figure 2a). The function of these features remains unclear, but they may have been parts of platforms or the lower elements of installations that are no longer entirely preserved, as they were all fairly close to the modern surface, immediately below the colluvial soil. A carved fragment of stone, perhaps the corner of a basin, was also found in this area and associated with the levelled surface. In some instances, the lowest part of the stone walls was placed directly on the *kafkalla*, as with the southern extent of Wall 2, while in other places, a layer of soil—apparently consisting primarily of deteriorated burnt mudbrick—had been laid out to create a more even level. This is visible in the northern part of Wall 2 and below Wall 3, both of which form the eastern section of Room 7 (Figure 2b).

Another open space using the natural bedrock as a surface can be found in Trench 3 and the eastern part of Trench 2 (Figures 1b and 3a). The area, roughly 4 × 6 m, again seems to have been an exterior or perhaps semi-covered space. The surface is only interrupted by the embedded pithos discussed below. As the area has not been fully excavated, we do not yet know how it connects with the spaces to the east or what its exact limits are, but it certainly extends further to the east and north.

The use of the *kafkalla* as lower parts of, or support for, walls can be seen in Trench 5 and Trench 4. In Trench 5, Wall 4 and Wall 8 form the northern and western limits of a room; the southern end of Wall 4 was built directly against a cut in the bedrock (Figure 2a). The depth of this cut is presently unknown as excavation is incomplete, but it would have provided both structural support for the wall and the southern limit of the room. In the northern trenches, Room 101 had dry stone walls on its western, northern and southern limits. However, the northern Wall 7 was constructed using a combination of bedrock and stones: the top preserved stones—consisting of two to four courses—had been placed on *kafkalla* hewn to form the lower foundation of the wall to a height of about 30 cm (Figure 3b). A similar technique was used for the eastern Wall 5, although here the cut *kafkalla* is only about 15 cm high and is only clearly visible in the central section. In contrast, the well-built western Wall 11 was constructed entirely of stones to the level of the plaster floor (Figure 3c). In addition, the northern facade of Wall 7 was partially built against the *kafkalla*.

In the northern trenches, the entire complex of rooms was sunk into the bedrock, creating a semi-subterranean sector. Although the earliest use-surfaces or floors have not yet been reached in all the rooms, it is possible to determine that they were hewn to different levels. Thus, the plaster floor of Room 101 was cut into the surrounding *kafkalla* by 75 cm, whereas the bottom of Room 106, with its stone basin, was cut 138 cm into the surface[3]. The two rooms are separated only by a narrow corridor. The other rooms—and corridor—in the complex are at least as deep as Room 101, suggesting that a significant effort was made to create the entire sector and to ensure its sunken character.

Installations

A number of installations and features were also constructed by carving into the bedrock. Trench 5 had a roughly circular pit, approximately 80 cm in diameter, cut directly into the *kafkalla* to a depth of at least 50 cm (F2 on Figure 2a). Its original function may have been for storage or as part of an installation related to wine or olive oil production, but it was reused as a dump at a later stage; upon excavation, it was found to contain mainly field stones and some worked stones. The pit is not directly associated with any other features, although another roughly circular impression of the same size is located about a metre to the east. However, this is very shallow and may be connected to manufacture rather than storage.

Just north of these two circular features is an installation consisting of two sets of stones placed as what may be platforms (F3/F4, initially identified as stubs of walls; Figure 2a); these were inserted in a cut in the *kafkalla*. In the western section, the base of a so-called bathtub was partly embedded in the stones, with the majority of a broken and fragmented small *pithos* crushed on top. The function of the entire installation is not clear, but the presence of the bathtub suggests that it might have involved liquids.

In Trench 3, the *kafkalla* was utilised in another way to embed a vessel. Here, in an otherwise open or semi-open space void of other preserved walls or features, a medium-sized pithos had been set into a custom-made cut in the bedrock (Figures 1b, 3a). Roughly the lower third of the vessel, which was encased within the soil, has survived. Its walls are fractured but in their original position; some of the body sherds had collapsed into the pithos, but at least the upper half would have been above the modern surface and was likely disturbed by modern activities. Apart from further ceramic sherds and a few stones, the pithos did not contain any finds. All the soil was collected for archaeobotanical analysis, which is currently in progress; however, a very preliminary examination indicated the presence of grape seeds and olive pits. The preserved and embedded part of the pithos has a capacity of *c.* 125 litres, suggesting a full capacity for the entire vessel of *c.* 300 litres (see also Clark and Recht 2025 for a discussion of this and other pithoi at Pitharka). In this case, the *kafkalla* was utilised for the permanent or long-term placement of the pithos, providing a stable setting, easier access and possibly a cooler temperature for the contents.

[3] This is the lowest level in the room, in its southern end, at the basin. Its northern end is slightly higher and the bedrock clearly visible. It is possible that the room is even deeper in its southern part; this was not possible to excavate further for security reasons and due to the presence of the basin (left *in situ*).

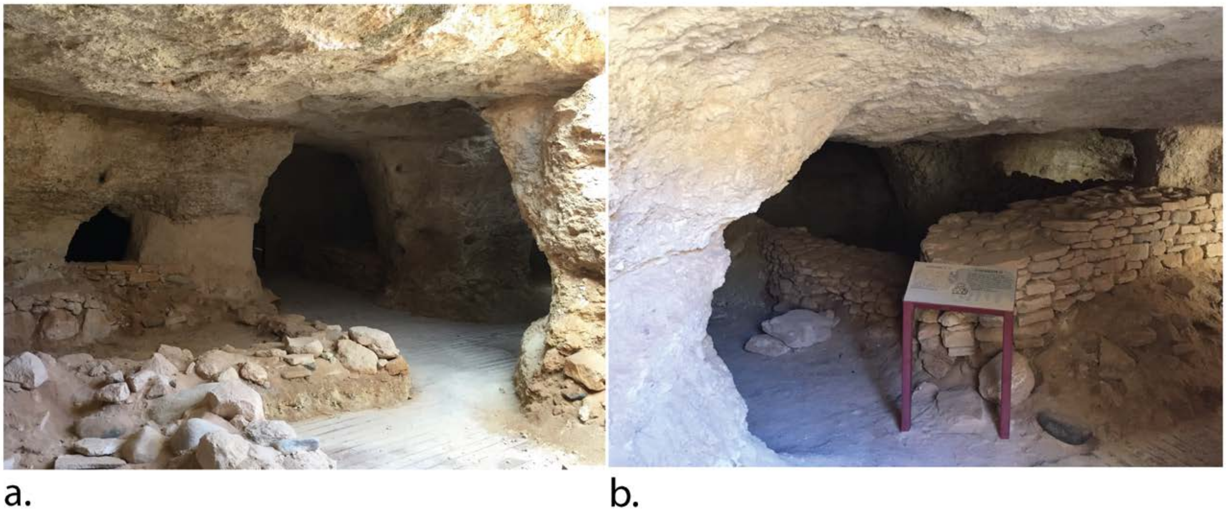

Figure 4. Interior of "Cave 1" at Erimi-*Pitharka*. Note that conservation work has been carried out, most notably in the wooden floors and the reinforcement of walls, but the layout of the chambers has been preserved. Photographs by L. Recht.

Further sunken installations were recorded in the 2007–2012 excavations by the Department of Antiquities. This is especially the case in Area II, where such structures included rock-cut tanks and deep depressions of oval or rectangular shape cut into the bedrock, which were associated with channels also carved from the bedrock (Papanikolaou 2012: 212).

Subterranean spaces

The sunken architecture and features discussed so far have all been semi-subterranean, partly situated in the ground and partly above the ancient ground-level of the site. But there are also entirely subterranean spaces at Pitharka, where either natural hollows in the *kafkalla* were exploited or where it was artificially carved. One such space is 'Cave 1', excavated by the Department of Antiquities, Cyprus, in 2002–2004 (Vassiliou and Stylianou 2004), with a subsequent conservation programme that included securing the entrance and covering the complex with an open roof. The cave consists of seven irregularly shaped chambers connected by corridors, low walls and benches (Figure 4). There are several rock-cut pillars for support and three ventilation/light holes; furthermore, niches carved into the walls may have been used for lamps (Vassiliou and Stylianou 2004: figs 5–7). The installations and finds suggest that the complex was a workshop used for domestic activities and/or storage—installations include benches, hearths and niches, whilst the finds primarily consist of pottery and stone tools associated with agricultural production. Visible tool marks on the walls indicate that the space was artificially modified. Based on the pottery, the complex was used during LC IIIA-B, thus extending in time beyond that of Area I/1A.

This 'cave' is not the only subterranean structure at Pitharka, and it seems likely that the use of such spaces was a deliberate and quite common strategy at the site. An additional nearby subterranean structure—similar in character, with at least four chambers, ceramic sherds and stone tools—was briefly visited by Vassiliou and Stylianou before being covered and paved over by a new road (Vassiliou and Stylianou 2004: 182). Caves and subterranean rock-cut installations were also recorded during the 2007–2012 excavations of Areas II and IV, including one smaller but similar to the first one; all are interpreted as workshops (Papanikolaou 2012: 312–313).

Conclusion

At Pitharka, the bedrock underwent various alterations to create functional surfaces, sections of walls, semi-subterranean rooms, permanent structures and fully subterranean spaces, including the utilisation of caves. This intentional and extensive carving of the *kafkalla* served numerous functions and fulfilled various needs of the community.

In areas such as Trenches 1, 3, and 5, levelled bedrock sections were used as open working spaces, similar to those identified at nearby Middle Cypriot Erimi-*Laonin tou Porakou* or Late Cypriot Pyla-*Kokkinokremos*. Certain walls (W2, W3, W4, W5 and W7) were either constructed directly upon the bedrock, adjacent to it or incorporated into their construction. Similar architectural uses of the *kafkalla* can be observed in other locations within the Kouris Valley, both at earlier sites such as Erimi-*Pamboula* and Erimi-*Laonin tou Porakou,* and at the contemporaneous site of Alassa. At Pitharka, entire semi-subterranean spaces were deliberately created in Rooms 101 (with a 75 cm cut) and 106 (with a 138 cm cut), forming sunken architectural areas. In another area, an entirely subterranean cave with additional carved chambers was utilised over an extended period. The bedrock was also carved at Pitharka to make pits and provide support for installations or storage vessels, such as the pithos embedded in the *kafkalla* within Trench 3.

It appears that the practice of carving into bedrock—the *hyposkafon* technique—primarily served the purpose of creating spaces for manufacturing and storage, including open work areas, installations, utilisation of caves and embedded storage containers like pithoi. By incorporating structures into the bedrock, the inhabitants could regulate temperatures to cooler and more stable levels and safeguard their resources from external factors like wind, light and heat, which was vital for both storage and daily manufacturing activities. The presence of various sunken features, such as embedded pithoi and storage installations, highlights the community's emphasis on agricultural production and storage.

The strategy of modifying the *kafkalla* using the *hyposkafon* technique is one that not only takes advantage of the local landscape and environment, but also represents the creation of sustainable permanent or long-term installations. This fairly simple technique would have provided a cost-effective means of creating installations for the short- and long-term storage of agricultural products, as well as spaces that offered a more stable environment and cooler temperatures. These practices of sustainability and engagement with the earth can be found not only at Pitharka but also at many other sites on Cyprus, though perhaps with a particular popularity in the Kouris Valley region. Their long tradition can be traced back to some of the earliest settlements on the island in the Neolithic period, thus demonstrating their benefits. These were utilised to the utmost for a variety of purposes at Pitharka, where the soft *kafkalla* was particularly suitable for this strategy.

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Interactions and Continuity: Characterising Earthen Building Techniques of the Iberian Northern Plateau in a Transitional Period (Late Bronze Age–Early Iron Age)

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Abstract: The transition between the Late Bronze Age (LBA) and the Early Iron Age (EIA) in the Northern Plateau of the Iberian Peninsula (*c.* 1100–800 BC) was a period of great change, marked by a shift in the socio-economic structure of local groups, triggered by southern and eastern contacts. This process is reflected in the farming practices, as well as in the emergence of a renewed ceramic repertoire and new kinds of settlements and building techniques: while LBA sites are characterised by isolated wattle-and-daub huts, EIA villages are dominated by mudbrick buildings. However, this was not a radical change, as for three centuries, villagers experimented with the new building techniques, an idea supported by the presence of both systems in the same settlements, as well as the use of mixed techniques.

Although much has been written about these changes, earthen architecture has been dramatically understudied in this context, which leads to conceptual confusion that overlooks the socio-economic practices involved in the different construction processes. Through a multidisciplinary study of a selection of earthen remains from several settlements, this contribution aims to characterise the building traditions used in the Northern Plateau during Late Prehistory. Discerning the construction *chaîne opératoire* and its implementation can help us to better understand these social and demographic changes, which seem to indicate a progressive adaptation of local traditions to outside innovations.

Keywords: Earthen architecture, macroscopic approach, wattle-and-daub, mudbricks, *chaîne opératoire*, Prehistory.

Resumen: La transición entre la Edad del Bronce Final y la Primera Edad del Hierro en la Meseta Norte de la Península Ibérica (*c.* 1100–800 a. C.) es un período de grandes desafíos, marcado por un cambio en la estructura socioeconómica de los grupos humanos locales, promovido por contactos meridionales y orientales. Este proceso se refleja en las prácticas agrícolas, así como en la aparición de un repertorio cerámico renovado y nuevos tipos de asentamientos y técnicas de construcción: mientras que los sitios del Bronce Final se caracterizan por chozas aisladas de zarzo y barro, las aldeas de la Primera Edad del Hierro están dominadas por edificios de adobe. Sin embargo, esto no es un cambio radical, ya que durante tres siglos los aldeanos experimentaron con nuevas técnicas constructivas, una idea que se apoya en la presencia de ambos sistemas en los mismos asentamientos, así como en técnicas mixtas. Aunque se ha escrito mucho sobre estos cambios, la arquitectura de tierra ha sido poco estudiada en este contexto, lo que lleva a una confusión conceptual que pasa por alto las prácticas socioeconómicas involucradas en los diferentes procesos de construcción. A través del estudio multidisciplinar de una selección de restos de tierra de varios asentamientos, este capítulo tiene como objetivo caracterizar las tradiciones de construcción utilizadas en la Meseta Norte durante la Protohistoria. Discernir la *chaîne opératoire* de construcción y su implementación puede ayudarnos a comprender mejor estos cambios sociales y demográficos, que parecen indicar una adaptación progresiva de las tradiciones locales a las innovaciones externas.

Palabras clave: Arquitectura de tierra, enfoque macroscópico, encestado, adobes, cadena operativa, Prehistoria.

Introduction

The study of prehistoric earthen architecture in Iberia has recently witnessed a surge in interest, evidenced by numerous publications, sessions, and even congresses dedicated to the subject (i.e. Fragnoli *et al.* 2023; Jiménez Viera and Rodríguez Gutiérrez 2022; Knoll *et al*. 2019; Previato and Bonetto 2023). Consequently, beyond the conventional categorisation of constructions as either ephemeral or stable, or the traditional search for modulation in the dimensions of mudbricks and other building elements, researchers are integrating new tools to delve deeper not only into building techniques, but also to better understand the different phases of the *chaîne operatoire* of earth technology through micromorphology (Mateu Sagués 2016; Mateu Sagués *et al.* 2022), to characterise the different forms of earthen construction (Pastor Quiles 2017, 2021, 2022) or to analyse the development of carpentry techniques (Pastor Quiles *et al.* 2022; Martín-Seijo 2023), among others.

Despite this renewed interest, research on the remains preserved in museums is still entirely anecdotal, due to several factors that are worthy of discussion. 1) In general, undergraduate studies have not given the same importance to the study of earthen construction material as they have to ceramics, lithics or other elements of material culture. This is due to the fact that earthen building material has not been an attractive research topic and there were not many experts in the field until recent years. 2) In archaeological excavations, earthen material is often under- and misidentified, which often results in its incorrect treatment, or even, its dismissal. 3) In the absence of basic training, when earthen remains of decayed buildings are identified, they are usually described with an erroneous technical attribution, photographed in the best of cases, and samples are usually not collected. 4) Regional museums usually store a few samples of earthen construction material because of their imprints or a few mudbricks, so the available material remains are scarce. 5) In museums, with some exceptions, these remains are not usually exhibited, so they remain invisible to the public. 6) Furthermore, in many cases, they are not properly preserved, leading to their eventual deterioration and, in some instances, disappearance. Consequently, most publications and studies on the subject focus on recently excavated remains, with a preference for material from the eastern region of the Iberian Peninsula.

Previous works (i.e. Blanco-González 2011) have concentrated on the social and phenomenological changes that exist between the architectures of the second and first millennium BC, exploring the oppositions between the two through various items. The present paper focuses on this key period in the prehistory of the Iberian Northern Plateau, with the aim of understanding the social, economic and political characteristics of the preceding and the immediately subsequent periods through architecture. To achieve this, we have selected four sites that were occupied during these periods: Fuente la Mora (Valladolid), Sacaojos (Santiago de la Valduerna, León), *Dessobriga* (Osorno, Palencia, and Melgar de Fernamental, Burgos), and Los Barahones (Valdegama, Palencia) (Figure 1). By analysing the architectural remains stored in museums and archaeological contexts based on publications and grey literature, we aim to answer the question of what occurs at this pivotal moment between the two cultural periods on both an architectural and social level. The remains analysed in this study correspond to the best-preserved examples from each site, selected to clearly show the identified architectural features and construction techniques.

Case studies

This contribution advocates the study of this period through its architectural remains, from archaeological excavations carried out in the region of Castilla y León, some of which are more than 30 years old. In this case, the excavated material has been studied macroscopically. Previous works by the ArchTerra Research Team (Ruano Posada and Sánchez-Polo 2023) explored the possibilities offered by the study of these remains. They noted that, despite the scarcity of published data and the fact that they

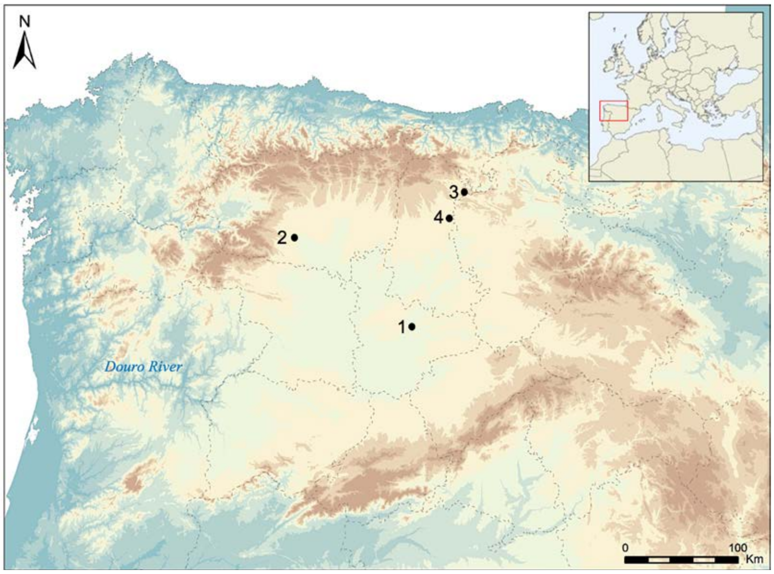

Figure 1. Map of the area under study. 1) Fuente la Mora (Valladolid, Spain). 2) Sacaojos (León, Spain). 3) Los Barahones (Valdegama, Palencia). 4) *Dessobriga* (Osorno, Palencia, and Melgar de Fernamental, Burgos) (© ArchTerra Research Group).

come from unpublished research, progress on the discrimination of the techniques used is not only possible but also significant. It was demonstrated that there were indeed important changes at the settlement level. Moreover, between the second and the first millennium BC, populations were not only open to technological change but also to construction experimentation, overcoming a rejection that had persisted for millennia.

Following a preliminary selection, unpublished earthen materials from sites of these chronologies were subjected to macroscopic study in the museums (Table 1), in accordance with the established methodology (Pastor Quiles 2022). Four sites, situated in the northern half of the Iberian Plateau and spanning the period from the Late Bronze Age (LBA, 1400–1100 BC) to the Early Iron Age (EIA, 900–600 BC), with a focus on the transition (1300–900 BC), are presented here as key sites for addressing the aforementioned issues. This approach allows us to advance the typological characterisation of the constructions and the building techniques applied, while also addressing spatial and temporal differences that are decisive regarding interactions, inventions and continuities in construction. It is important to note that there is a paucity of radiocarbon dating for these sites. Consequently, the input of ceramic typology and other auxiliary methods is essential.

Fuente la Mora (Valladolid)

In the centre of the Northern Plateau, near the Douro River, the site of Fuente la Mora was excavated in 2008 during a rescue intervention by Strato (2009). A total of 10,500 m^2 was excavated, revealing through postholes 16 circular huts of between 8 and 76 m^2 (Figure 1A). Thermoluminescence dating indicates that the huts were constructed around the turn of the second millennium BC. Dwellings were not constructed on top of older structures; rather, they were all erected anew, as it used to be in preceding times (Sánchez-Polo 2021). It is not known whether they were constructed simultaneously. A certain degree of spatial organisation of dwellings is considered because of the segregation of features related to pyrotechnological activities (Figure 2A, in red), such as metalworking or pottery production, as well as a field of pits that would have been constructed at the same time. A variety of mud building materials was documented in this pit field, including plaster, which was used as a secondary material to fill pits containing ceramics that lack a good typological definition. These remains were found in scattered structures, rather than concentrated at a specific point. The fragments exhibited many calcareous incrustations due to the local geology and were not burnt but preserved dry. It is possible that further investigation into the plant life in the area may yield further insights.

In pits number 319 and 412, fragments of plaster were recorded, comprising one irregular and one flat surface with several layers (Figure 2B). This appears to be the earliest context in the Northern Plateau where maintenance activities related to the care of the domestic space are present. Other

Table 1. General description of the studied earthen fragments.

Earthen fragment	Description	Site	Figure
Plaster	Fine wall plaster with coatings up to 3 mm thick. Some of them exhibit a painted finish in white or brownish colours.	Fuente La Mora, *Dessobriga*	2B; 5b
Plank coatings	Thin burned earthen remains of plank plasters, with wood impressions on the inner face.	Sacaojos	3Bd
Vegetal tempered plaster with cylindrical imprints	Fragments of renders with vegetal temper, 7 mm thick. All were burnt and exhibit cylindrical imprints on the redness surface.	Sacaojos	3Bc
Daub with arched profile	Earthen remains with an arched profile and smooth surfaces, resembling an opening.	Fuente La Mora	2B: Pit 324
Wattle-and-daub	Earthen remains with a flat surface and imprints of posts, planks and branches on the reverse.	Los Barahones, *Dessobriga*	4Bb; 5a
Cob-ball (?)	Fragment of earth with a trim profile and smooth surface.	Fuente La Mora, *Dessobriga*	2B: Pit 399
Clay box	Box made of clay and vegetal temper of various types: parallelepiped with a circular opening; and with plank imprints on the base to facilitate mobility.	Sacaojos, Los Barahones, *Dessobriga*	2Ba; 4Bc; 5Bd
Hand-shaped mud-brick	A coil-like clay core surrounded by additional clayey layers, forming a parallelepiped.	Sacaojos, *Dessobriga*	3Bb

fragments were recovered from pit 324: four of them appear to be daub fragments, likely from the upper part of an architectural opening, with both faces smoothed and a curved upper edge suggestive of an arched profile, representing a novel addition to the regional record. In pit 399, a rounded fragment was found, possibly a cob-ball or a similar feature (Knoll *et al.* 2019), as suggested by its morphology and manufacturing characteristics, exhibiting rounded top and sides, suggestive of a half-height partition wall or similar structure.

Sacaojos (Santiago de la Valduerna, León)

In 1996, due to roadworks that affected Sacaojos hillfort, in the northwestern part of the Douro River, an excavation of 900 m^2 was carried out on its eastern slopes (Misiego Tejeda *et al.* 1999). At Sacaojos, several phases of occupation have been identified up to the end of the EIA, resulting in a stratification in certain sectors. Although no radiocarbon dating has been carried out for this site, it was assimilated into the regional LBA to the EIA. Eight circular houses from the former phase (Figure 3A) were identified by perimeter postholes; three of them had central circular hearths, while another had a preserved floor. Some of the huts cut into each other, demonstrating a certain temporality. Some LBA pits are also interspersed, overlapped by the later huts.

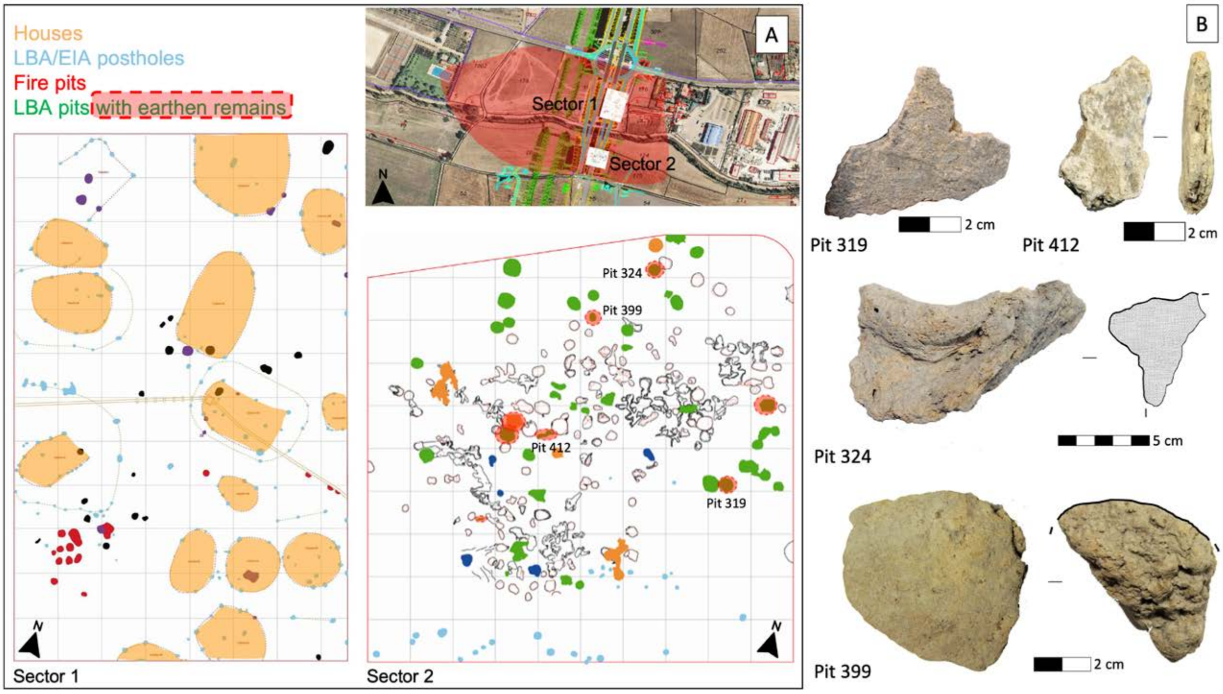

Figure 2. Fuente la Mora (Valladolid, Spain): A) Plan of sectors 1 and 2 and a general map of the area (modified from Strato 2009). B) Earthen remains found in pits at the site (© ArchTerra Research Group).

Once again, the earthen architectural remains were located in pits. As in the previous case, there are singular pieces that did not work as walls or supporting elements. In this instance, the remains were burnt, resulting in the formation of orange or blackish colourations because of varying degrees of exposure to fire. A total of four distinct types of earthen artefacts has been identified, all of which are unpublished for Recent Prehistory in the area. First, fragments of a parallelepiped box with a circular mouth and a textile imprint on one side were registered (Figure 3Ba). Secondly, there is a hand-shaped mudbrick (Knoll *et al.* 2019: 20), plastered on at least two sides (Figure 3Bb). It has a parallelepiped form with a square cross-section. A coil-like clay core is visible, over which additional layers were applied to enlarge the piece and achieve the form described above. There are other elements of unknown function, with one side fairly flat, although irregular, blackish and with many plant temper, while the opposite side is completely smoothed, reddish in colour and with completely straight cylindrical imprints in several holes (Figure 3Bc). And finally, there are very fine black clay plank coverings, with scarce and very chopped plant degreasers (Figure 3Bd).

Los Barahones (Valdegama, Palencia)

Excavated in the late 1980s by Magdalena Barril Vicente, the hillfort of Los Barahones was inhabited from the LBA through the EIA (Barril Vicente 1995), with a sequence similar to that of other previously discussed sites. It is located in the foothills of the Cantabrian Mountains, on the periphery of the Northern Plateau, an area where, unlike other studied territories, we do not observe a transition from wattle-and-daub to mudbrick architecture. However, although wattle-and-daub architecture persisted throughout the Iron Age, there was indeed some experimentation with earthen building techniques (González Gómez de Agüero *et al.* 2023; Ruano Posada 2020; 2021; Ruano Posada *et al.* 2025).

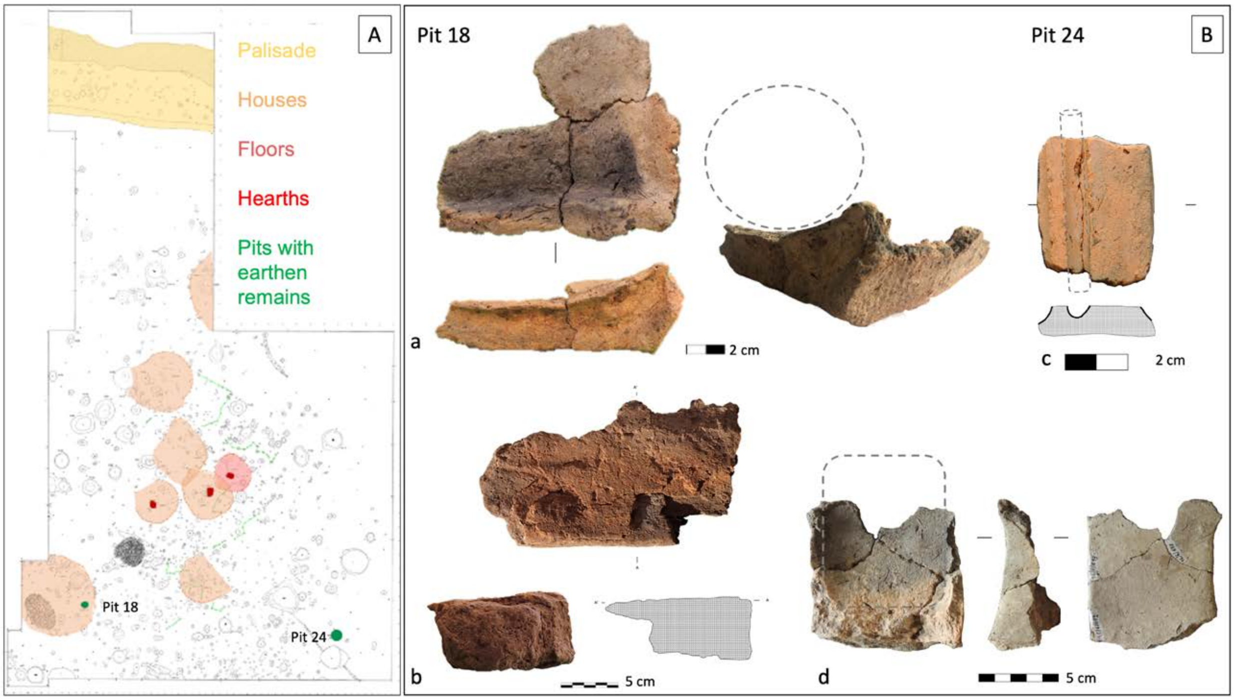

Figure 3. Sacaojos (León, Spain) hillfort. A) Plan of the site (modified from Misiego *et al*. 1999: fig. 3). B) Earthen remains from the site: a & b from pit 18, and c & d from pit 24 (© ArchTerra Research Group).

The hillfort, which possibly extended over 12 ha in its later phase, was naturally defended to the northwest by a rocky spur and to the south and east by limestone ridges; on the western side, the more accessible area, the remains of a 2 to 4-metre-wide rampart can still be observed. On this slope, an inhabited area was documented with a sequence of at least five overlaid huts (Figure 4A). Remains are scarce, but enough to allow us to discuss the evolution of building traditions. In the earliest phase, above the natural ground level, Hut 5 and possibly Hut 4 were documented. This phase is characterised by a layer of pebbles and earthen floors, delimited by postholes of about 18 cm in diameter. There also seems to have been a central post, nearly 30 cm in diameter, which would have supported the thatched roof. The abundant fragments of daub with branch imprints, as well as the presence of burnt posts, allow us to argue for the existence of wattle-and-daub structures with simple posthole foundations. At a certain point, these structures were destroyed, and another hut (Hut 3) was built over them. Of this structure, only a potential earthen wall and floor have been identified (Barril Vicente 1995: 405). The next phase of occupation is documented by Hut 2, a circular structure of 6.6 m in diameter. This hut presents an innovation compared to previous constructions, featuring a plinth of crushed sandstone with several whitish plaster layers. At least three postholes were found along the exterior face of the wall, with associated fragments of mud from the wall. In this case, along with the branch impressions, plank imprints appear, indicating the use of some kind of framework or lattice structure filled with wattle-and-daub (Figure 4Ba). The structure was destroyed by fire, and the remains of charred wood have been dated to between the 11th and the 9th centuries BC[1] (Barril Vicente 1995: 405).

Using the remains of this structure for levelling purposes, a subsequent occupation was established, as evidenced by Hut 1. It has a diameter of 7 m, delimited by a plinth of crushed sandstone compacted with

[1] 2770 ± 40 BP (1100–823 cal BC), and 2740 ± 50 BP (1001–808 cal BC) (Barril Vicente 1995: 405).

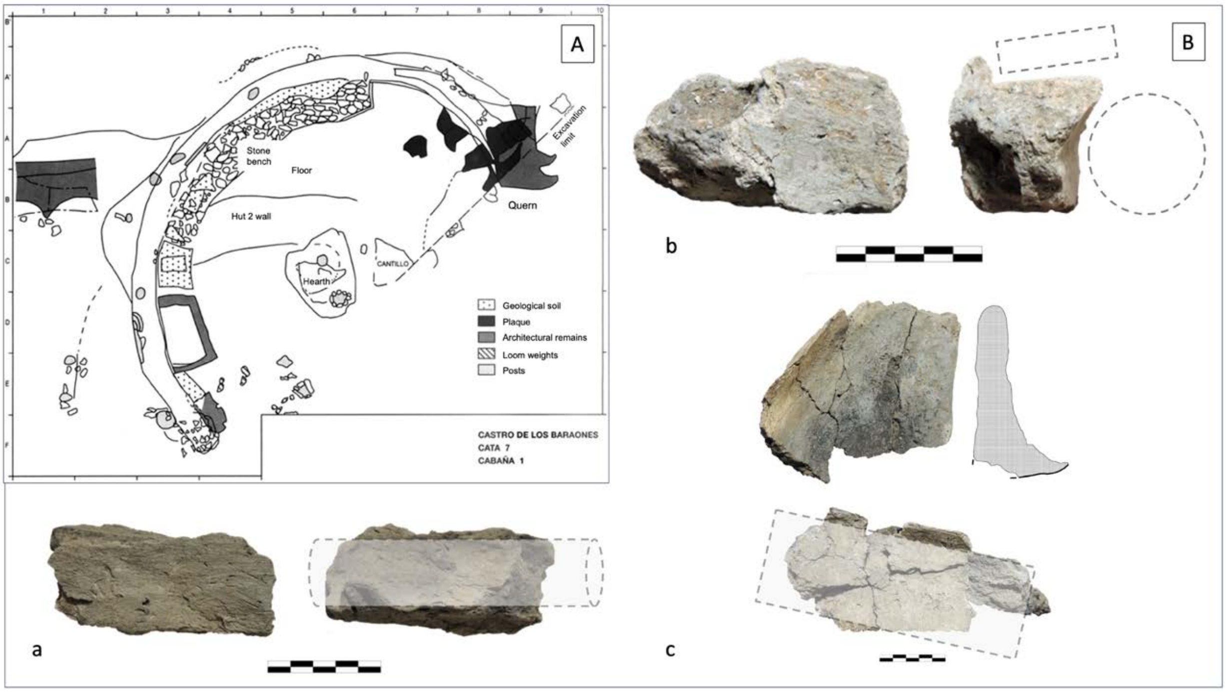

Figure 4. Los Barahones (Valdegama, Palencia): A) Plan of Zone 5 (Barril Vicente 1995). B) Earthen remains: a) Fragment of wattle-and-daub wall. b) Fragment of lattice-and-daub wall. c) Fragment of clay box (© ArchTerra Research Group).

earth, within which several postholes have been documented. Associated levels reveal fragments of plastered mud with branch and plank impressions (Figure 4Bb). While similar to previous construction techniques, a notable change is observed with the inclusion of posts within the wall, providing additional strength to the structure and preventing erosion of the earthen walls. In this structure, the earliest examples of earthen furniture were documented. Alongside the stone plinth, there was a white-plastered 'clay box' featuring fine renders and abundant vegetable temper, with an imprint of a wooden plank at the base (Figure 4Bc). This can be interpreted as a portable item, some sort of silo structure, which could have been used to collect flour, as it was found in association with two querns. Additionally, there is evidence of a type of earthen basin, as well as a central clay hearth. The dating for this phase of occupation ranges between the 6th and 5th centuries BC[2] (Barril Vicente 1995: 403–404).

***Dessobriga* (Osorno, Palencia, and Melgar de Fernamental, Burgos)**

The large archaeological site of *Dessobriga* is located at the northern end of the Douro basin, in a predominantly flat area with highly clayey soils. The settlement extends across the summit, slopes and foothills of a vast plateau, whose elevation allows for complete control over the surrounding territory. The total area has been estimated at 194 ha, albeit with different phases of occupation, ranging from the 11th century BC to the 1st century AD. Although better known for its Roman occupation, initial interventions conducted in 2001 by Strato at the base of the northern slope revealed a settlement of circular huts dating back to the EIA. The chronology remains somewhat imprecise, as few dates have

[2] Radiocarbon dating: 2485 ± 35 BP (667–475 cal BC), and 2350 ± 70 BP (593–349 cal BC) (Barril Vicente 1995: 403–404).

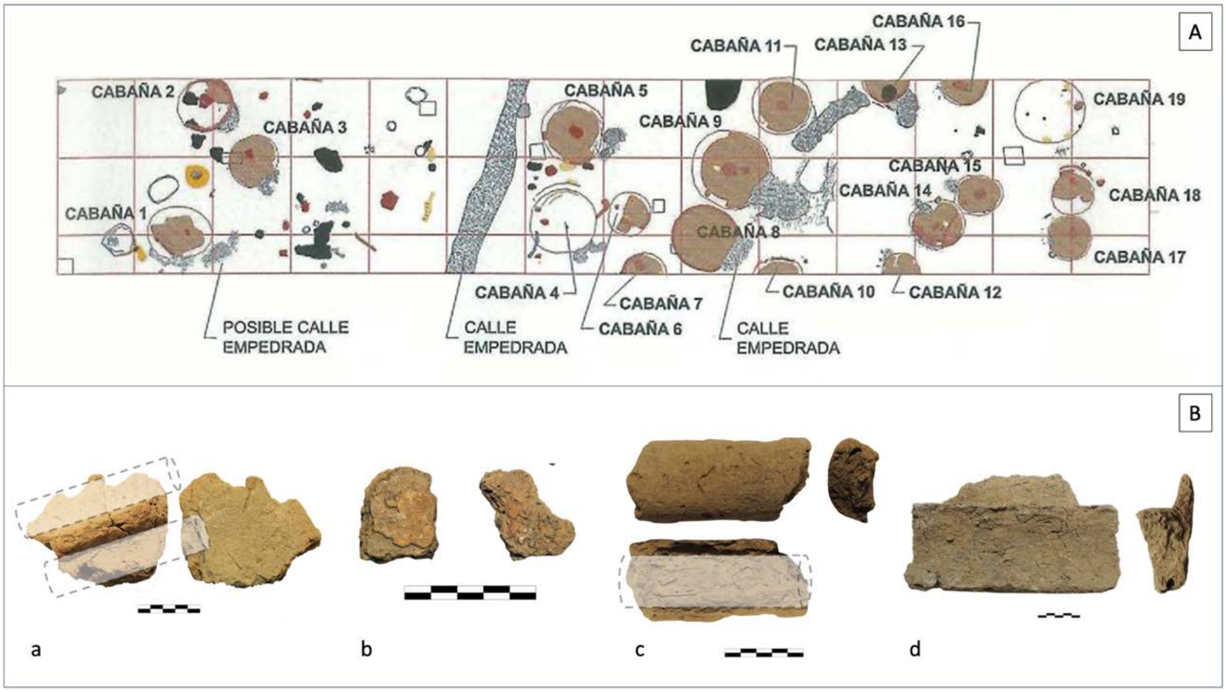

Figure 5. *Dessobriga* (Osorno, Palencia, and Melgar de Fernamental, Burgos): A) Plan of the lower area (Misiego Tejeda *et al.* 2003). B) Earthen remains: a) Fragment of wattle-and-daub wall. b) Fragment with red coating. c) Fragment of clay container. d) Hand-made mudbrick (© ArchTerra Research Group).

been obtained, spanning a broad period from the 8th to the 5th century BC[3] (Misiego Tejeda *et al.* 2003). More recent interventions led by Margarita Torrione in the 2010s have revealed that this phase also extended into higher areas, with similar structures and spatial organisation[4] (Torrione 2018).

With no records of previous architectural features, all the structures in the lower plain were circular semi-excavated huts, ranging from 5 to 9 m in diameter (Figure 5A). These structures appear to be arranged along several paths, while others were built away from these main pathways, perhaps forming small clusters. Although their walls are largely lost due to post-depositional processes, the presence of earthen fragments with branch imprints and abundant vegetal temper suggests the existence of a wattle-and-daub architecture (Figure 5Ba). In at least three structures—Huts 4, 5 and particularly 10—perimeter postholes have been documented, which appear to confirm this hypothesis (Misiego Tejeda *et al.* 2003: 82–84). However, postholes have not been located in most of the constructions, which might lead us to consider another building system, perhaps cob walls that were later hardened. It is debated whether this hardening was accidental, resulting from a fire, or deliberate, as seems to be the case for the hardened earthen floors. These walls were covered with plaster and subsequently whitened and/or painted with red pigments (Figure 5Bb). It is worth noting that in some constructions, inner postholes have been documented, which appear to indicate interior partitions separating spaces with different purposes (Misiego Tejeda *et al.* 2003: 84). On the other hand, the circular structures excavated in the upper area, around 3–7 m of diameter, clearly show mudbrick walls with a stack bond pattern

[3] Radiocarbon dating: CSIC-1737: 2444 ± 39 BP (756–408 cal BC); CSIC-1738: 2914 ± 40 BP (1227–991 cal BC); CSIC-1739: 2554 ± 40 BP (807–544 cal BC); Thermoluminescence dating: MAD-261: 2539 ± 233 BP (538 cal BC), and MAD-2612: 2595 ± 242 BP (594 cal BC).
[4] A chronological range between the 6th and 5th centuries BCE is assumed (Torrione 2018: 41).

and mudbrick benches (Torrione 2018: 40–41). The materials from both areas date back to the EIA, and the sparse radiocarbon dating seem to suggest that the constructions in the lower part of the site were older, whereas the occupation on the hill would be somewhat more recent. Although with uncertainties, we could be witnessing an evolution in the techniques of earthen architecture in this area.

The study of the materials deposited in the Museum of Palencia has allowed us to better understand the different uses of raw earth at this site during the EIA. On the compacted earthen floors of the lower site and within associated stratigraphic units, a collection of artefacts has been unearthed. While some, such as fragments of hearths, are identifiable because of their sandy composition and redness surfaces, others pose a greater interpretative challenge. Among these finds is a fragment featuring a rounded rim and impressions of branches, with a significant amount of vegetal temper (Figure 5Bc). This fragment may be indicative of a portable clay container or vessel, which possibly used wood branches to facilitate its transportation. Similarly, modelled raw earth pieces have been uncovered, some found in proximity to ovens and others in association with vessels. Several of these pieces display somewhat flat sides and roughly rectangular shapes, although they are irregular and show no evidence of being moulded, which suggests that they may represent some kind of hand-made pieces. Notably, certain specimens exhibit imprints resembling wooden planks (Figure 5Bd). Due to their scarcity, they do not appear to have served a construction function but rather seem to have been part of some structure or furniture fabricated from wood and clay.

Discussion

Returning to the initial question—what aspects of continuity, innovation and transformation are evident in the constructions of this pivotal period in Iberian Prehistory?—the macroscopic analysis of the mud fragments from the structures of these four different but nearly contemporaneous sites has enabled us to establish a set of key data points, which are summarised in Table 2.

These remains highlight the unusual dynamism of this transitional period regarding the ways of inhabiting the territory, which also materialises in the architectural forms and building traditions. However, there seems to be no uniformity regarding a temporal and territorial gradation of transformations and innovations; rather, there are elements that could be considered lagging behind in somewhat more modern contexts, along with the emergence of hand-made modelled pieces, maybe even mudbricks, as secondary elements in others with an earlier appearance. These shaped blocks exhibit parallelepiped forms and non-standardised dimensions, with coil-like cores, and are well preserved, retaining all six faces. The faces consistently show added layers of mud applied to regularise and homogenise their surfaces, yet they lack the typical marks from a mould frame, which could indicate that these pieces were hand-formed, potentially representing early versions of hand-made mudbricks (Pastor Quiles *et al.* 2024). Moreover, they occur as isolated finds, with no associated clusters of adobe fragments, which supports their interpretation as portable objects and underscores their singular character, possibly as experimental pieces. All of this stands in contrast to the evidence observed in 7th to 6th-century BC mudbricks, whose *chaîne opératoire* has been analysed at the macroscopic scale (Sánchez-Polo *et al.* 2025) and is currently being investigated through micromorphological analysis.

Indeed, certain structural elements persist over time and across the entire studied region, those which are likely more difficult to change because the *chaînes opératoires* are more established, and because the very logic of construction prevents transformation: the erection and covering of the huts, which was done through perimeter posts and earthen plasters. The same occurs with abandonment patterns, as at least two of the sites—coincidentally lacking radiocarbon dates and appearing more ancient—maintain secular dynamics in the closure of their settlements (Sánchez-Polo 2021, 2024).

Table 2. Key points in continuity, transformation and innovation in earthen building traditions between the LBA and the EIA.

	Continuity	Transformation	Innovation
Huts patterns	Circles formed by postholes (Fuente la Mora, Sacaojos, Barahones, *Dessobriga*) Semi-excavated huts (*Dessobriga*)		Segregation of residential and pyrotechnological areas (Fuente la Mora)
Architectural techniques	Wattle-and-daub (Sacaojos*, *Dessobriga*, Barahones)	Possible cob-ball walls (Fuente la Mora, *Dessobriga**)	Stone plinths (Barahones) Internal partitions (*Dessobriga*) Mudbrick walls (*Dessobriga*)
Carpentry	Wattle (Barahones, Sacaojos, *Dessobriga*)		Wooden planks frameworks (Barahones, Sacaojos)
Wall finishes		Fine earthen coating recovering the inner wood structure (Sacaojos)	White renders (Fuente la Mora, Los Barahones) Multiple layers of red and white renders (*Dessobriga*)
Furniture			Architectural opening made by kneading earth (Fuente la Mora). Possible examples of hand-made mudbricks (Sacaojos, *Dessobriga*) A continuous stone bench (Barahones)
Boxes			Box with an oval mouth and textile impressions (Sacaojos) White-plastered clay box with plank imprints (Barahones) Clay box with plank imprints (*Dessobriga*)
Abandonment patterns	Architectonic earthen remains infilling pits (Fuente la Mora, Sacaojos)	Superimposed huts (Sacaojos) Non-superimposed huts (Fuente la Mora, *Dessobriga*) Oval hearths and floors *in situ* (Sacaojos, *Dessobriga*)	Superimposed huts with different construction techniques (Barahones) Burnt clay fragments with branch imprints left *in situ* (*Dessobriga*)

*No direct evidence, it is an inference from the archaeological record.

The record of transformations attesting to construction experimentation is certainly scarce. Some examples could be the use of the cob-ball technique for some walls in Fuente la Mora and *Dessobriga*; or the development of carpentry where thin planks are used jointly with branches to create the walls in Los Barahones. Sacaojos stands out, since fine renderings covering authentic beams with rectangular sections have been detected. Furthermore, it is important to highlight that after the second millennium BC, where only pits are detected with almost no surviving structures, in this transitional period we can indeed speak generally of, at least, huts with authentic foundations in all studied sites. Undoubtedly, new social and construction logics seem to be acting, yet they still resemble the previous pit fields.

Finally, innovations appear to be the prevailing trend during this period and are evident across all four studied cases. This demonstrates a significant dynamism across the nine recorded variables: dwelling and activity areas are distinctly separated for the first time at Fuente la Mora, while architecturally, roughly hewn stone foundations are present at Los Barahones, along with clay floors and discernible internal partitions at *Dessobriga*. However, the greatest novelty lies in the internal finishes and furniture: possible modelled openings at Fuente la Mora, early mudbricks made without moulds at Sacaojos and *Dessobriga*, or a stone bench in the most recent phase of Los Barahones are among the innovations, as well as clay boxes that were presumably portable in Sacaojos and Los Barahones. Fine coatings in white and red colours (now under study by the ArchTerra I Project, founded by E-RISH) are found in almost all sites except Sacaojos, indicating a care for housing and a desire to maintain the walls—and therefore the dwelling—with a certain aesthetic. It is worth noting that this type of everyday actions in the domestic sphere involving scrupulous care of the dwelling will continue in the following centuries, constituting one of the most significant characteristics of what will be the Early Iron Age of the Northern Plateau (for example, see García-Sánchez *et al.* 2025).

In consequence, despite the proliferation of architectural innovations, there was a noticeable resistance to altering construction methods. This resistance was driven not only by the necessity of adopting new, unknown operational techniques but also by the fact that such changes could threaten the communities' ability to retain their cultural identity, assert control over their territories and determine their own solutions to social and domestic issues (Oliver 2003: 261; Rapoport 1972: 104). As can be seen in the archaeological evidence, the communities transitioning from the second to the first millennium BC were conservative, both psychologically and socially, in their approach to the construction of their huts. Hence, as we defend in this paper, transformations occurred primarily in structural elements, albeit intertwined with traditional construction practices, such as the use of more advanced carpentry techniques that allowed for the use of planks along with branches and sticks.

At this juncture, it becomes necessary to conduct a comprehensive analysis that allows us to delve into the roots of these changes. On one hand, we observe how the *habitus* or way of doing things of traditionally change-resistant communities prevails *in situ*ations where control appears limited (González Ruibal 2014: 325–326). Over time, even in the absence of dating and undoubtedly due to the arrival of eastern populations to the east and south of the Iberian Peninsula and at several points along the Atlantic coast, as well as other continental peoples throughout the Ebro Valley, we observe reflections of contacts and interactions that would have led to the changes observed in the care and maximisation of comfort in the Northern Plateau dwellings. Even at the fringes of both phenomena, similar dynamics are observed in other synchronous settlements: sites such as Guaya (Berrocalejo de Aragona, Ávila; see Misiego Tejeda *et al*. 2005), Ecce Homo (Alcalá de Henares, Madrid; see Almagro Gorbea and Dávila 1988), Las Camas (Villaverde, Madrid; see Agustí García *et al.* 2012) or Las Lunas (Yuncler, Toledo; see Urbina Martínez and Urquijo 2012) denote a segregation of living, productive and storage spaces, as well as a certain standardisation in architectural design. Regarding the construction techniques of these sites, we cannot delve deeper, although researchers report that 'remains of wood, ceramics, stones, and mudbrick or rammed earth were documented inside [the postholes]', in the case of Las Camas (Agustí García *et al.* 2012: 125), and at Las Lunas, well-built raised hearths with layers of clay were also excavated (Urbina Martínez and Urquijo 2012: 184). However, in the absence of specific studies like the one undertaken here for these four sites, it is not possible to compare them in architectural and building terms, to assess innovations, transformations and persistence.

These comparisons between chronologically nearby sites are intriguing for delving into the territorial extent and depth of architectural changes. From this, other transformations emerge that affect lifestyle or extensive social relationships. However, we believe it is necessary to change the scale and assess them at the settlement level, or even at the household level. Considering the limitations of the environment and the building techniques, they manage to implement the use of partition walls and make their homes more comfortable by crafting openings or more stable hearths, as well as plastering and painting their walls. In essence, they made technical improvements to the best of their abilities, surely after learning—but not fully incorporating into their building operational technical chain—other forms of dwelling already developing in other territories of the Iberian Peninsula. At this point, it is not possible to speculate whether entire populations were moving from one area to another, but there is indeed a sense of likeness in terms of construction techniques, architectural forms and the arrangement of elements in the huts during this transition from the LBA to the EIA. This may be indicative of significant communication flow between different communities, or even a genuine movement of entire groups.

Final remarks

These analyses highlight the importance of integrating these seemingly inconspicuous earthen fragments into discussions of social practices, as they represent an additional dimension for identifying continuities, innovations and experiments. Challenging binary antagonisms such as wattle-and-daub and mudbrick architecture, mobility and sedentary lifestyle or archaic and modern traditions emphasises the necessity of approaching prehistoric earthen architecture from a postcolonial perspective (Nitschke and Lorenzon 2020). By doing so, this critical lens will allow for a deeper understanding of the intertwined complexities of architectural traditions inherent in these challenging transitional periods. Additionally, this type of study also underscores the importance of incorporating sites identified through partial surveys or large infrastructure projects into the discussion, with a focus on recovering and analysing archaeological remains preserved, and sometimes forgotten, in museums.

In a broader architectural debate, this study demonstrates that the shift from the wattle-and-daub architecture of the LBA to the widespread use of mudbrick architecture by the end of the EIA did not happen abruptly or uniformly across all regions. Instead, we observe an experimental phase in the use of modelled clay and wood in the different studied structures and sites, first in household furnishings and later in structural elements. Thus, contrary to the theories suggesting a direct correlation between the emergence of mudbrick architecture and a significant population rupture associated with the arrival of new people, these findings suggest a more nuanced process of interaction among diverse populations. This implies a gradual assimilation and adaptation of different techniques for building with clay and wood, influenced by environmental factors and the specific needs of each community inhabiting these huts.

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‘Tell Me How You Build and I Will Tell You Who You Are’: Earthen Construction Techniques at Sant Jaume d’Alcanar (Catalonia, NE Iberian Peninsula) and Their Cultural Attribution

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Abstract: This paper presents a detailed study of the construction techniques documented at the Early Iron Age site (*c*. 750–650 BC) of Sant Jaume d’Alcanar (Catalonia, northeastern Iberian Peninsula), a fortified settlement of a singular character. The building was destroyed by a fire that produced an exceptional stratigraphic sequence and allowed the preservation of numerous fragile structural remains, including earth facings (some of them painted), fragments of earthen upper floors, carbonised beams, stored construction materials and pavements. The study also addresses the reconstruction of the architectural *chaîne opératoire*, with particular attention to the provenance of raw materials, the construction techniques employed and their cultural characterisation. It is based on the premise that the ways in which architecture is conceived and integrated into the landscape are closely linked to the technical knowledge and traditional practices specific to the social groups that produced them. Finally, the paper reflects on the possible cultural significance of the use of certain construction techniques and forms, understanding culture as a set of material and technical traits that reflect transformations in the social and economic spheres of human communities. Beyond the nature of the raw materials used (earth, stone or other resources), it is the manner in which these materials were transformed and employed that permits the identification of processes of persistence or change in the communal practices of a given human group.

Keywords: Earthen architecture, building techniques, Protohistory, Phoenicians, Iberian Peninsula

Resumen: Este trabajo presenta un estudio detallado de las técnicas constructivas documentadas en el yacimiento de la Primera Edad del Hierro (*ca*. 750–650 a. C.) de Sant Jaume d’Alcanar (Cataluña, nordeste de la península ibérica), un asentamiento fortificado de carácter singular. El edificio fue destruido por un incendio que generó una estratigrafía excepcional y permitió la conservación de numerosos restos estructurales frágiles, como revestimientos de tierra (en algunos casos pintados), fragmentos de pisos superiores realizados con tierra, vigas carbonizadas, materiales de construcción almacenados y pavimentos. El estudio aborda asimismo la reconstrucción de la cadena operativa de la arquitectura, con especial atención a la procedencia de las materias primas, a las técnicas constructivas empleadas y a su caracterización cultural. Se parte de la premisa de que la manera en que se conciben la arquitectura y su integración en el paisaje está estrechamente vinculada a los conocimientos técnicos y a las prácticas tradicionales específicas de los grupos sociales que las producen. Finalmente, se propone una reflexión sobre el posible significado cultural del uso de determinadas técnicas y formas constructivas, entendiendo la cultura como un conjunto de rasgos materiales y técnicos que reflejan transformaciones en los ámbitos social y económico de las comunidades humanas. Más allá de la naturaleza de las materias primas utilizadas (tierra,

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piedra u otros materiales), es la forma en que estas han sido transformadas y empleadas la que permite identificar procesos de persistencia o cambio en las prácticas comunitarias de un grupo humano.

Palabras Clave: Arquitectura en tierra, técnicas constructivas, Protohistoria, fenicios, península ibérica

Introduction

The purpose of this article is to demonstrate the use of earthen materials within the framework of the architecture of the Early Iron Age (800–500 BC) in the *terres del Sénia* (north-east of the Iberian Peninsula), evaluating how this evidence contributes to the cultural characterisation of these archaeological sites. This paper focuses on the documentation and analysis of architectural elements at the archaeological site of Sant Jaume d'Alcanar. The GRAP (*Grup de Recerca en Arqueologia Protohistòrica* / Protohistoric Archaeology Research Group), based at the University of Barcelona, has been conducting archaeological excavations at several sites in this area of southern Catalonia since 1985. These sites frequently yield a high number of architectural elements originally made of earth. Particular care has been taken by the research team in the recovery of these fragile materials, applying meticulous excavation and documentation procedures in order to enable their subsequent detailed analysis. Some of these construction elements are presented here for the first time.

The study is based on a multi-analytical approach, where the stratigraphic study serves as the primary framework for identifying and classifying the various structural elements described herein. This is complemented by micromorphological analyses, which were applied during the PhD research of one of the authors (MM) to a targeted selection of samples. The objective was to achieve a deeper understanding of the *chaîne opératoire*, from the sourcing of raw materials to the specific construction techniques employed (Mateu 2016, 2025; Mateu *et al.* 2013). By integrating the macroscopic study with these microscopic data, this work aims to highlight the use of earthen materials at the Sant Jaume site, providing new data for its cultural characterisation and enhancing the interpretative framework of this specific complex, as discussed in the following sections.

Site description

Sant Jaume is located in Alcanar, in the southernmost part of Catalonia, and dates to between the 8th and 7th centuries BC (Garcia i Rubert *et al.* 2016; Gómez-Paccard *et al.* 2019), during the Early Iron Age of the north-eastern Iberian Peninsula. According to the traditional working hypothesis, this site forms part of a broader group of settlements belonging to one of the indigenous groups identified in the *terres del Sénia*. This settlement cluster is referred to as the Sant Jaume Complex (SJC). The sociopolitical organisation of this group corresponds to what is defined in social anthropology as a chiefdom (Skalník 2018) or a hierarchical community in terms of socioeconomic formation. In this view, the local chief would have exercised direct control from the main site of Sant Jaume, a kind of large fortified house or small palace which would perform the functions of a political centre, over the nearby settlements: La Moleta del Remei (Alcanar), La Ferradura, Cogula and Castell (Ulldecona) (Álvarez *et al.* 2021; Garcia i Rubert 2011; Garcia i Rubert *et al.* 2016: 394; Sardà *et al.* 2016). This chiefdom established intense, lasting trade relations with Phoenician seafarers who had arrived in this region around 750 BC. All these settlements were abandoned as a result of external aggression that led to their destruction by fire. An alternative hypothesis should also be mentioned, currently under evaluation, which interprets Sant Jaume d'Alcanar not so much as an indigenous settlement but rather as a small Phoenician trading post (Mateu *et al.* 2025).

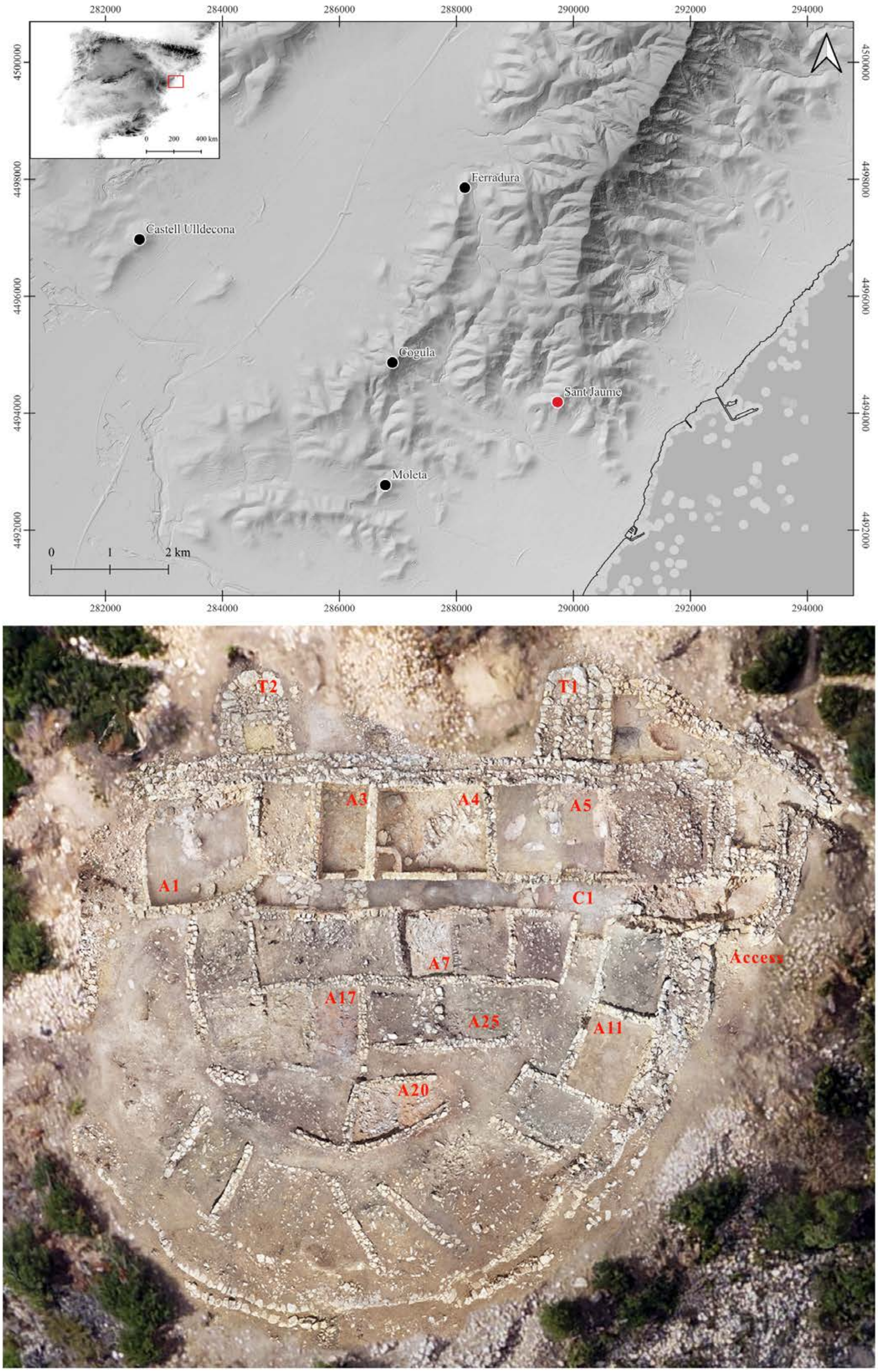

Figure 1. Map of Sant Jaume and other contemporary sites within the Sant Jaume Complex (SJC), using a 2 m-resolution DTM from the Instituto Geográfico Nacional (IGN) as a base. Below, an orthophotograph of Sant Jaume showing the locations of the rooms discussed in this article. GRAP archive.

Sant Jaume is situated on a hilltop at 224 m a.s.l. in the south of Catalonia (Figure 1), some 5 km north of the Sénia river mouth, and roughly 20 km south of the Ebro delta. It is a small, strongly fortified site of roughly 700 m^2 with a complex ground plan, completely unusual in these territories. It shows an excellent state of preservation, as evidenced by the surviving walls with an average height of about 2 m. To date, the overall layout of the site is known for slightly more than 90% of its extent, although systematic excavation has so far been carried out on only about 40% of the settlement (Álvarez *et al.* 2021).

The building, with a pseudo-circular plan and enclosed by a fortified wall, comprises several groups of rooms arranged in a more or less orthogonal layout interconnected by corridors (Figure 1). Each group is made up of rectangular, two-storey rooms; 25 rooms and 5 corridors have been identified. Its walls are constructed entirely of stone (4 m high at their highest point) bonded with earth, and the entire structure rests on a robust and substantial foundation system of Semitic tradition, which provided a wide, stable and level base for the construction of the building (Mateu *et al.* 2025, and references therein). In the larger rooms, pillars that would be related to the upper levels of the spaces were identified. During the excavations, and aside from the stone walls, the archaeological record has revealed floors made entirely or partially of earth. In some cases, the ground floor of the rooms excavated so far seems to have been used as a stable, while in others it appears to have been used for the processing of livestock and agricultural products, meeting spaces, ritual uses or as a metallurgical workshop. None of the rooms investigated to date show evidence of a strictly domestic use (such as resting or sleeping) (Garcia i Rubert *et al.* 2016).

All the rooms excavated so far show the existence of upper floors, always used to store large quantities of containers, manufactured products, raw materials and other goods and objects. Regarding the roofing system, the stratigraphy indicates that the corridors could have been partially covered, due to their narrow dimensions (around 1.30 m) combined with the overhanging eaves of the roofs of the different rooms on either side (Garcia i Rubert *et al.* 2016: 190; Mateu *et al.* 2025). Nevertheless, the rooms may have been covered by sloping thatched roofs (Garcia i Rubert *et al.* 2025, and see below, Section 2.1).

The settlement features a powerful defensive system; although a detailed description is omitted here as it falls outside the scope of this paper, its significance remains noteworthy. Its conceptual foundations originate from the Semitic tradition, characterised by two square towers and a complex access system involving several construction phases (Garcia i Rubert 2009; Garcia i Rubert *et al.* 2016; Mateu *et al.* 2025).

Basic stratigraphic sequence

The building was destroyed by fire, after either the inhabitants themselves or the attackers had taken the most valuable objects. This fire caused total destruction and resulted in a very specific sedimentation. However, this episode contributed to the preservation of many structural remains that, due to their nature, would not otherwise have been preserved. Some well-preserved elements include earthen facings (some painted), upper-floor fragments, beams, stored building materials, pavements, etc.

The excavation work has made it possible to establish a sequence of depositional and post-depositional processes which are repeated in a similar manner across all the spaces of the site. In this regard, it is common to find stratigraphic levels that are the result of the collapse of an upper massive structure made of earth (Figure 2a). Between and under the fallen fragments of this structure, the items originally stored on its circulation level are usually found (Mateu *et al.* 2025), as well as the remains of the charred beams that supported this upper element, covered in ash (Figure 2b). This suggests that the various rooms within the building's internal space featured a first floor or upper storey. Figure 2a shows the remains of the collapse of the upper floor of room A7. Note the arrangement of the earthen upper

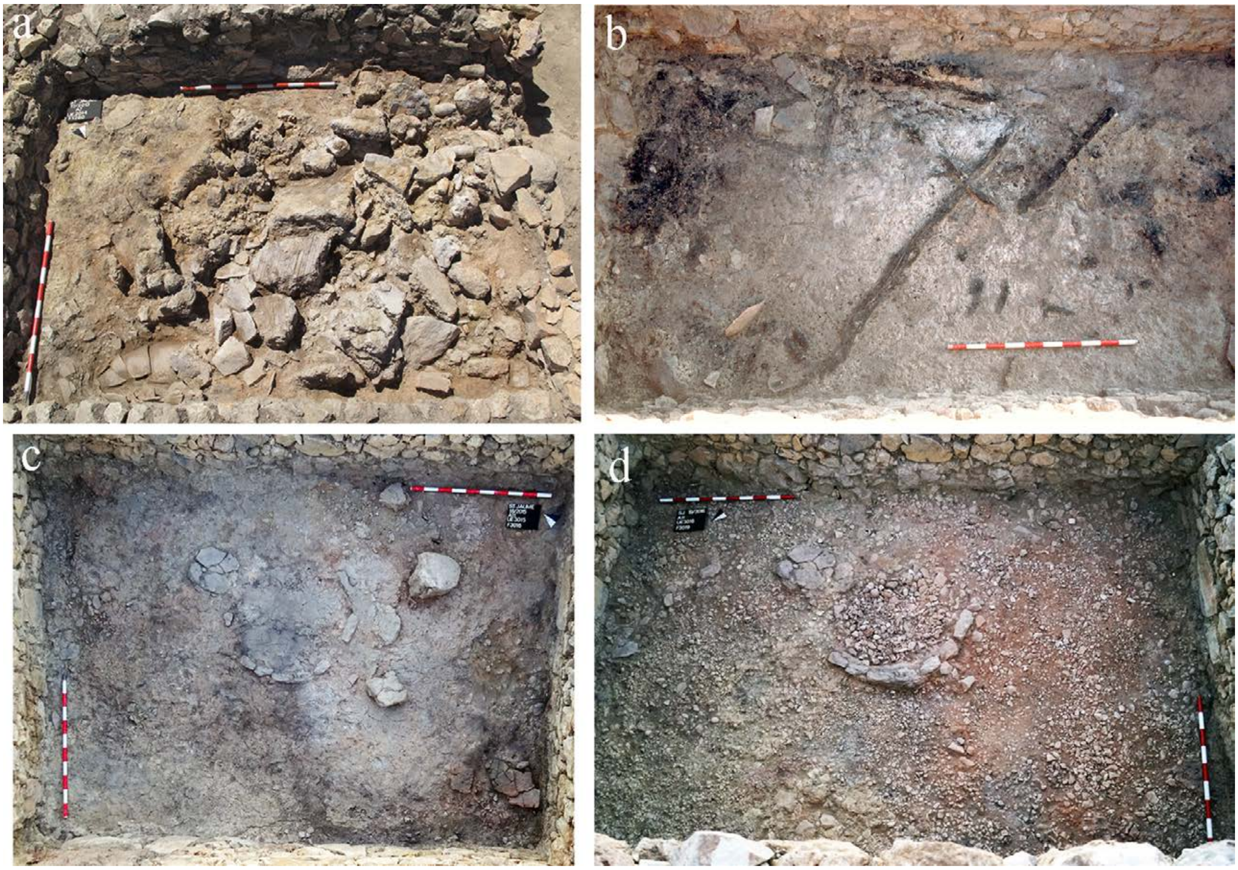

Figure 2. Building stratigraphy: a) Debris from the upper floor (earthen fragments, stones and archaeological material) (A7). b) Charcoal and ashes from the upper floor and its roof beams (A3). c) A11 ground floor with a combustion structure in the centre of the room. d) Preparation of the floor with pebbles and blocks (A11). All images GRAP archive.

floor fragments and the marks left on some of them by a primary support base made from reeds. The excavated evidence suggests that this structural element consisted of an 8 to 20 cm layer of earth laid over a horizontal framework of parallel reeds. This structure rested on beams supported by the stone walls and, in larger rooms, by additional stone and wooden pillars (Belarte 1997; Garcia i Rubert *et al.* 2016: 190; Mateu 2016). The surface of the top layer of this upper floor would have been smoothed so that it could be used for storing items and for circulation.

Below the layer of ash and charcoal resulting from the combustion of the roof and upper room—consisting of thatch, reeds and beams—lie the floors of the ground level. These floors are composed of compacted earth, sometimes combined with the utilisation of the same bedrock. In Figure 2c, a fine earthen floor is visible throughout room A11. Furthermore, in certain rooms such as this one, a preparatory layer is identified (Figure 2d), which serves to compensate for the unevenness of the bedrock on the hilltop.

Earthen building remains

Having described the site's stratigraphy and established the context of the materials presented here, this section briefly characterises their composition and *chaîne opératoire* as identified through micromorphological analysis. While a comprehensive and detailed account of these microscopic analyses can be found in the PhD dissertation (Mateu 2016, 2025), the following summary outlines the key findings essential for understanding the building remains.

Through micromorphological analysis (Mateu 2016, 2025; Mateu *et al.* 2013), it was determined that architectural elements, such as fragments of upper floors, were manufactured using a carbonate groundmass with a high proportion of dolomite and calcite sands, alongside a low proportion of coarser fractions and microfossils (Figure 3e). This sediment was sourced from the slopes of the hill adjacent to the site. Vegetal temper was added to this mixture, identified by both moldic voids and phytoliths (Mateu 2016, 2025: Matthews 2010), as well as by carbonised plant remains. Notably, the material selected for construction differs from that used in the manufacture of portable earthen objects or ceramics.

The integration of micromorphological technological features with macroscopic observations provides deeper insights into the construction techniques and manufacturing processes involved (Cammas 2018; Mateu *et al.* 2022). These include mixed building techniques (daub fragments with imprints of a reed panel used for upper floors and walls) as well as compacted earth or cob (for floors and wall coatings) (Knoll *et al.* 2019). In the following sections, the most characteristic earthen construction elements identified at the site are presented.

Upper-floors fragments

The construction of the upper floors involved the deposition of a dense, sandy-silty sediment, mixed with abundant vegetal temper, while still plastic, onto a thick framework of reeds. Consequently, the recovered fragments typically feature one smoothed side, occasionally finished with fine layers up to 1 cm thick, and an opposite side bearing regular, parallel reed impressions (*c*. 10 mm in diameter) (Mateu 2016; Garcia i Rubert *et al.* 2016: 193–196) (Figure 3c-d). These elements vary in thickness, generally ranging from 8 to 10 cm, though reaching 20 cm in some instances. The groundmass is characterised by very fine sand and frequent vegetal temper, with varying proportions of coarser sands and gravels, typically presenting a light white-orange hue.

Fragments of this type are frequently found at Iron Age sites in the north-east of the Iberian Peninsula. For example, in Serra del Calvari (La Granja d'Escarp, Segrià), Barranc de Gàfols (Ginestar, Ribera d'Ebre), Puig Roig (Masroig, Priorat), Aldovesta (Benifallet, Baix Ebre), Turó del Calvari (Vilalba dels Arcs, Terra Alta) or in Turó de la Font de la Canya (Avinyonet del Penedès, Alt Penedès) (Pastor *et al.* 2023), among others (see references in Garcia i Rubert *et al.* 2016: 193–196), where usually, and unlike at Sant Jaume, they have been interpreted as the remains of roofs. More recently, these elements have also appeared at other sites, such as La Ferradura (Ulldecona, Montsià) or El Vilar (Valls, Alt Camp), although they have not yet been published in detail.

The defining feature of these elements is the presence of regular impressions left by the reed layer (species identification is ongoing). Beyond their alignment, the specific arrangement of these reeds offers significant technological insights; in several fragments, distinct impressions of string have been observed (Figure 3d), closely paralleling those documented at the Turó de la Font de la Canya site (Pastor *et al.* 2023: fig. 4). We interpret these as indicators of how the reeds would have been tied together to form the flat, thick surface that served as the base for the construction of the circulation level of the floor. At the moment, it is unknown whether this corresponds to a joining pattern of several sections of reeds or if the presence of this rope is due to a specific event. It is an issue that is still being studied and is not yet fully understood.

Roofs

The shape and materials of the roofs of these buildings are more difficult to define. Since the 1990s, Catalonian archaeology has assumed that during Protohistory, the indigenous architectural tradition consisted of flat roofs made of earth (following the construction process described for the upper floors). This format would also be consistent with the Phoenician tradition. However, we have recently evaluated the possibility that these roofs were completely different, and that they were in fact sloping thatched roofs, made of plant materials. This new approach would be more consistent with the local climate and regional construction traditions, among other circumstances (Garcia i Rubert *et al.* 2025).

The site's stratigraphy, along with the distribution and quantity of the recovered fragments, suggests that these elements primarily belonged to the upper-floor structure rather than a rooftop. Indeed, the volume of material is insufficient to account for a roof of similar construction. Instead, we hypothesise a lighter, organic roofing system, the remains of which would likely have been integrated into the ash layers derived from the combustion of wooden beams and reeds. This interpretation is further supported by the preserved height of the walls and the presence of some cavities that may relate to the positioning of the upper floor joists. However, a comprehensive structural reconstruction of the building remains under study and falls outside the scope of the present article.

Ground floors

The dolomite mixture was also used to make the ground floors at this archaeological site. In some rooms (such as A5), earth was used to regularise the natural surface of the uneven bedrock (Belarte 1997: 58 and 99; Garcia i Rubert *et al.* 2016: 196–197; Mateu 2016). The aim was not to build a general and thick layer of earth, but only to carry out a partial conditioning of what would later become the circulation surface. In this case, a yellowish soil with a very fine sand matrix was used to level the surface and create— in many places together in a mixed formation with the bedrock—a use/circulation layer (Mateu 2016; Mateu *et al.* 2019). This has been documented in rooms A1, A3 and A4 and passage C1. In some areas of these rooms, levelling fills are documented within the natural depressions of the bedrock, followed by a preparatory layer prior to the application of the final thin sandy-matrix floor. Similar floor typologies are found at other archaeological sites in the region, such as La Ferradura, Aldovesta, Puig Roig, Barranc de Gàfols, El Calvari or Turó del Calvari, among many others (see references in Garcia i Rubert *et al.* 2016: 197).

However, it has also been possible to document the construction of general thick earthen floors in other rooms, such as A5, A7, A11 and A17. In these cases, a solid preparation of stone blocks and gravel had previously been arranged below the earth layer (Figure 2c-d). This can also be seen at other sites (Belarte 1997: 99).

Other examples of floor types (e.g. cob technique or handmade mudbricks) and floor preparations identified in the northeastern area of the Iberian Peninsula—and specifically from the perspective of micromorphological analysis—are those at the protohistoric sites of Vilars (Arbeca, les Garrigues) and Gebut (Soses, el Segrià), studied by J. Carbonell-Roca (2024: 500–504).

Partition walls

Although many of the rooms were open spaces, Sant Jaume has provided evidence that in some cases the upper floors were divided. This was carried out with partition walls constructed using a mixed building technique: in this case, daub fragments with imprints of a reed panel. Figure 3b shows, for example, the remains of one of these partitions, which originally divided the upper floor of room A11. Both fragments with reed imprints and also fragments of the opposite face (the finished surface of the wall) are visible. This partition consisted of a vertical panel of reeds covered on both sides with earth mixed with plant fragments.

Usually, such partitions are not found in such a clear state of preservation; however, fragments are frequently recovered that can be interpreted as belonging to walls or structures built using this reed and daub technique (Garcia i Rubert *et al.* 2016: 192–193; Mateu 2016). These fragments usually have a smoothed face and an opposite face with imprints of reeds (Figure 3a-c). In rare instances, the smooth face retains a finishing layer—similar to those documented in upper-floor fragments—which is occasionally covered with red or white paint (Figure 3a). These fragments range between 1.5 cm and 3 cm in thickness. The impressions are also mostly from the reeds, about 8–10 mm in diameter and very regular, but sometimes impressions from twigs or even a map of other plants, such as palm leaves, are also present (Figure 3a). In terms of composition, all fragments are similar, consisting of a whitish-brown groundmass of very fine dolomite-calcite sand with occasional coarser limestone sand or gravel and vegetal temper; notably, these components are finer than those observed in the floors.

In the north-east of the Iberian Peninsula, these structures have been documented since the Neolithic. They consist of a construction type that combines earth placed over a vegetal or wooden frame (which acts as the core of the structure). Numerous nearby sites yield fragments of this type, such as Barranc de Gàfols (Belarte 1997: 109), Turó de la Font de la Canya (Pastor *et al.* 2023) or several sites in Baix Aragó, as well as more distant sites such as Mas Gusó (Bellcaire d'Empordà, Baix Empordà) or Mas Castellar (Pontós, Alt Empordà), among many others (see references in Garcia i Rubert *et al.* 2016: 192–193).

There are other fragments with impressions of subangular gravel, but of the same thickness as those described above, that could be interpreted as wall fragments (or some kind of gavel and daub structure), but coming either from hearths of combustion structures (Garcia i Rubert *et al.* 2016: 198–199; Mateu 2016), or from other structures, such as benches or some type of floors, but out of their original context. This last circumstance makes it difficult to determine their original use. One of the aspects that contributes to this characterisation is the degree of thermal alteration, and whether such effects are uniform across the samples. This involves determining whether the alteration results from intentional firing (combustion for hardening) or from accidental exposure to fire. Micromorphological studies of the composition of these elements will provide crucial data for their characterisation. These studies are currently being carried out, not only at this site, but also within the MICRODOM and TRANSCOMB projects (ICAC).

Facings

All the walls at Sant Jaume, as well as other architectural elements (pillar bases, partitions, benches, stairs, plinths, etc.), were finished with a render. Most of the time, this facing is not excessively thick and a notable presence of vegetal temper is detected in its composition. In some cases, these facings were painted in white, red or black colours. Finally, the purpose of these facings was to prevent the stone walls bonded with earth from being exposed to the erosive action of climatic agents (Garcia i Rubert *et al.* 2016: 197–198; Mateu 2016). For examples and comparisons of earth renders and plasters, see the micromorphological work at Vilars and Gebut (Carbonell-Roca 2024: 504–507).

Other elements

Additional fragments have been recovered featuring various types of impressions, including those of wood and beams, while others lack any such markings. All of them have a similar groundmass (composition), characterised by consistent colours and matrices. These fragments originate from different construction components of the rooms and their internal structures; their original primary position cannot be definitively determined.

Figure 3. Earthen building elements: a) Fragments of walls where we can see some painted and others with non-reed imprints (palm leaves can be seen). b) Fallen wall of reeds and daub (A11); c) Cross-section of different earthen construction elements. d) Images of upper-floor fragments clearly showing the reeds and some impressions of the ropes that connected them. e) Scan of the thin sections used in the micromorphological study with the microphotographs showing the sandy groundmass, with vegetal temper. All images GRAP Archive and Mateu.

Discussion: Phoenician influences?

The construction technique of the walls follows the traditional indigenous practices of the region: structures composed entirely of medium-sized limestone blocks bonded with earth. Similar observations apply to other architectural features, such as the ground floors, upper floors, and potentially the roofing systems. On one hand, the raw materials are strictly local; analytical data confirms the use of dolomitic and calcitic sandy earth sourced from the immediate slopes of the settlement (Mateu 2016, 2025). These materials were specifically selected for their building properties rather than for the production of earthen objects or ceramics. Furthermore, the vegetal components used as temper consist of agricultural by-products.

While these construction techniques are somewhat universal, they strictly follow the traditions documented in the north-east of the Iberian Peninsula. This is further reinforced by the use of stone for the primary walls, a characteristic feature of the study area. Notably, the absence of mudbricks is significant; while not a definitive cultural marker, given their presence in the Ebro Valley since the Late Bronze Age (e.g. Alto de la Cruz, Cortes de Navarra, Munilla *et al.* 2025), their absence here reinforces the use of a specific local lithic tradition.

Consequently, at a technical level, the craftsmanship and labour appear to be indigenous. However, these techniques were employed to execute a predefined plan rooted in external architectural knowledge. A clear example is the caisson foundation system (stone-filled 'boxes'), which, despite being constructed with local stone and lacking earthen fill, follows an Eastern Mediterranean structural logic (Mateu *et al.* 2025). At the same time, evidence has emerged of ideas, elements, behaviours, and spatial organisations (including the overall design of the site) that do not correspond to indigenous traditions. Instead, these features trace their origins to the architectural traditions of the Mediterranean Levant, specifically within the Phoenician sphere (Mateu *et al.* 2025). This idea of a relationship between local communities and Phoenician groups has already been identified at other archaeological sites, such as Cabezo Pequeño del Estaño (Guardamar del Segura), whose most prominent feature is a π-shaped citadel that is formally aligned with examples from the eastern Mediterranean coast, including Hazor, Khirbet or Qeiyafa, among others. In the specific case of Cabezo Pequeño del Estaño, researchers have pointed out that the construction of the defensive structure involved the use of local materials and indigenous labour, carried out under the guidance of an Eastern architect, highlighting the importance of understanding and conducting deeper studies into the relationships established between these groups (García and Prados 2017; García *et al.* 2017).

At the beginning of this article, the main working hypothesis was established, interpreting Sant Jaume as a large, fortified residence, serving as the political centre of a small-scale chiefdom within the framework of the Sant Jaume Complex (SJC). Nevertheless, the evidence concerning the settlement's layout, along with data accumulated over years of research, has prompted the parallel assessment of an alternative hypothesis, without discarding the former: that Sant Jaume could represent a Phoenician factory. This introduces the possibility of identifying a colonial settlement in this area dating to *c.* 800 BC. Among other cultural indicators, architectural or otherwise, that seem to point in this direction, the following can be highlighted:

- The design of the defensive system and its constituent elements (Garcia i Rubert 2009; Garcia i Rubert *et al.* 2016).
- The interior design of the site, including the distribution, dimensions, orientations and metrical and morphological standardisation of the rooms, as well as the functions of some of these rooms. This includes clear evidence of Phoenician religiosity, with Middle Eastern-type structural

arrangements in religious spaces, such as room A7. In fact, none of the constructions excavated to date at the site can be considered a domestic dwelling (Álvarez *et al.* 2021).

- The construction of a caisson foundation in a clearly Phoenician format, a unique case for the entire protohistoric period (800–50 BC) throughout the north-east of the Iberian Peninsula (Mateu *et al.* 2025, and references therein).
- Among the combustion structures, it has been possible to document a large-format furnace (*c.* 1.5 m in diameter) of Phoenician type (Saorin 2025).
- Regarding the material culture, the objects found in these rooms mostly reflect commercial interests. Their storage in large quantities indicates that they were intended for trade or exchange (Sardà *et al.* 2016). In this sense, 30% of the total ceramic fragments recovered so far at the site correspond to Phoenician vessels, while in the rest of the indigenous settlements in the vicinity, this percentage never exceeds 3%. Furthermore, 90% of the Phoenician vessels at Sant Jaume are amphorae, a circumstance that reinforces the interpretation of the commercial orientation of the site (Miguel *et al.* 2015, 2023). Notably, several elements of domestic crockery have been recovered among the Phoenician ceramics—such as plates, bowls and jugs—a circumstance practically unheard of in the entire north-east of the Iberian Peninsula (Rodés and Garcia i Rubert 2025). Finally, some of the handmade pottery, traditionally considered entirely indigenous, may actually be of Phoenician origin (Barrachina *et al.* 2014).
- Furthermore, three specific lines of inquiry remain under active investigation: 1) the identification of a metallurgical workshop at the site where small-format jewellery of Levantine type was produced; 2) the recovery of balance weights based on the Phoenician shekel system and 3) the discovery of more than a thousand loom weights that could also be of Phoenician type.

In any case, whether one or the other of the interpretive options is ultimately correct, Sant Jaume stands out as a unique case along the entire Mediterranean coast of the Iberian Peninsula. If further research confirms the site as an indigenous settlement, understanding the causes and socio-cultural mechanisms behind the adoption of architectural concepts from the Levant becomes crucial. This would shed light on how these societies integrated external influences, such as architecture, and adapted them to their own context.

In the event that it is demonstrated, on the other hand, to be a Phoenician factory, apart from many other circumstances, it will also be interesting to explore the interactions between very diverse cultural traditions materialised in the architectural record and everything related to it. We are talking about aspects that are perhaps more common and better studied in contexts of similar contact, such as the use of indigenous construction techniques to erect colonial Phoenician buildings (Perra 2017; Stiglitz and van Dommelen 2024). In this case, the abandonment of traditional mudbrick wall construction in favour of locally adopted techniques—using exclusively stone bonded with earth, or mixed techniques with daub and reed panels—reflects a significant shift in architectural practice.

But also, others less considered possibilities, such as the likelihood that the Phoenician colonial world was sufficiently permeable and adaptive to adopt, during the construction process of its buildings in these contexts, not only the local construction technique but even some structural elements specific to the indigenous world. In the present case, for instance, sloping thatched roofs may have been adopted in place of the flat earthen roofs typical of Levantine architectural traditions. A fact like this would not be at all strange, as the choice between different types of roofing largely depends on the climate, especially the rainfall regime of each region. Sant Jaume's location above the 38th–39th parallels, which separate the rainy Mediterranean from the dry, further influences architectural preferences based on latitude. In societies where architecture relies on traditional materials such as earth, stone, plant fibres, wood and water, the roofing materials are often adapted to suit the prevailing climatic conditions (Garcia i Rubert *et al.* 2025).

Finally, if confirmed as a Phoenician factory, Sant Jaume would be the northernmost Phoenician settlement in the entire Mediterranean. However, it would not be the only one situated in geographical contexts with a rainy climate. Therefore, all of this could open the door to exploring the possible use of sloping thatched roofs also in these other places, especially in the south of the Valencian Country, on the island of Sardinia and, beyond the Mediterranean, along the Portuguese coast.

Conclusions

The manner in which architecture and landscape are conceived is inextricably linked to the traditional knowledge and practices of social groups. This research emphasises the cultural significance of specific construction techniques and forms, under the premise that culture is represented by a set of phenomenal features reflecting social and economic shifts within human groups. Whether involving earth, stone or other raw materials, the modification and application of these resources reveal the persistence or transformation of a community's activities.

The research conducted at Sant Jaume has facilitated a deeper understanding of local protohistoric construction techniques and the diverse applications of earth within this architectural tradition. Evidence has been documented of a compelling architectural case study emerging from the intense interaction between the Phoenician and local spheres. Furthermore, a significant architectural convergence has been identified, characterised by the use of local construction techniques to erect a building that is conceptually Levantine. While the techniques—and potentially certain structural components—are indigenous, the overarching concepts and various implemented structures are predominantly foreign.

The documentation and definition of these preserved construction remains serve as a foundation for future research, particularly in addressing what may not have survived in the archaeological record. Key questions remain regarding the assessment of architectural elements that may have degraded entirely: What was the structural significance of these now-absent elements? Furthermore, methodologies must be developed to identify, for instance, the potential existence of sloping thatched roofs, given that such organic materials often leave no direct evidence in the record.

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Early Neolithic Earth Mortar in the Iberian Peninsula: Chaff Tempering, Manufacture and Functionality in Domestic Structures

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Abstract: Raw earth was frequently used for both manufacturing and building activities during Late Prehistory. However, due to its perishable nature, preservation issues have hindered its archaeological identification, analysis and functional interpretation. This chapter introduces the results of the first combined micromorphological and macroscopic analyses of selected earthen samples from the sites of Mas d'Is and Los Cascajos to explore construction techniques of domestic facilities associated with Early Neolithic houses in the Iberian Peninsula. Our results reveal the use of chaff from the plant inflorescence, as well as variability between sites in earth-based mortar recipes and the techniques implemented when mixing vegetal matter, local mineral clay and water, depending on the intended functionality of the end product. The use of lime in a domestic cooking installation is also discussed. This is the first time that direct evidence has been provided for the use of crop-processing by-products and lime in the manufacture of domestic structures in the 6th millennium cal BC in the Iberian Peninsula. This research improves our understanding of early farming villages by providing details on how earth manufacture integrated the management of mineral resources and crop residues in daily practices.

Keywords: Earth mortar, domestic structures, chaff, lime, Early Neolithic

Resumen: La tierra cruda se utilizaba frecuentemente tanto para la fabricación de objetos como para las actividades de construcción durante la Prehistoria Reciente. Sin embargo, debido a su naturaleza perecedera, los problemas de conservación han obstaculizado su identificación arqueológica, análisis e interpretación funcional. Este capítulo presenta los resultados de los primeros análisis combinados micromorfológicos y macroscópicos de una selección de muestras de barro de los sitios de Mas d'Is y Los Cascajos para investigar las técnicas constructivas de instalaciones domésticas asociadas a casas del Neolítico Antiguo en la Península Ibérica. Nuestros resultados revelan el uso de paja así como una variabilidad en las técnicas implementadas al mezclar materia vegetal, arcilla mineral local y agua dependiendo de la funcionalidad prevista. El uso de cal en la construcción de un horno también se discute. Por primera vez se han proporcionado evidencias directas del uso de residuos del procesado de cultivos como estabilizante, así como del empleo de cal, en la fabricación de estructuras domésticas durante el sexto milenio cal AC en la Península Ibérica. Esta investigación proporciona detalles sobre la gestión de recursos minerales y vegetales en la producción cotidiana de barro de los primeros poblados agrícolas.

Introduction

During the Neolithic transition, the Western Mediterranean region shared a common cultural horizon represented by the so-called impressed ceramics (*Sillon d'Impressions* and Cardial pottery) (Bernabeu *et al.* 2009; Manen *et al.* 2019). In the Iberian Peninsula, this technological innovation was accompanied by a new economic system based on domesticated crops and animals, entailing new settlement patterns and architectural features (Bernabeu and Martí 2014; Martí and Bernabeu 2012; Rojo *et al.* 2012).

Our knowledge of Early Neolithic open-air sites in Spanish research has undergone a substantial increase since the 1990s; since then, a growing number of projects focused on habitat structures have been conducted at a regional level in the Northeast (Bach *et al.* 2025), the Central and Southern Mediterranean Coast (Gómez 2009; Jover *et al.* 2019) and the Northern Plateau (Rojo *et al.* 2008).

In the eastern area of the Iberian Peninsula, the Early Neolithic started *ca*. 5600 cal BC (Bernabeu *et al*. 2003). While the diffusion mechanisms of this process, the species cultivated and domesticated, the material culture (pottery and lithic industry) and even the symbolic and artistic aspects of the first farmers have been investigated and debated for decades, the earliest manifestation of domestic architecture (houses and facilities) in farming villages remains poorly understood.

To date, regardless of the cultural period, the analysis of mud as a raw material for the construction of objects and houses has mainly adopted a macroscopic approach (Gómez 2008; Pastor 2021; Ruano 2021; Sánchez 2024).

Furthermore, micromorphology offers key descriptive parameters for the study of manufacturing techniques and the taphonomy of prehistoric earthen materials (e.g. Cammas 2018; Friesem *et al.* 2017; Hourani 2003; Karkanas and Efstratiou 2009; Mateu and Daneels 2020; Matthews *et al.* 1997; Shahack-Gross *et al*. 2005)

In the Iberian Peninsula, high-resolution investigations of mud-made features have focused on the Later Prehistory (Goldberg and Pérez-Juez 2018; Mateu 2016; Mateu *et al*. 2013), while the Early Neolithic period has been hardly explored in this regard, in part because of the scarcity of remains reported. For example, in La Draga, mud and straw are assumed to have been applied onto wooden wall structures during the Cardial Neolithic occupation (Tarrús 2008). Recent micromorphological analyses have found no evidence of constructed floors or rammed walls made of earthen materials at the site during this phase. However, travertine, and possibly insulation mortar, was used in construction features during the later Epicardial Neolithic settlement (Andreaki 2022; Andreaki *et al*. 2025).

Despite available data, detailed information regarding earthen materials in the Iberian Peninsula during the Early Neolithic is still sparse. Therefore, gathering new evidence in this arena is crucial for a better understanding of building methods as a technological expression of the sedentary way of life introduced in the region.

Here we present the results of the first combined micromorphological and macroscopic analyses conducted on selected earthen materials used in domestic features from two of the most relevant Early Neolithic open-air sites in the Iberian Peninsula: Mas d'Is (Alicante, Spain) and Los Cascajos (Navarra, Spain). First, they have provided pottery assemblages of the earliest Neolithic ceramic groups: *Sillon d'Impressions* and Cardial for Mas d'Is (Bernabeu *et al.* 2011) and Cardial and Epicardial for Los Cascajos (García *et al.* 2011); second, they represent some of the oldest Neolithic villages in the Iberian Peninsula (Martí and Bernabeu 2012).

Materials and Methods

Archaeological sites

As indicated above, samples selected for this study come from the settlements of Mas d'Is and Los Cascajos. At both sites, abundant earth mortar was recorded within abandoned occupation layers partly

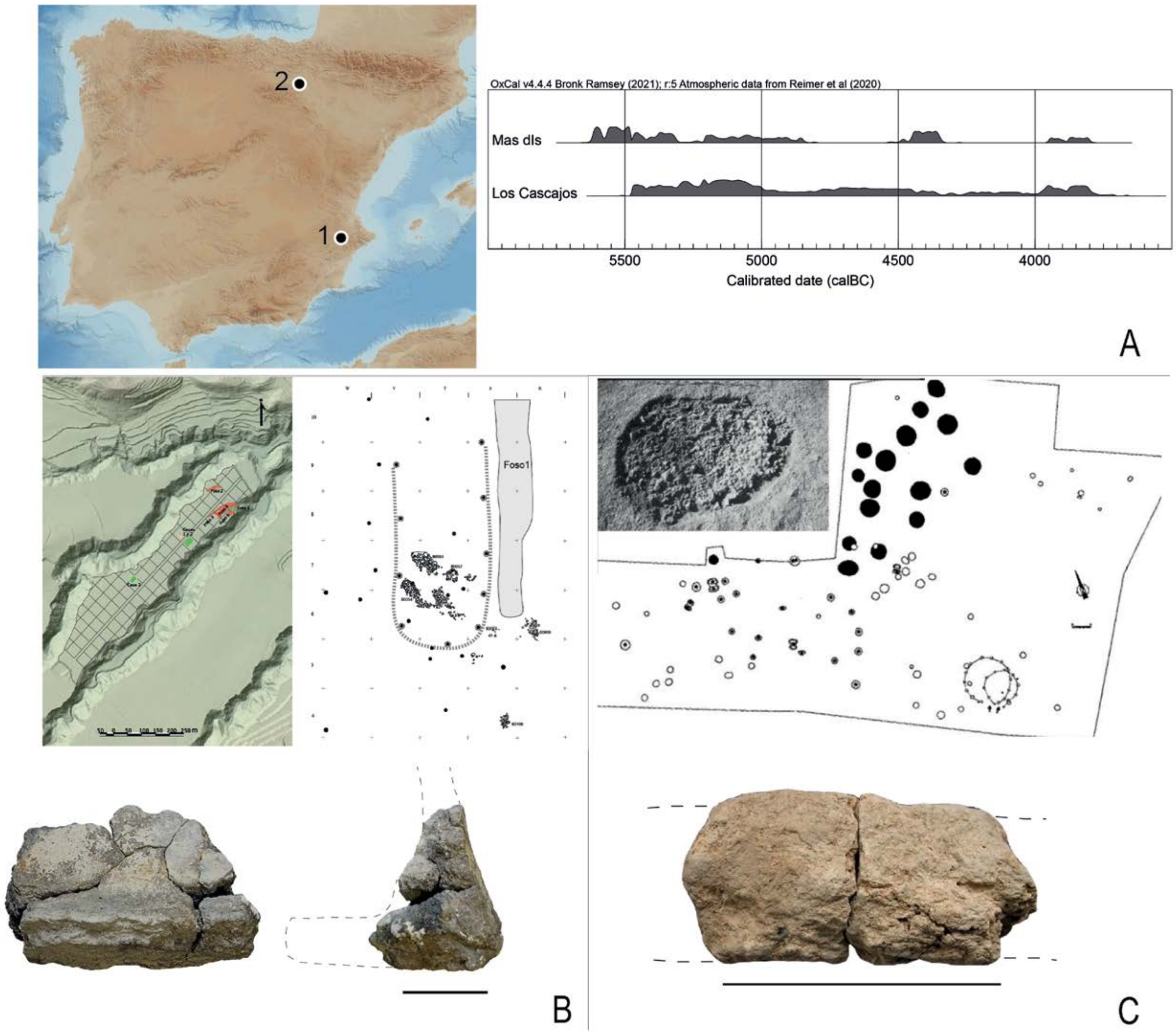

Figure 1. Archaeological context and earth mortar artefacts analysed. A. Left: location of the sites studied in the Iberian Peninsula: 1) Mas d'Is. 2) Los Cascajos. Right: chronological range of occupation (Bernabeu *et al.* 2003; García *et al.* 2011) using summed probability distribution. Oxcal v. 4.4, IntCal20 (Reimer *et al.* 2020). B. Mas d'Is. Top left: digital terrain model (DTM) showing the settlement layout (Bernabeu *et al.* 2012); top right: House 1 layout (Bernabeu *et al.* 2003); bottom: earth mortar fragment of mobile domestic oven/heater (Bernabeu *et al.* 2003) to which the samples analysed (MID39 and MID43) belong. Scale is 5 cm. Note the whitish thin coating on the inner and outer walls and the base of the feature. C. Los Cascajos. Top: combustion structure in the field and plan of the site showing the distribution of structures (García and Sesma 1999); bottom: earth mortar fragment sampled for micromorphological analysis (LC325). Scale is 10 cm (Gómez-Puche unpublished).

altered by post-depositional processes. Radiocarbon dates place the Early Neolithic occupation of both settlements in the second half of the 6th millennium cal BC.

Mas d'Is (Valencia, Spain)

This site was excavated by an interdisciplinary team of field archaeologists, archaeobotanists and geomorphologists over more than three decades (1998 to 2018), providing the oldest archaeological evidence of Early Neolithic domestic structures in the Iberian Peninsula, dating to 5500 cal BC (Bernabeu *et al*. 2003: 42) (Figure 1A).

Mas d'Is is located on a strip of land at the headwaters of the Penáguila River, a tributary of the Serpis River (southeast coast of the Iberian Peninsula, Figure 1A). The sedimentological context is characterised by homogenous beds of Miocene marls and alluvial deposits (Gallello *et al.* 2014). A number of archaeological structures were excavated over an area of almost 10 ha. In the 6th millennium cal BC the site could have been divided into two main areas: the village, where the domestic features were found (Bernabeu *et al.* 2003), and the area of the ditches, located over 150 m to the east of the village (Bernabeu *et al.* 2012) (Figure 1B). Regarding the remains of domestic structures in the village area, three houses were documented. The most complete architectural layout comes from House 1 where different alignments of post-holes delimit a domestic space, associated with a hearth, cobble pavements and small stone platforms (Bernabeu *et al.* 2003: 42) (Figure 1 B).

The earth mortar collection associated with houses is small (n = 52; weight = 250 g) but quite representative. Despite the preservation issues normally affecting this kind of perishable evidence, we documented earth mortar fragments showing visible vegetal imprints of different sizes, related to the walls or roofs of these domestic structures. The specimens analysed here were selected from a set of thirty fragments that could be interpreted as a domestic oven/heater, installed or moved as needed; this artefact was in spatial relationship with House 1, appearing at the same depth as paved structures inside the house, in the same stratigraphic unit (Figure 1B).

Los Cascajos (Navarra, Spain)

The site of Los Cascajos (Upper Ebro Basin) has been the subject of several rescue excavation campaigns (from 1996 to 2007) (García and Sesma 2007). The site has an area of around 3.5 ha of extension and is located on a Pleistocene terrace of the Odrón River, 6 m above its current riverbed.

Both the site area and the river valley are located on an elongated hill composed of red clays, continental Cenozoic sands and Miocene gypsum (Iriarte *et al.* 2019). Los Cascajos is characterised by more than 500 negative structures interpreted as post-holes, storage pits, hearths, waste areas and burial pits (García and Sesma 2007, García *et al.* 2011.). Radiocarbon dates confirm a multi-period occupation starting in the last third of the 6th millennium cal BC (García *et al.* 2011: 137) (Figure 1A). Circular clusters of post-holes have been interpreted as the remains of up to seven houses. No occupation floors have been preserved, but abundant earth mortar fragments with vegetal imprints were recovered from the filling of some of the interpreted post-holes (Figure 1C). The earth mortar collection is quantitatively larger than the one from Mas d'Is (n = 1825; weight = 51,222 g). In this case, the fragment studied comes from a storage pit reused as a burial (UE 497), dated to the Early Neolithic using a short-lived sample (i.e. human bone) (García *et al.* 2011). This inhumation structure was covered by a layer of local cobbles, sandstone fragments, a good number of lithic artefacts related to cereal processing (mills, grinders and mortars) and heterogeneous hardened earthen fragments. All this detritus presented traces or fractures produced by fire (García and Sesma 2007: 55).

Methods

All fragments of earth mortar larger than 2 cm from both sites were weighed and analysed individually. First, we carried out macroscopic observations describing their morphology and certain characteristics of the sedimentary matrix (texture, porosity and colour), in order to differentiate groups of pastes (Gómez 2009). In parallel, we also recorded particular traits observed in some fragments: organic or inorganic temper added (type, size, quantity, distribution), imprints (dimension, amount, orientation) and smoothed surfaces, to tentatively classify pieces into two main groups: (1) mobile artefacts and domestic furniture: fragments with two or more smoothed surfaces and medium/abundant small vegetal imprints within the matrix; and (2) building remains, such as walls, parapets, roofs and furniture:

pieces of thicker appearance, with one or two smoothed surfaces and sometimes vegetal imprints on the opposite side of the smoothed surface.

The results of the full macroscopic analysis will be presented elsewhere.

Three fragments from the first group (mobile artefacts and domestic furniture) were selected for micromorphological analysis based on uncommon features observed at a macroscopic level, as well as the relevance of their respective archaeological contexts. The goal was to detail macroscopic observations and test the potential of combining low- and high- resolution analyses for the characterisation of Early Neolithic earthen materials.

Small (4 × 3 cm) thin sections (MID43 and MID39 for Mas d'Is and LC325 for Los Cascajos) from transversal cuts were prepared at the IPHES Geoarchaeology laboratory (Tarragona). Microscopic analysis was conducted using plane-polarised light (PPL) and cross-polarised light (XPL) across a range of magnifications (x20-x400). The micromorphological and microfacies descriptions followed the standards established by Courty (2001) and Stoops (2003).

Results

Mas d'Is: macroscopic and microscopic characterisation

The samples investigated come from a larger fragment (16 cm long, 13 cm wide and between 3 and 6 cm thick) that presents an 'L' shape and a flat base with two parallel smoothed surfaces. On visual inspection, the colour is light brown/beige with dark grey, reddish and blackish patches on the surface, the latter apparently resulting from combustion; abundant vegetal imprints are clearly visible to the naked eye within the matrix and appear more sporadically on the smoothed sides. A thin whitish layer is observed on the outer and inner surfaces as well as on the base of the artefact (Figure 1B).

Thin sections MID43 and MID39 present four microfacies types (MFTs) (Table 1). MFT1 is a 1 mm thick layer consisting of a calcitic silty clay loam with few embedded calcitic and siliceous marl microfossils. The groundmass is light brown (PPL) and semi-isotropic with calcitic crystallitic b-fabric domains (XPL). Fine fissures are observed. The coarse fraction consists of fine quartz sands as well as light or dark brown-greyish and grey very fine to fine sands with a microcrystalline groundmass. These latter sands are dominant and exhibit high or low birefringence, occasional fissures and relicts of calcitic marl microfossils. Sand-sized angular moldic voids with indistinct silica phytolith residues (amorphous, clear-grey, isotropic) are sparsely embedded in the groundmass. The coarse fraction is homogeneously distributed. Combustion traits are observed in the marl microfossils dispersed in the matrix.

The groundmass of MFTs 2, 3 and 4 (Table 1) consists of a silty clay loam with a calcitic crystallitic b-fabric; the colour (PPL) ranges from reddish-brown at the outer parts (MFTs 2 and 3) to dark grey-brown at the centre (MFT4). Porosity is abundant and presents a subhorizontal orientation. Sand- to granule-sized angular moldic voids are dominant, followed by vughs.

The geogenic mineral fraction consists of limestone and quartz silt and sands, scattered clay grains as well as abundant calcitic and siliceous marl microfossils, all of which show traits of burning (very dark grey and dull surfaces with frequent fissures). Fe-oxide staining is frequent and indicates that combustion also affects the groundmass. Voids and mineral inclusions are homogeneously distributed within the matrix.

Moldic voids most frequently preserve phytolith structures, although these are thermally altered to varying degrees: they appear blackened (PPL) from reducing combustion at the centre of the samples

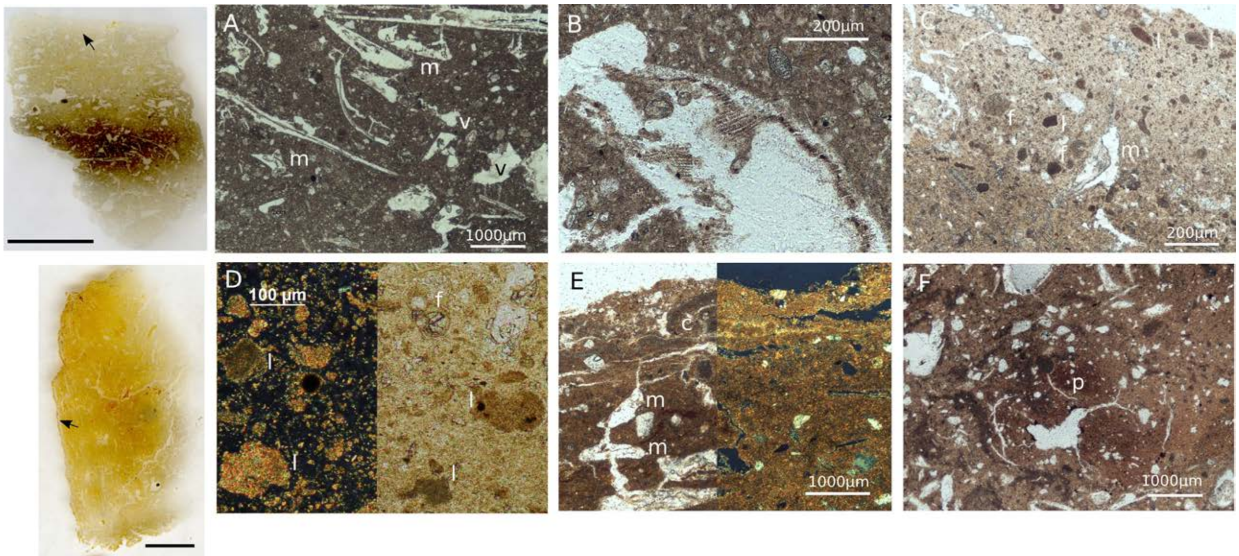

Figure 2. Left: flatbed scans of thin sections MID43 (top) and LC325 (bottom). Lime layer in MID43 and calcitic crust in LC325 (arrows). Note the highly porous groundmass of MID43 from chaff tempering (scale = 1 cm). Right: images of microscopic features. A: MID43. General view of chaff-tempered groundmass. Note angular morphology and edges of moldic voids (m) compared to vughs (v) (PPL). B: MID43. Detail of moldic void from grass inflorescence bract. Note multicellular structure of articulated, elongate dendritic and papillate cells affected by combustion (PPL). C: MID39. Contact between MFT1 (at the top) and MFT2 (at the bottom). Note concentration of very fine to fine light and dark brown sands (l) (lime lumps), embedded in a light brown matrix. Note also moldic void (m) and burnt fossil relicts (f) (PPL). D: MID39. Detail of lime lumps in MFT1. Left: mixture of aggregates displaying microcrystalline groundmass (l) with high (bright) and low (dark) birefringence (XPL). Right: brown-greyish microcrystalline aggregates (l) embedded in a light brown matrix. Note burnt calcitic microfossil—marl planktonic foraminifer—(f) (PPL). E: LC325. General view of the groundmass. Calcitic micritic crust at the top (c) and chaff-tempered matrix at the bottom showing moldic voids (m). Note indistinct plant residue inside moldic voids and subhorizontal fissures (PPL and XPL). F: LC325. Detail of rotation feature (p) in MFT2 (PPL).

(MFT 4), while grey and dull (PPL), as well as partially melted, at the outer areas of the samples (MFTs 2 and 3) due to oxidising combustion.

Despite this alteration, phytolith multicells with elongate morphotypes within moldic voids are dominant. Furthermore, articulated elongate dendritic (ELO_DEN) and papillated (PAP) morphotypes are preserved in some cases, as well as acute bulbosus (ACU_BUL) attached to undetermined elongate phytoliths.

Los Cascajos: macroscopic and microscopic characterisation

The fragment sampled for micromorphological analysis from Los Cascajos is 12 cm long, 6 cm wide and 3 cm thick, delineating a slightly curved shape. Macroscopically, the colour is light brown/beige with light grey and reddish patches, the latter apparently resulting from combustion; vegetal imprints are also visible to the naked eye. As with the fragment from Mas d'Is, it shows two smoothed faces, tough with a rounded rim resulting in a U-shaped profile.

Table 1. Description of the main macroscopic and microscopic features of samples MID39 and MID43 from Mas d'Is and LC325 from Los Cascajos. Interpretation and relevant contextual information are also detailed.

Site: Mas d'Is			
Sample ID	**Macroscopic description**	**Microscopic description**	**Archaeological context & interpretation**
MID39; MID43	Samples from an "L" shape fragment flat at the base with two parallel smoothed surfaces; 16 cm L × 13 cm W × 3 cm T. Light brown/beige with dark grey, reddish and blackish patches on the surface; vegetal imprints on the surface visible to the naked eye; whitish fine coating on the outer and inner walls as well as on the base. **MFT1:** whitish, 1 mm thick, regular surface, clear lower boundary. **MFT2:** orange, 4 mm thick, gradual lower boundary.	**MFT1** **Microstruture and porosity:** light brown (PPL); semi-isotropic with calcitic crystallitic b-fabric domains; vughy microstructure; 15 % void frequency; moldic voids (250–2000 µm) with angular and subangular morphology and edges. **Geogenic coarse mineral:** subangular and subrounded light and dark greyish-brown and grey very fine to fine-sized sands with microcrystalline groundmass (15 % frequency approx.); high and low birefringence in microcrystalline sands, with occasional fissures; very fine to fine quartz sand (5 % frequency approx.); very scarce calcitic and silica marl microfossils darkened and dull in PPL; partial structure of calcitic marl microfossils visible in microcrystalline sands; homogeneous distribution of inclusions. **Plant remains:** indistinct silica phytolith residues (amorphous, clear-grey) inside moldic voids. **Pedofeatures**: calcitic recrystallisations (partial infillings in voids).	Fragment from a portable cooking installation (oven/ heater) associated with House 1. Cardial Pottery Neolithic; mid- 6th millennium cal BC. **MFT1:** calcareous silty clay loam; chaff-tempered marl lime coating. **MFTs 2-3-4:** calcareous clayey silty clay loam chaff- tempered from marly source; post-construction burning.
	MFT3: grey-orange, 7 mm thick, clear lower boundary. **MFT4**: dark grey, 8 mm thick, clear lower boundary. Subhorizontal whitish short laminations and moldic voids visible on flatbed scans in all microfacies except in MFT1.	**MFTs 2-3-4** **Microstructure and porosity:** brown reddish to dark grey-brown (PPL); vughy microstructure; calcitic crystallitic b-fabric; 25-30 % void frequency; moldic voids (≤ 4 mm) with angular and subangular morphology and edges dominant, followed by vughs; moldic voids preserving articulated phytoliths dominant; subhorizontal orientation of voids dominant; homogeneous distribution of voids. **Geogenic coarse mineral:** subangular silt to fine sand-sized quartz and occasional plagioclase (5 % frequency), calcitic and silica marl microfossils (e.g. foraminifera, sponges, spicules, diatoms) darkened and dull in PPL; subrounded limestone sands with dull, brown-grey/very dark grey surface and fissures; subrounded reddish and brown-reddish clay aggregates (coarse sands); one rounded sand-sized flint fragment; homogeneous distribution of inclusions. **Plant remains**: articulated silica phytoliths inside moldic voids very frequent; phytoliths with altered surface and morphology (darkening, dullness, melting, margin alteration); frequent multicells with articulated elongate morphotypes inside angular moldic voids; multicell structures with dendritic (ELO_DEN) and papillated (PAP) morphotypes; multicell structures with acute bulbosus (ACU_BUL) attached to undetermined elongate phytoliths; amorphous grey dull residue inside moldic voids. **Pedofeatures**: Fe-oxide staining; calcitic recrystallisations inside moldic voids.	

<table>
<tr><th colspan="4">Site: Los Cascajos</th></tr>
<tr><th>Sample ID</th><th>Macroscopic description</th><th>Microscopic description</th><th>Archaeological context & interpretation</th></tr>
<tr><td rowspan="4">LC325</td><td rowspan="4">Sample from a fragment 12 cm L × 6 cm W × 3 cm T with two smoothed faces and a rounded rim.
Light brown/beige with light grey and reddish patches on the surface; vegetal imprints abundant and visible to the naked eye.

MFT1: light brown- whitish, 1 mm thick, irregular surface, sharp lower boundary.

MFT2: light brown/beige with light grey and reddish patches, 26 mm thick, vegetal imprints abundant and visible to the naked eye.</td><td>MFT1</td><td rowspan="4">Fragment from a fixed artefact surrounding a combustion structure; found on top of a burial deposit in a pit (UE 497). Early Neolithic; last third of the 6th millennium cal BC.

MFT1: calcitic micritic crust from exposure to surface conditions.

MFT2: silty clay loam tempered with chaff and possibly with calcitic sands and fine gravels; post-manufacture burning.</td></tr>
<tr><td>Microstructure and porosity: grey at the bottom and brownish grey at the top (PPL); massive microstructure; subhorizontal fissures; calcitic crystallitic b-fabric.

Geogenic coarse mineral: unsorted subangular quartz sands (2-5 % frequency approx.); random distribution.

Plant remains: no documented.

Pedofeatures: calcitic micritic recrystallisations inside pores, affecting also the top of MFT2.</td></tr>
<tr><td>MFT2</td></tr>
<tr><td>Microstructure and porosity: dark brown grey (PPL); complex microstructure (massive and vughy dominant); crystallitic b-fabric; 10-20 % void frequency; moldic voids (≤ 4 mm) with angular and subangular morphology and edges followed by vughs, vesicles and planar voids; overlapping of voids; subhorizontal pattern of vughs, vesicles and fissures dominant: subhorizontal fine fissures at the top and thicker vertical fissures in general; uneven distribution of voids.

Geogenic coarse mineral: unsorted subangular-subrounded sand to fine gravel limestone grains (10-15 %) with dull, brown-grey or dark grey surface and fissures; silt-medium sand-sized quartz (5-10 % approx.); uneven distribution of inclusions.

Plant remains: occasional and randomly distributed charred vegetal matter inside moldic voids; silica phytolith elongate morphotypes inside moldic voids; moldic voids with indistinct calcitic/siliceous residue or lacking residue are dominant.

Pedofeatures: frequent Fe oxide impregnations and orthic nodules; deformation pedofeatures (rotation, shearing); clayey silt intercalations.</td></tr>
</table>

Thin section LC325 from Los Cascajos presents two MFTs (Table 1). MFT1 is a continuous and massive layer of micritic calcite. Neither moldic voids nor traits of combustion have been observed. The outer rim is irregular and the lower boundary is sharp.

MFT2 consists of a silty clay loam, dark brown to grey colour (PPL), with a crystallitic b-fabric. The groundmass is more massive than that of Mas d'Is. Still, porosity is frequent with angular moldic voids, vughs, vesicles and subvertical planes. Fine fissures with a subhorizontal orientation are concentrated at the top. The occasional overlapping of voids interferes with a clear morphological characterisation of the pores. Sand- to granule-sized moldic voids most frequently contain indistinct plant residue, altered elongated phytoliths or no remains at all.

The geogenic mineral fraction consists mainly of unsorted quartz sands and sand- to fine-gravel-sized limestone; the latter with traits of combustion (i.e. darkening, dullness and fissures). Evidence of burning is also present in the matrix in the form of abundant Fe-oxide staining and orthic nodules. Clayey silt intercalations and deformation pedofeatures (e.g. rotation, shearing) are observed. The mineral and plant inclusions present an uneven distribution.

Discussion

The Neolithic transition in the Iberian Peninsula entailed a shift in settlement patterns and a more stable occupation of open-air sites established close to farming plots (Bernabeu *et al.* 2003: 50). This certainly favoured the building of new homes using locally sourced materials.

Earth mortar examination from Mas d'Is and Los Cascajos has enabled us to clarify the manufacturing techniques and discuss the functional use of domestic structures during the second half of the 6th millennium cal BC.

Chaff-tempering and alteration of plant micro-remains

Plant matter used as the dominant temper has been documented at both macroscopic and microscopic levels. Furthermore, thin-section analysis has revealed tempering with the lighter fraction of crop residues (i.e. spikelet remains as opposed to coarser straw fibres) (Figure 2A, B, E). This identification is based on diagnostic cereal anatomy (Jacomet 2006), phytolith morphotypes (Neumann *et al.* 2019), the correlation between distinctive moldic void shapes and phytolith morphotypes (Pető and Vrydaghs 2016) and burned chaff remains (Nicosia and Canti 2017).

Despite phytolith alteration hindering morphotype characteristics in thin section, elongate dendritic and papillate epidermal multicells resembling wheat/barley glume residues have been recorded at Mas d'Is. These features have survived inside voids left by bract structures in MFTs 3 and 4 (Figure 2B), which evinces the recycling of chaff from the cereal inflorescences for artefact production. Grains of *Triticum monococcum*, *Triticum aestivum-durum* and *Hordeum vulgare subsp.vulgare* reported from the Cardial Neolithic context of the site (Pérez and Peña-Chocarro 2013) support our interpretation.

Multifactorial and interrelated physico-chemical and mechanical processes are involved in the alteration and taphonomy of plant remains (Matthews 2010). Combustion elicits such processes, as it is known to be a major agent of distortion for silica phytoliths (Braadbaart *et al.* 2012).

Burning traits are clearly distinguished in the samples from Mas d'Is at a microscopic level—confirming the preliminary report on combustion features from the visual examination. The central area of the specimens (MFT4) contains a concentration of charred plant matter resulting from reducing firing conditions, while ashed plant residues (darkened and dull surfaces, as well as melting of the margin decorations in phytoliths) are observed in the outer zones (MFTs 2 and 3), in line with the chromatic gradation observed at the macroscopic level (Figure 2).

Chemical dissolution is another main factor in phytolith alteration, which is particularly favourable in alkaline environments (Cabanes *et al.* 2011). The combined effect of combustion and dissolution processes, enhanced by the calcitic mineral source, explains the poor preservation of phytoliths at Mas d'Is. Nonetheless, experimental work has shown that elongate and multicelled forms of elongates are resistant to combustion (Portillo *et al.* 2020), which clarifies why these morphotypes are the most discernible features in our samples despite alteration.

In the slide from Los Cascajos, angular moldic voids—characteristic of chaff from the inflorescence bracts—are present, suggesting that residues from the spikelet were also added to the paste in this case; however, indistinct or absent plant remains are dominant within the pores (Figure 2E). Combustion has been confirmed by micromorphological means in this sample as well. However, the reason behind the poorer preservation of the phytolith remains at Los Cascajos is uncertain at this point of our research.

Further research is required to clarify this issue and assess the possible impact of mineral raw materials, manufacturing and/or post-depositional factors on the alteration of vegetal residues.

Archaeobotanical analysis of the archaeological context (UE 497) from which the sample was taken has provided evidence of spike chaff fragments, mainly of *Triticum dicoccum* (Peña-Chocarro *et al.* 2005). Accordingly, the addition of plant temper from the dehusking of emmer to the paste of the artefact studied here is a sensible assumption. Revealing such a practice, in turn, provides indirect evidence for multistage cereal processing conducted on-site, as required by hulled wheats (Alonso *et al.* 2013).

The use of fine sieving residues in building materials can be traced back to the Pre-Pottery Neolithic of Southwest Asia, where chaff from wild cereals was used in daub manufacture (Wilcox and Fornite 1999). This finding proves that the technical benefits of adding plant matter—minimising shrinkage and increasing the tensile strength of the end product (Skibo *et al*. 1989)—were appreciated in construction practices before the full domestication of grasses.

During the Early Neolithic, the particular use of chaff as a temper has been observed at several sites in South-east and Central Europe in ceramic and daub production (Dzhanfezova 2021; Kreiter and Szakmány 2011*;* Kreiter *et al.* 2013; Moskal-del Hoyo *et al*. 2017), as well as in the creation of a figurine made of marl (Kreiter *et al.* 2014).

Concerning the Iberian Peninsula, chaff temper from hulled wheats cultivated during the last third of the 6th millennium cal BC has been identified at La Lámpara and La Revilla del Campo. At these two Early Neolithic villages, cereal imprints on coarse ceramics and daub, respectively, were recorded through macroscopic and mesoscopic analyses (Stika 2005).

Assessing our data in the context of artefact production tempered with chaff in the Iberian Peninsula and Europe, it seems that Mas d'Is and Los Cascajos shared manufacturing practices of earthen materials common to Early Neolithic groups at a broader regional level during the 6th millennium cal BC. Moreover, our data suggest that Mas d'Is provides the earliest evidence known to date of chaff-tempered earthen materials in the Iberian Peninsula. A cereal grain dated to *c*. 5550 cal BC (Bernabeu *et al*. 2003) from the archaeological context (House 1) of the artefact analysed supports this claim.

Lithic use-wear analyses have documented the harvesting of cereals by cutting only the upper section of the crops at Mas d'Is during the Cardial Neolithic (Gibaja *et al.* 2007); a practice that has also been proposed for the 6th millennium at Los Cascajos (Ibáñez *et al.* 2008).

Accordingly, the presence of mainly spike remains in our samples can be attributed to the harvesting methods implemented at the sites investigated, rather than to the intentional selection of specific crop residues residues.

Manufacture and functional use

Mas d'Is

Micromorphological analysis has demonstrated that the mineral source of the artefact from Mas d'Is corresponds to a fine sediment rich in calcareous and siliceous microfossils. This evidence is consistent with the local sedimentological context, where very homogeneous beds of Miocene marls have been recorded (Gallello *et al.* 2014).

It is interesting to note that both the mineral inclusions and the pore assemblage—including moldic voids—present a uniform pattern in terms of distribution and size range, which indicates exhaustive or long mixing of the sediment (Cammas 2018).

The evidence of burning observed in the groundmass, as well as in the plant and geogenic inclusions of MFTs 2, 3 and 4, is likely a by-product of the functional use of the feature, which is interpreted as an oven/heater. Accordingly, thermal alterations would not be attributable to the manufacturing technique. Furthermore, combustion traits could have been favoured by chaff tempering due to higher temperatures attained by the artefact as a result of the addition of the vegetal stabiliser (Forget *et al.* 2015). Besides, the highly porous paste (Figure 2) provided lightness to the end product and supports its interpretation as a portable artefact.

One unexpected result of the analysis of samples MID39 and MID43 has been the identification of features suggesting the presence of poorly to moderately carbonated lime in MFT1.

Well-known microscopic analyses have reported the use of lime in chalk/marl pastes in architectural remains from the Pre-Ceramic Neolithic (Goren *et al.* 1991). Experimental investigations into calcite-based mortars have highlighted the relevance of ultra-microscopic techniques for determining the presence of lime and its pyrogenic origin (Poduska *et al.* 2012), since the production of lime is not always involved in the manufacturing process (Friesem *et al.* 2020). Accordingly, combined micromorphology and infrared spectroscopy have confirmed the use of lime plasters during the Late Neolithic (Karkanas and Stratouli 2008) and the Epipaleolithic (Friesem *et al.* 2019), in addition to the Pre-Ceramic Neolithic (Toffolo *et al.* 2017).

Nevertheless, experimental data have also provided useful parameters for the identification of lime plaster by petrographic and micromorphological means (Karkanas 2007).

Lumps with microcrystalline matrix are one of the most characteristic features of lime production (Karkanas 2007). In MFT1 of Mas d'Is, light to dark greyish-brown fine sands displaying microcrystalline groundmass are frequent (Figure 2C and D). These sands resemble the lime lumps referred to in the literature and are embedded in a light beige (PPL), semi-isotropic (XPL) groundmass (Figure 2D). The mixture of highly birefringent (well-reacted/carbonated material) and slightly birefringent (poorly reacted/quicklime) lumps is indicative of irregular and incomplete carbonation of the original marls; this is also evidence of pyrogenic lime plaster (Friesem *et al.* 2019; Karkanas 2007) in the samples analysed. The calcitic microfossil relicts observed in some of the microcrystalline aggregates from Mas d'Is reinforce our hypothesis pointing to the local marls as the source for the lime (Figure 2C and D).

Indistinct phytolith residues (amorphous, clear-grey, isotropic) observed within moldic voids of MFT1 could be related to intense chemical dissolution triggered by slaked lime.

The presence of lime on the surface of the artefact investigated suggests the intentional application of a finishing coat and also raises the question of how the lime was produced. Concerning this latter issue, a relatively large (2.5 × 1.5 m) shallow combustion structure located 23 m away from House 1 was documented at the site. The singularity of this feature led to its interpretation as a cooking installation or a heating point of undetermined function (Bernabeu *et al.* 2003: 42-44).

In light of MFT1 characterisation, we wonder whether the combustion structure described above could be related to the on-site production of lime. Features observed in an experimental lime kiln (Goren and Goring-Morris 2008) have shown some similarities with those observed at Mas d'Is (e.g. a concentration of cracked rocks from burning, dark sediment, charcoal and fired clay/sediments).

In addition, estimations from experimental data suggest that a relatively low investment of time and effort is required for lime production, making it a feasible activity for small groups, as proposed for the size of local Early Neolithic communities in eastern Iberia (Jover 2013).

At the nearby site of Benàmer, a mortar fragment from the Cardial Neolithic period was found to contain a calcitic binder including vegetal ashes. The residues were interpreted as fuel remains from combustion structures, possibly intended for the burning of calcitic rocks as a precursor to lime production (Vilaplana *et al.* 2011). Subsequent analyses have been unsuccessful in verifying the use of lime at the site during the Post-Cardial Neolithic (Jover *et al.* 2016).

Benàmer and Mas d'Is are located within the same geographical area and belong to similar cultural contexts (García Atienzar 2011), suggesting possible shared earthen manufacturing practices, including the production of lime on a small scale. However, field evidence of lime production has not been confirmed for either site to date, which, on the other hand, could be related to the labile nature of the residues generated by this activity (Goren and Goring-Morris 2008).

Regardless of whether the combustion structures referred to above can be confirmed as related to the production of lime by future investigations, current evidence from Mas d'Is suggests that lime produced from local marls, tempered with chaff, was applied to the artefact studied. Furthermore, this finishing treatment covers the external and internal walls, as well as the base of the artefact, as indicated by the extent of the whitish fine coating observed during macroscopic examination (Figure 1B).

The artefact from Mas d'Is studied here has been described as an oven with a semi-hemispherical domed shape (Bernabeu *et al*. 2003), which is in agreement with its use as a cooking installation.

The construction of a feature using the technology revealed by our research fully aligns with such functional interpretation. First, the thoroughly homogenised chaff-tempered paste would have provided resistance to thermal stress. The vault of oven structure 614, documented in the Late Neolithic occupation of Dikili Tash, was found to contain a high concentration of temper from the glumes of domestic cereals for that purpose (Germain *et al*. 2011), which supports our statement. Second, two distinctive advantages would have been obtained from the usage of a lime coating: applied on the outer surface of the oven, it would have offered protection from weathering, while on the inner side, it would have enhanced insulation and heat efficiency.

The use of lime plastering in cooking installations can be traced back to the Pre-Pottery Neolithic of the Near East (Grosman *et al.* 2020). In eastern Iberia, the earliest use of lime in manufactured materials has been suggested for the mid-3rd millennium cal BC at La Torreta-El Monastil, a site located in the same geographical area as Mas d'Is (Jover *et al.* 2016). Accordingly, our finding would push back the use of lime in earthen artefacts to the Cardial Neolithic period, while at the same time establishing Mas d'Is as the earliest site known to date with such evidence in the region.

Los Cascajos

The mineral characterisation of the sample from Los Cascajos also points to a local supply of raw earth, as recent archaeosedimentary studies in the surrounding area have identified possible sources of siliciclastic and calcitic clays (Iriarte *et al.* 2019).

Plant-tempering has been documented at this site as well; however, a tougher manufacturing compared to Mas d'Is can be inferred from the poorly homogenised mixture: the unsorted coarse fraction and uneven distribution of mineral inclusions and voids imply relatively limited time or work invested (Cammas 2018) during the kneading action of the earthen material at the plastic stage.

Distinctive puddling traits (Figure 2F) provide clear evidence of deliberate preparation (Friesem *et al.* 2014); furthermore, subhorizontal fissures at the top of the sample (Figure 2E), combined with vertical planar voids, indicate pressure (Cammas 2018), possibly from manual compaction during production.

Clayey silt intercalations and vesicles indicate that more water was added during mixing compared to Mas d'Is, where the absence of clay coatings (Mateu and Daneels 2020) and the predominance of vughs (Cammas 2018) suggest low- to medium-water content.

The presence of limestone sands and fine gravels could be interpreted as a mineral stabiliser added separately to the paste; alternatively, it could have been inherited from the substrate. Comparative analyses of local mineral sources could shed further light on this question.

In contrast to Mas d'Is, the outer coating of the sample from Los Cascajos (Figure 2) is of natural origin and consists of a calcitic crust (Figure 2E) formed by exposure to surface conditions, possibly after the abandonment of its archaeological context. Therefore, it cannot be related to the manufacturing technique of the artefact.

In sum, the results obtained indicate that the fragment of mortar from Los Cascajos is made of local mud tempered with light chaff, which is preliminarily interpreted as the constructed outer section of a combustion/heating structure. The two smoothed faces and the rounded rim documented support this interpretation.

This specimen was recovered from an accumulation mixing burnt rock fragments together with lithic and earthen artefacts, which was sealing a burial deposit in UE 497 (section Materials and Methods). Microscopic analysis has confirmed macroscopic observations of burning traits in the sample from Los Cascajos, further detailing that combustion was a major agent involved in the alteration of the phytolith assemblage. Nonetheless, how the artefact from Los Cascajos was burnt, and what the possible connection of such combustion traits to the functional use of the feature is, seems less apparent here than in the case of Mas d'Is.

Additional fragments of similar characteristics to the sample analysed were documented in the field by one of us (Gómez, M.) in the deposit sealing UE 497. Artefact reconstruction, currently in progress, suggests that the specimen analysed and related pieces possibly belong to the constructed perimeter of a combustion/heating structure. Our hypothesis is based on parallelisms observed with artefacts recorded at Dikili Tash, a Neolithic site in south-eastern Europe (Prevost-Dermarkar 2003: 216), the Chalcolithic site of El Malagón (De la Torre *et al.* 1984), the Early Bronze Age site of Cabezo Pardo (López Padilla 2014) or the Late Bronze Age settlement of Can Roqueta II (Fernández 2016: 216; García 2010), to name a few examples. These rings would have served the dual function of delimiting fire and embers, acting as an additional support for cooking vessels.

Microscopic and macroscopic characterisation of the sample studied has revealed a coarse production and a somewhat casual and hasty manufacture. Accordingly, the artefact from Los Cascajos would reflect an expedient manufacture intended to improve the thermal performance of an extemporaneous combustion structure for which a finer finish would not be needed.

Such a type of artefact seems unlikely to have required firing during manufacture once the raw tempered mud was modelled; accordingly, we propose that the combustion traits are a post-construction effect of the activity conducted in the structure of origin. The relationship between the sealing deposit and the underlying burial in UE 497 is still to be clarified. Nevertheless, the lack of thermal alteration in the underlying human remains suggests that the burning traits observed in the rock and earthen detritus—including the fragment analysed—occurred elsewhere, but still simultaneously with or shortly after the inhumation took place, since both the burial and the sealing layer belong to the same Early Neolithic phase (García *et al.* 2011).

Conclusions

The integration of macroscopic and micromorphological data has enabled a detailed characterisation of raw earth artefacts from the Early Neolithic sites of Mas d'Is and Los Cascajos.

The samples examined are made of a mixture of fine sediments tempered with chaff, most likely derived from cereals processed at the sites.

Crop-processing by-products—likely from wheat/barley at Mas d'Is and wheat at Los Cascajos—were used in the manufacture of elements interpreted as a portable oven and a combustion/heating structure, the latter of undetermined function but possibly also used for cooking. The chaff identified in the artefacts seems to reflect the particular harvesting methods of Early Neolithic groups during the 6th millennium cal BC in the region.

The use of local pastes (including marl) and the recycling of chaff in earthen materials from Mas d'Is and Los Cascajos during the Early Neolithic reflects a technological knowledge also detected in artefacts of the 6th millennium cal BC in other areas of Europe. This suggests a common regional technological approach to domestic earthen manufacture present in the Iberian Peninsula since the earliest phases of the Neolithic period.

The distinctions in the manufacture between the sites investigated likely relate to variability in the function of domestic spaces during the mid- and second half of the 6th millennium cal BC.

The artefact from Mas d'Is shows thoughtful crafting, implying that time and effort were invested in the end product. The manufacturing characteristics can easily be related to the construction of an oven possibly intended to endure daily/frequent use. A lime coating made from local marls and tempered with chaff has been documented on the oven remains, providing further grounds for the interpretation of the structure as a cooking installation. Furthermore, it takes the use of lime to the 6th millennium cal BC and the Cardial Pottery Neolithic period. The details regarding how lime was produced at the site is a question to be explored in future investigations.

In the case of Los Cascajos, at the moment it cannot be fully ascertained whether the coarser fabric detected is actually connected with technical shortcomings or not, since it could be derived from the intended casual purpose of the artefact.

Combustion traits reported on visual inspection of the samples have been confirmed by micromorphological analysis. Furthermore, results of the contextual analysis suggest that burning traits were acquired after production and are not related to the manufacturing technique.

Notwithstanding the limited number of samples analysed, our results prove the potential of contextualised microscopic analysis to bring qualitative progress to our knowledge of how and when crop processing and mineral resource exploitation were integrated in the construction of domestic spaces of Neolithic groups.

Future steps in our research will build on the findings presented in this work to improve our understanding of daily practices in early farming villages of the Iberian Peninsula.

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Constructions in Raw Earth in the Bronze Age Navetiforms in Mallorca (Spain): A Microstratigraphic View of Naveta I at Closos de Can Gaià

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Abstract: This paper presents the microstratigraphic analysis of naveta I at Closos de Can Gaià (Felanitx, Mallorca), dating from *c.* 1850 to *c.* 850 BC, covering nearly the whole of the Balearic Bronze Age. The sedimentary record includes different stratigraphic units, among which the use of raw earth in the manufacture of different elements of domestic architecture stands out. The best-recorded phase dates to *c.* 1000–850 BC, in which the use of various hand-modelled, *in situ* construction techniques by these communities is evident, applying two systems: the stacking and kneading of balls (cob balls) and a mixed technique (wattle and daub) where earth was applied to frames of reeds and branches; the latter system was also documented in the previous phase, *c.* 1550–1000 BC. Kneading earth into balls is the predominant technique and was used in this case to construct the floors. A characteristic feature of this more recent stage is that the use of stone as an internal building material is secondary, serving only as part of the floor preparation. Occupation surfaces have been identified, allowing us to consider aspects related to the articulation of space within these navetiform constructions.

Keywords: Micromorphology, cob balls, wattle and daub, Navetiform, Balearic Islands

Resumen: En este trabajo se presenta el análisis microestratigráfico del yacimiento de la naveta I de Closos de Can Gaià (Felanitx, Mallorca), datado *c.* 1850 hasta *c.* 850 BC, cubriendo prácticamente toda la Edad del Bronce balear. El registro sedimentario abarca diferentes unidades estratigráficas, de las cuales destaca el uso de la tierra cruda en la elaboración de distintos elementos propios de la arquitectura doméstica. La etapa mejor registrada es la que abarca *c.* 1000–850 BC, en la cual se constata que estas comunidades realizaban distintas técnicas constructivas modeladas a mano, *in situ*, aplicando dos sistemas: el de apilamiento y amasado a partir de bolas y el de la técnica mixta (bahareque), donde la tierra se aplica en armazones de cañas y ramas, documentado este último ya en la fase anterior, *c.* 1550–1000 BC. El amasado en bolas es el que domina más y es utilizado en este caso para elaborar los pavimentos. Un rasgo característico de esta etapa más reciente es que el uso de la piedra como material constructivo interno es secundario y solo se constata formando parte de la preparación del pavimento. Se reconocen superficies de ocupación, lo cual permite plantear aspectos relacionados con la articulación del espacio en el interior de estas construcciones navetiformes.

Palabras clave: Micromorfología, bolas de tierra cruda, bahareque, Navetiforme, Islas Baleares

Introduction

The most common Bronze Age habitation structures in the Balearic Islands, specifically in Mallorca and Menorca, are navetas. These are large, U-shaped buildings constructed using dry stone techniques with large blocks. These structures have been known for over a century and, from a construction point of view, scientific research has focused primarily on the use of stone, due to both the monumentality and the durability of these constructions over time (Javaloyas *et al.* 2011).

Research conducted during the late 20th century marked a change of direction in the study of the building materials used in these structures. Since then, the analysis of elements made from raw earth—such as adobes, clay components and other portable elements, including loom weights—has gained prominence and is now systematically integrated into archaeological research. These materials have also been incorporated into archaeometric studies, as is the case with some from navetiform I of Closos de Can Gaià (Albero and García-Amengual 2010).

Although geoarchaeological studies on recent prehistoric settlements in the Iberian Peninsula and the Balearic Islands remain scarce, work carried out on the islands shows their significant potential. Noteworthy investigations in Mallorca, such as at Son Matge (Bergadà *et al.* 2005), and in Menorca, including Cova des Morts and Torre d'en Galmés (Bergadà and Nicolás 2005; Corral *et al.* 2018; Goldberg and Pérez-Juez 2018; Pérez-Juez *et al.* 2011; Pérez-Juez and Goldberg 2018), demonstrate the usefulness of this approach for the analysis of anthropogenic sediments. Human activity is responsible for a significant portion of the sedimentary filling documented within these sites and, in particular, in the case at hand, the navetas. The identified sedimentary deposits derive mainly from the construction materials used—including raw earth—as well as from human occupation *sensu stricto*.

In this regard, soil micromorphology provides detailed information that is not apparent during archaeological fieldwork, significantly complementing the study of anthropogenic activities and, ultimately, the use of the site by the communities that inhabited it. This methodological approach enables the characterisation of construction processes and techniques, as well as the identification, differentiation and interpretation of occupation surfaces, levels of use and associated post-depositional processes.

The objectives of this work focus on the microstratigraphic characterisation of the sedimentary record of Naveta I in relation to its different chronological phases. The aim is, on the one hand, to identify and characterise the earth construction materials, their associated construction technologies and their functionalities; and, on the other hand, to recognise and differentiate the floors and their respective areas of use.

Description of the site

Geographical location and geological context

Closos de Can Gaià is located in Portocolom, in the eastern part of Mallorca, in the municipality of Felanitx and about 700 m from the coastline (Figure 1a). The lithological materials that make up this area correspond to a stratigraphic sequence belonging to the upper-middle Miocene, consisting of calcarenites, calcisiltites and bioclastic limestones at the base (Santandreu *et al.* 2020). The calcarenites, locally referred to as *marés*, are of particular interest to this study and consist of an oolitic variety known as Santanyí stone. Additionally, the calcisiltites formations are more clayey and contain minerals such as kaolinite and illite, among others (Mas Gornals 2017). *Terra rossa* sediments are dominant and are considered relict, as their derived materials are frequently transported, reworked and even modified by new pedogenetic cycles (De la Cruz *et al.* 2001; Ginés *et al.* 2012).

Archaeological context of the site

The Closos de Can Gaià site has a chronology that ranges from approximately *c.* 1850 to 850 BC, with reoccupation phases during the Early Iron Age and the historic period (Fornés *et al.* 2009; Javaloyas *et al.* 2011). This settlement consists of at least eight navetas houses in the shape of a horseshoe, five of which are still visible (Figure 1b). They are built with a cyclopean technique and arranged in a dispersed pattern with similar orientations from S to SE.

Naveta I, the focus of this study, was excavated in its entirety between 1996 and 2006 by the ArqueoUIB research team of the University of the Balearic Islands (UIB), while the excavation of Naveta II was completed in 2025. Naveta I is an elongated, U-shaped structure, measuring 16 m long and 7 m wide at the façade, with walls 2–3 m thick and a preserved height of no more than 1.5 m (Figure 1c).

Four phases were identified during the study: a) before the construction of the monumental structure (*c*. 1850–1600 BC), in which scattered archaeological materials were located; b) the construction phase of the naveta, comprising two different archaeological occupation stages: phase 1 (*c*. 1550–1000 BC) and phase 2 (*c*. 1000–850 BC); and finally, c) a post-abandonment phase (after *c*. 850 BC). Several phases of reoccupation and reuse were also detected during the historic period.

This monumental building was used between *c*. 1550 and 850 BC, with two clearly defined phases that resulted in different internal configurations (Fornés *et al.* 2009; Oliver 2005; Salvà and Hernández 2009). For phase 1 (*c*. 1550–1000 BC), no defined areas of activity have been documented in the interior, likely due to recurrent cleaning processes (Fornés *et al.* 2009). The domestic spatial organisation was articulated both transversally—separating the rear two-thirds of the space and the front third with a diaphanous entrance—and longitudinally—dividing the naveta into two halves, which resulted in limited light in the apsidal area (Figure 1d). Two stone floors were found: one in the eastern interior and the other at the entrance/façade. Furthermore, four stone column bases were found, interpreted as an apsidal loft (Calvo and Salvà 1999; Fornés *et al.* 2009; Hernández *et al.* 2004). Based on this evidence, it has been proposed that the front part of the structure was used as a public space for social relations where the domestic group interacted, while the rear part corresponded to a more private space used mainly by the household (Fornés *et al.* 2009; Javaloyas *et al.* 2011).

During phase 2 (*c*. 1000–850 BC), a major restructuring of the internal space of the naveta occurred. The entrance to the house was narrowed by the construction of a wall, which consequently reduced visibility between the interior and exterior (Figure 1e). Another important modification was the placement of fixed macrolithic elements—such as a table and mortar—related to food processing (Fornés *et al.* 2009; Hernández *et al.* 2004). The longitudinal axis is reinforced during this period, occupying the entire

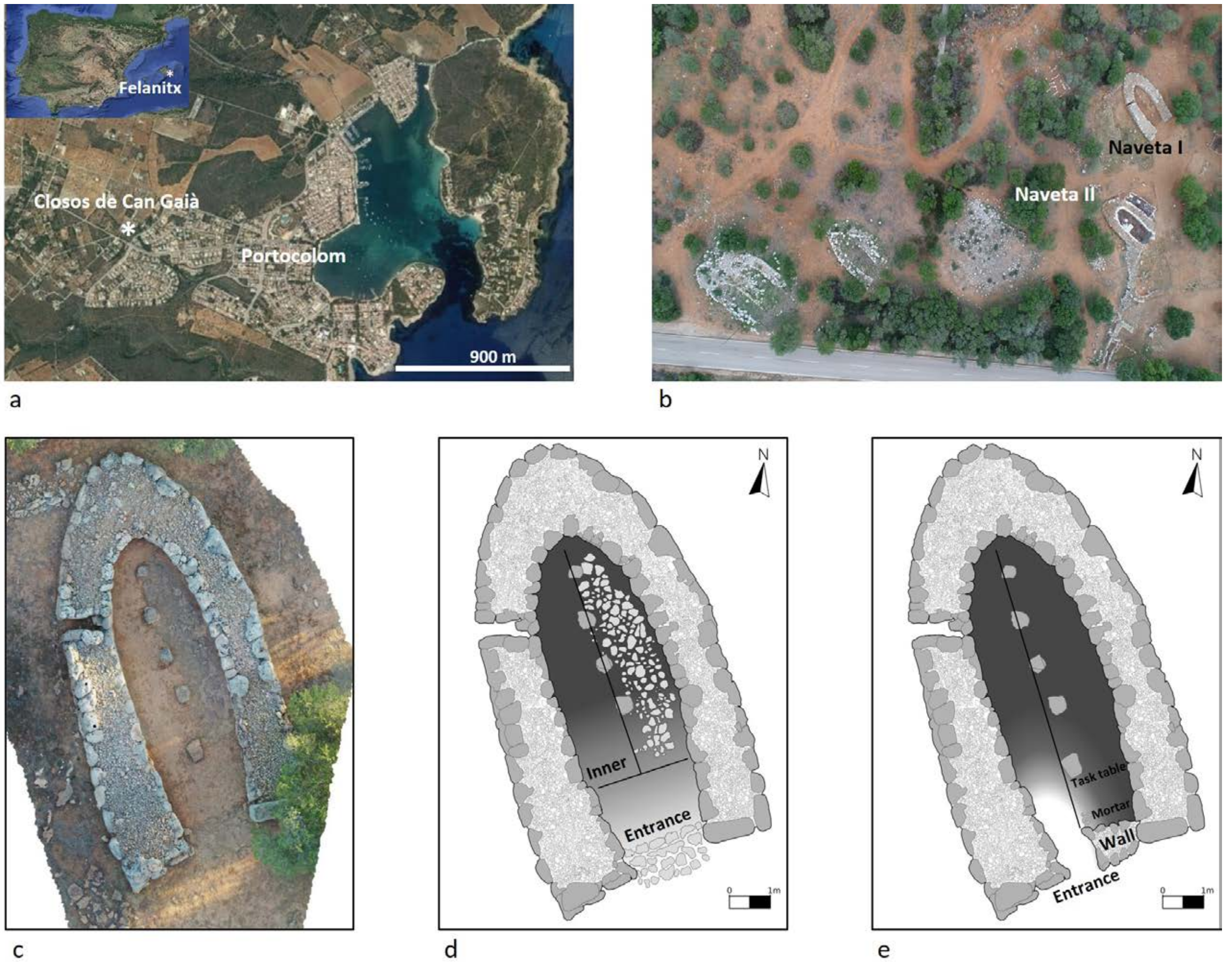

Figure 1. Closos de Can Gaià (Felanitx-Portocolom, Mallorca). a) General geographical situation and location of the Closos site. b) Aerial view of the five navetas. c) Orthophoto of naveta I. d) Phase 1 (*c.* 1550–1000 BC). Spatial distribution and light entrance reconstruction in the interior of the naveta, showing little light in the apse area. e) Phase 2 (*c.* 1000–850 BC). Spatial distribution and light entrance reconstruction in the interior of the naveta, lighting is significantly reduced.

length of the naveta, with a consumption/cooking area situated in the entrance zone. These changes are interpreted as a desire for increased privacy within the dwelling, associated with the general and growing social complexity leading towards supra-domestic structures at the threshold of the Talaiotic period—Iron Age (Fornés *et al.* 2009).

Materials and methods

The methodology employed consisted of a stratigraphic-sedimentary field description and the application of micromorphology to the following stratigraphic units (hereafter SUs) located in different profiles of the naveta (Figures 2a, 2b, 2c and 2d):

- SU 37, in profile 3, corresponds to the pre-settlement phase (*c.* 1850–1600 BC).
- SU 36, in profile 3, linked to phase 1 (*c.* 1550–1000 BC).

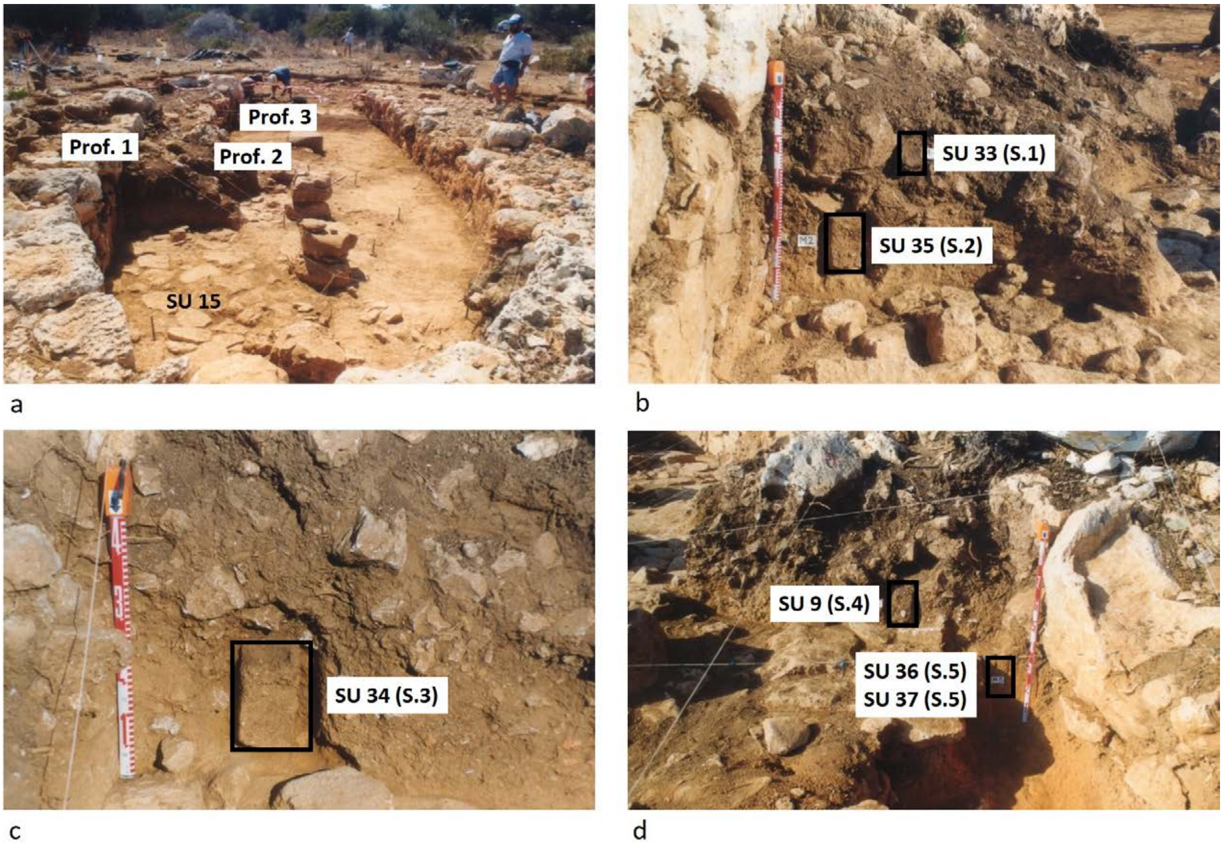

Figure 2. Micromorphological sampling of Naveta I at Closos de Can Gaià. a) General view of the sampled profiles. Detail of stone floor (SU 15). b) Profile 1: SU 33 (sample 1) and SU 35 (sample 2). c) Profile 2: SU 34 (sample 3). d) Profile 3: SU 9 (sample 4) and SU 36 and SU 37 (sample 5).

- SU 35, in profile 1, and SU 9, in profile 3, related to phase 2 (*c.* 1000–850 BC).
- SU 34, profile 2, and SU 33, profile 1, corresponding to the post-abandonment phase (after 850 BC).

We also incorporated the study of a series of raw earth aggregates recovered during the archaeological interventions, corresponding to SUs 36, 35, 9 and 34.

The protocol followed for extracting samples from the sedimentary record—a total of five—involved taking them with the help of boxes lined with plaster. These were air-dried and subsequently impregnated with polyester resin. Thin sections measuring 13.3 × 5.5 cm and 30 µm thick were obtained from the materials according to the procedure described in Benyarku and Stoops (2005). A total of nine thin sections were made from the five blocks, alongside four from the raw earth aggregates. These were observed under a polarising stereomicroscope and a petrographic microscope at magnifications ranging from 0.63x to 200x, using plane polarised light (PPL), crossed polarised light (XPL) and oblique incident light (OIL). Thin section description and interpretation follow the guidelines proposed by Bullock *et al.* (1985), Nicosia and Stoops (2017), Stoops (2021) and Stoops *et al.* (2010).

Results

Thanks to the micromorphological study of the different stratigraphic units within the sampled profiles, it has been possible to identify various microfacies types (Courty 2001; Goldberg and Macphail 2022). These are defined as groups of similar micromorphological attributes that reflect a shared depositional or formative process, whether of geogenic (sedimentary and pedogenic) or anthropogenic origin.

In most cases, these microfacies correspond to the identified stratigraphic units. However, SU 35 and SU 9 have been subdivided into a and b due to differences in microstructure, porosity, coarse material and pedofeatures. We have also added the colour, as recorded during the field description.

In order to present these results, this section is divided into different subsections corresponding to the identified microfacies type, which are as follows: quaternary substrate, floor layer preparation, floors, human activity surface, raw earth building material and soil horizon formation (pedogenesis).

The most relevant micromorphological features are presented for each microfacies; however, the characteristics related to the composition of the coarse fraction (rocks and minerals), micromass and pedofeatures are, in general, the most homogeneous among them. Furthermore, Table 1 summarises the main features by microfacies and stratigraphic units.

The lithological and mineralogical composition consists of subrounded to subangular oolitic calcarenites and micritic limestones, as well as quartz, calcite and some feldspar. The micromass is mainly of the speckled b-fabric type, although in the microfacies related to floors, human activity surface and raw earth construction material, calcitic crystallitic b-fabric is also present. In the soil horizon formation (pedogenesis), it is also undifferentiated. Regarding pedofeatures, we would like to highlight the activity of soil fauna, represented by loose continuous infilling of channels by ellipsoidal faecal pellets of earthworm and passage features, especially in microfacies type such as floor layer preparation, floors and human activity surfaces.

Quaternary substrate

This microfacies is represented by SU 37 (Figure 3a) and consists of reddish-brown (5YR 5/6) silty clays with fine sands (Figure 3b). It exhibits a microstructure of subangular blocks. Some bone fragments were found, as well as occasional charcoal and organic matter residues (Figure 3c).

Notable pedofeatures include calcitic hypocoatings in voids (Figures 3d and 3e), resulting from carbonate precipitation linked to plant root metabolism (Durand *et al.* 2010), as well as channel-type voids, also due to roots.

Its origin is likely linked to the decalcification of the calcarenites (*terra rossa).* In some areas of the settlement, an earlier occupation attributed to the Early Bronze Age has been documented, probably to a pre-naveta stage.

Floor layer preparation

Floor preparation layer is represented by detrital sedimentary accumulations, comprising SU 36 (Figure 3a) and SU 35b.

SU 36 does not differ significantly from SU 37, although an increase in biological activity results in a granular and channel-type microstructrure, with a porosity consisting of compound packing voids and channels. It is distinguished by an increased human activity components, such as bone fragments (Figure

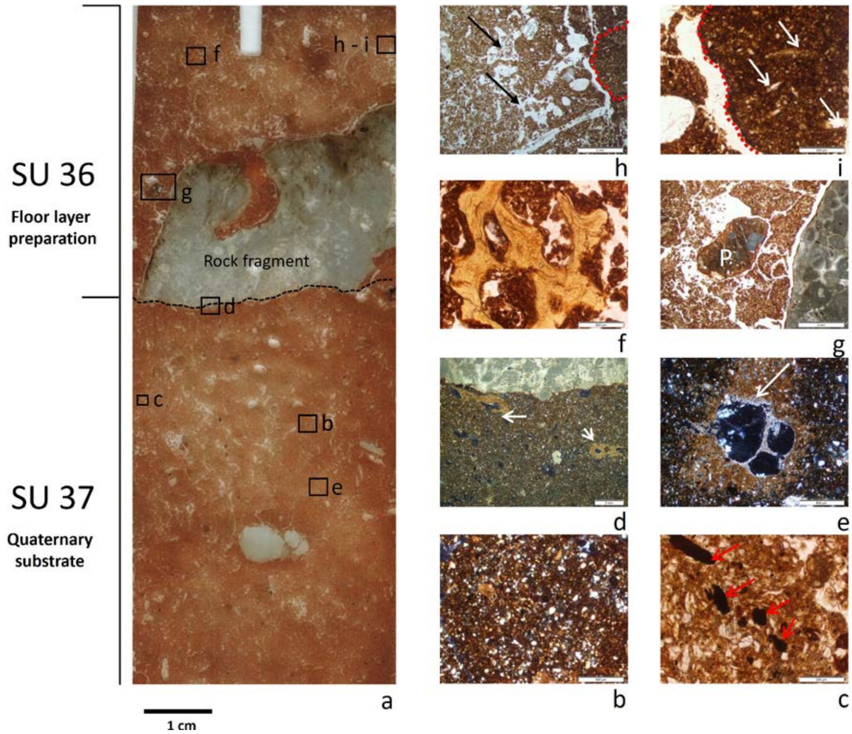

Figure 3. Quaternary substrate (SU 37) and floor preparation layer (SU 36) from phase 1 (*c.* 1550–1000 BC). a) Overview of the transmitted light scan thin section showing the units and the location of the following images. b) SU 37, silty clays with quartz sands (XPL). c) SU 37, residues of organic material marked with red arrows (PPL). d) SU 37, general view, showing the groundmass with calcitic hypocoatings (XPL). e) SU 37, detail of a calcitic hypocoating (XPL). f) SU 36, bone fragment (PPL). g) SU 36, pottery fragment (P) in inclined position in a biopore. h) SU 36, fragment of raw earth microaggregate (red discontinuous lines) and loose discontinuous infillings (black arrows) typical of biological activity. i) Detail of the previous image, with moldic voids (white arrows) (PPL).

3f), pottery (Figure 3g) and flint, alongside some rounded raw earth microaggregates (Figures 3h and 3i), distinguished by the presence of some moldic voids. All these elements are randomly distributed and have no clear orientation. At the base, highly irregular contours are visible, typical of dissolution traces.

SU 35b, on the other hand, is characterised by the presence of cobbles at the top of the unit (Figure 4a). It is composed of clayey silts with light brown fine sands (7.5YR 5/4). There is an appreciable increase in porosity with respect to SU36, together with subrounded raw earth aggregates with an increase in clay content; some exhibit thermoalteration traces (Figure 4b). There are also some gravels with high-intensity combustion traces and evidence of possible rewetting (fissures, more opaque colouring and some isotropic sectors in XPL), all within a random distribution.

Floors

This microfacies is represented by SU 35a (light brown, 7.5YR 5/4) and SU 9b (dark brown, 7.5YR 4/2). These floors are made of raw earth and are composed of rounded balls with a coalescent arrangement.

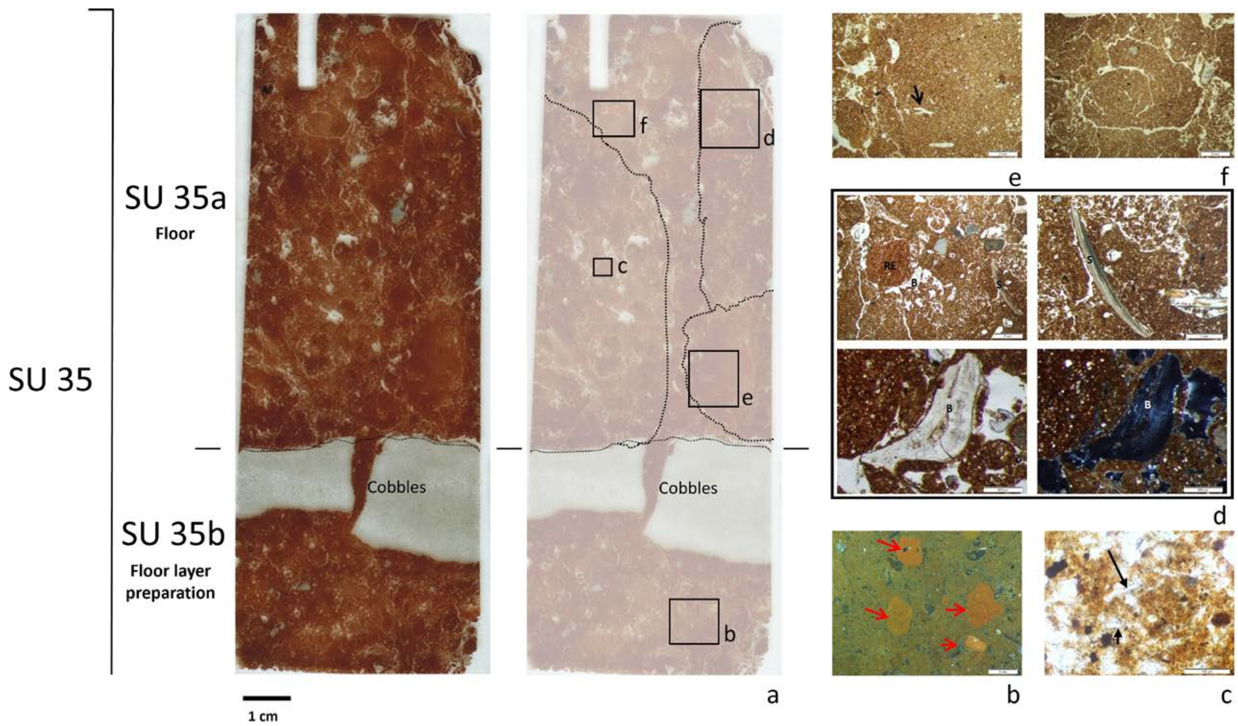

Figure 4. Floor preparation layer and floor (SU 35) from phase 2 (*c.* 1000–850 BC), rear area of the naveta. a) Transmitted light scan of SU 35 thin section. The floor (SU 35a) and the floor preparation layer (SU 35b) are indicated. On the right, the raw earth balls are partially visible (dashed lines). The location of the following images is shown. b) SU 35b, raw earth microaggregates in groundmass (red arrows) (OIL). c) SU 35a, silica phytoliths included in the groundmass inside the ball (arrows) (PPL). d) SU 35a, anthropogenic components used as tempering agents such as raw earth microaggregate (RE), bone (B) and shell (S). Detail of bone (B), in PPL and XPL, and shell (S) in PPL; e) SU 35a, detail of arrow pointing to a moldic void typical of a plant debris (PPL). f) Subrounded raw earth aggregate with a curvilinear fissure and partially convolute morphology, *colombin* (PPL).

Three balls were partially located in SU 35a (Figure 4a) and four in SU 9b (Figure 5a), with dimensions ranging from 2.5 to 5 cm, resting directly on cobbles. In SU 35a, the balls rest on the cobbles of the floor preparation in SU 35b, while in SU 9b they rest on the stone floor of SU 15 from the previous phase, which facilitates the construction of the floor.

These balls consist of clayey silts with fine sands, exhibiting a massive microstructure with some vesicles and fissures. They are formed by partially accommodated raw earth microaggregates containing some anthropogenic components, all of them reused, such as bones—appearing pale yellow in PPL and isotropic in XPL, with fissures—shells and silica phytoliths, especially in SU 35a (Figures 4c and d). Some microaggregates appear with moldic voids from plant remains (Figure 4e), while others exhibit fissures. A subrounded raw earth aggregate with a curvilinear fissure and a partially convoluted morphology, known in French as *colombin*, was also identified in SU 35a (Figure 4f).

The main difference between SU 9b and SU 35a lies in the greater presence of reused raw earth microaggregates in the former. The groundmass also consists of clayey silts with a noticeable increase in fine sands; notable, some cobbles appear in the centre of one of the balls, acting as a core around which the raw earth material was organised (Figure 5a). Some of the cobbles also show thermoalteration traces.

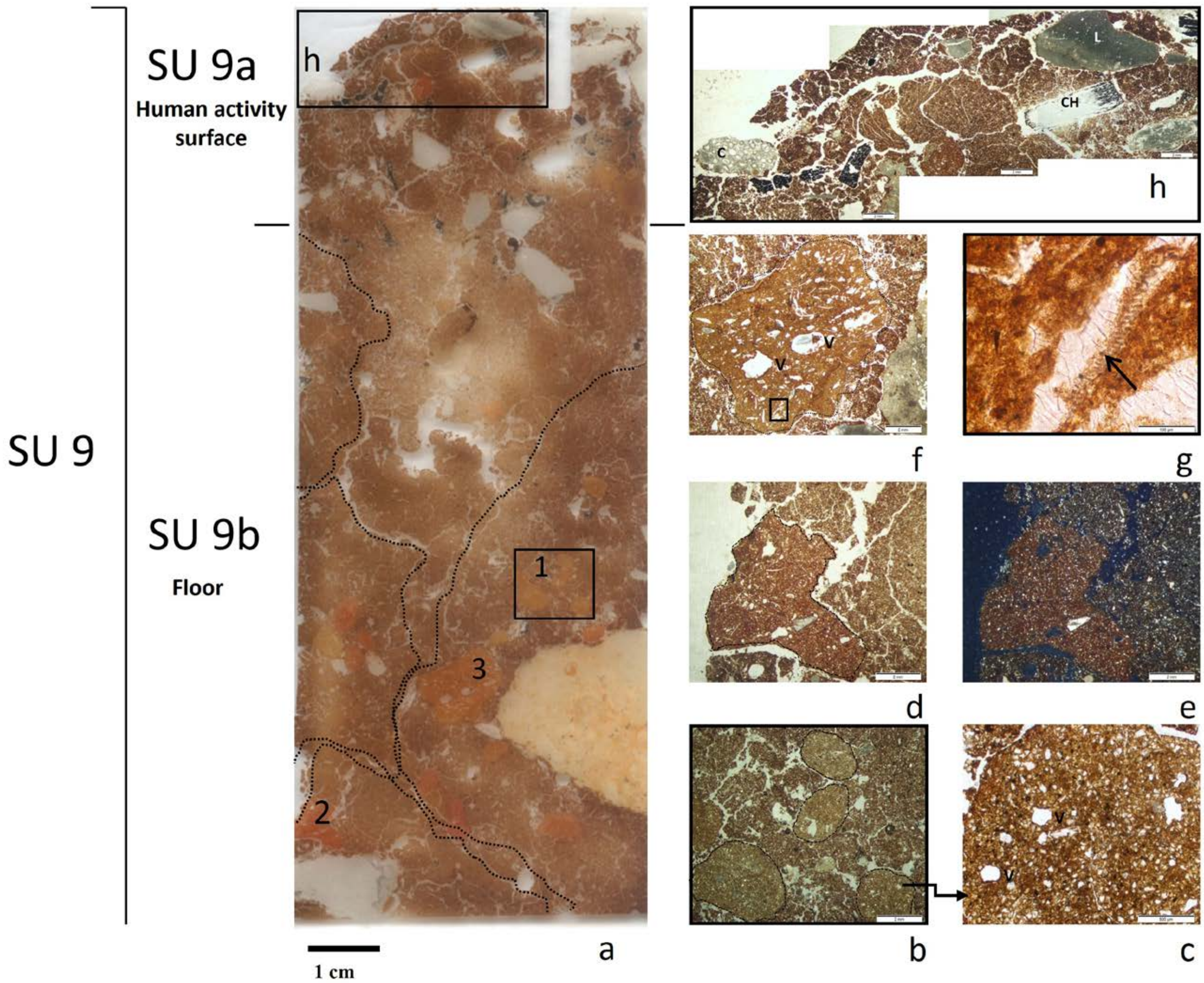

Figure 5. Floor and Human activity surface (SU 9) from phase 2 (*c*. 1000–850 BC), front area of the naveta. a) Transmitted light scan of SU 9 thin section. The human activity surface (SU 9a) and the floor (SU 9b) are indicated, in which the ball modelling is shown (dashed lines). b) Type I, raw earth microaggregates, number 1 in the black box in a). c) Type I, detail of raw earth microaggregate with some vesicles (V). d) Type II, raw earth microaggregate, number 2 in a) (PPL). e) Same as d) (XPL). f) Type III, raw earth microaggregate, number 3 in a). Vesicular voids (V) are observed (PPL). g) Detail of a moldic void with elongate dendritic phytoliths (grasses) (arrow), in the black in f). h) Detail of the human activity surface, active zone (SU 9a). Charcoal remains (CH) and the detrital fraction, calcarenite (C) and limestone (L) show an oriented and horizontal distribution. It appears with horizontal and vertical fissuring denoting strong compaction, possibly due to trampling, in the black box in a).

Among these raw earth microaggregates, three types have been distinguished according to their porosity and texture:

Type I: Composed of clayey silt with a predominance of fine sands, not very porous (< 5%), with some vesicles and/or moldic voids, generally massive, with a subrounded morphology. It is the most frequent and can be distinguished from the groundmass of the unit by a decrease in very fine material and a lighter colour (Figures 5b and 5c).

Type II: Consists of reddish silty clays with sands, some of which are coarse to medium-sized limestones with increased vesicular and moldic voids. Subrounded to subangular morphology (Figures 5d and 5e).

Type III: Predominantly silty clays with a dominance of vesicular and moldic voids (Figure 5f), in some of which elongate dendritic phytoliths (ICPT, 2019) are observed (Figure 5g), with coatings and hypocoatings of fine material in the voids, mainly in the vesicles, and with orthic nodules of Fe oxides and hydroxides. This type is not very frequent in the sequence analysed.

The second and third types are both characterised by a predominance of clay and higher porosity, both in vesicles and moldic voids, although they differ appreciably from each other due to the increase sandy fraction in the former.

The raw earth aggregates documented during the archaeological interventions could also fall into two of these categories. Those from SU 36 would belong to the second type (Figures 6a, 6b and 6c), as well as those from SU 9 (Figures 6d, 6e and 6f). Conversely, those belonging to SU 35 (Figures 6g, 6h and 6i) and SU34 (Figures 6j, 6k and 6l) belong to the Type III. In the latter, the possible imprint of the plant remains to which it would be attached can be seen.

Human activity surface

This microfacies is shown in SU 9a and has a thickness of 3 cm. While it does not differ from the groundmass of SU 9b, there is an increase in human-made debris, such as fragmented woody charcoal remains (possibly hardwoods), as well as bone (yellow in PPL and isotropic in XPL) and possibly bivalve and gastropod shell fragments. The coarser components appear horizontally oriented with horizontal and vertical fissuring denoting strong compaction, possibly due to trampling, giving rise to a platy microstructure with a tendency towards granular. There are also some rounded raw earth microaggregates with very little porosity (Figure 5h).

Raw earth building material

This microfacies is represented by SU 34. It is composed of clayey silts with fine brown sands (7.5YR 4/4), featuring fissures and some moldic voids. It contains several reused raw earth microaggregates, mainly consisting of reddish silty clays with sands and vesicular and moldic voids, as well as some bone with the same optical characteristics as described above, small-sized charcoal residues and anorthic $CaCO_3$ nodules. All of them are very well arranged and coalescent, with most exceeding 4 mm in size. There is no evidence of significant hydration of the material. Notable pedofeatures include calcitic hypocoatings in the voids, similar to those in SU 37, linked to root activity.

These characteristics represent a raw earthen building material and differ from the others described so far in that the anthropogenic components act as a temper and are tightly bound together within the fine material.

Soil horizon formation (pedogenesis)

SU 33 has the same groundmass as the previous units with some cobbles, but it is distinguished by a significant increase in amorphous organic matter, which results in a dark brown colour (5YR 4/2). The microstructure is granular and channel-like. There are also remains of gastropods, bones, raw earth microaggregates and flint fragments.

SU 33 is strongly influenced by the sub-current and recent pedological activity, especially by the high organic matter content, which imparts the characteristic features of an A horizon soil.

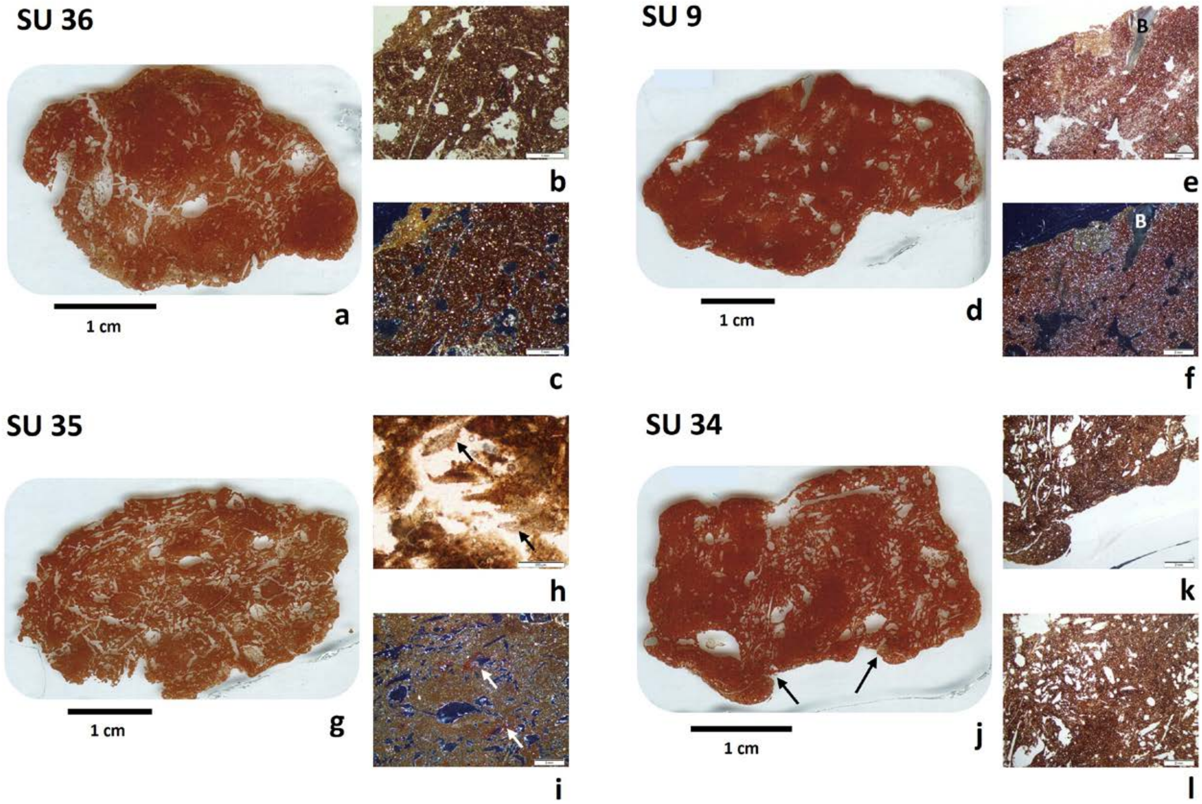

Figure 6. Raw earth aggregates from different SUs. a) Transmitted light scan of SU 36: b) **r**eddish silty clays with sands with vesicular and moldic voids (PPL) and c) (XPL). d) Transmitted light scan of SU 9: e) detail of the groundmass with some possible burned bones (B) used as temper (PPL) and f) (XPL). g) Transmitted light scan of SU 35: h) **d**etail of the interior of a moldic void with elongate dendritic phytoliths (grasses) by arrows (PPL) and i) detail of the groundmass with a predominance of silty clays with clay hypocoatings in voids, indicated by arrows (XPL). j) Transmitted light scan of SU 34. A possible imprint of a plant remains can be observed (arrows): k) detail of j) (PPL) and l) moldic voids indicating the addition of plant remains (PPL).

Discussion

Raw earth construction techniques

One of the direct modelling construction techniques identified in Naveta I is the use of cob balls, especially in the floors. This technique consists of a mixture of earth and water, to which different tempers can be added, applied in a wet state and with different forms of lumping (Knoll *et al.* 2019). At Closos de Can Gaià, this is evident by more or less spherical and coalescent balls. These forms were made by hand and placed side by side while still wet. They are formed by clayey silts with coarse fraction—in the case of SU 9b, gravels and cobbles—and with anthropic elements such as charcoal, bones, microaggregates of raw earth, likely reused from earlier construction materials or occupation soils. In this case, they are characterised by a moderate homogenisation and hydration of the material, which in the case of the bones is reflected in the subrounded contours and the pale yellow colouring in PPL, a result of water-mediated effect (Hedges and Millard 1995). The contours of the balls are defined by fissures. In the case of SU 35a, a microaggregate identified as a *colombin* is visible in cross-section, in which a cylindrical pattern can be distinguished, typical of the raw earth rolling (Onfray *et al.* 2020).

Table 1. Micromorphological description of Naveta I at Closos de Can Gaià. Class frequencies (after Bullock *et al.* 1985; Stoops 2021): * very few (< 5 %); ** few (5–1 5%); *** frequent (15–30 %); **** common (30–50 %); *****dominant (50–70 %); and ****** very dominant (> 70 %). Class abundance of pedofeatures after (Bullock *et al.* 1985): + rare (< 2 %); ++ occasional (2–5 %); +++ many (5–10 %); ++++ abundant (10–20 %); and +++++ very abundant (> 20 %).

Microfacies Type	SU	Microstucture	Groundmass	C/f rel. distr. Pattern	Coarse material		Micromass	Pedofeatures
	(Sample, profile)				Rock fragments	Org. and inorg. frag.		
Quaternary substrate	37 (S.5, profile 3)	Subangular blocky and granular. 10% porosity (compound packing, channels and fissures voids).	c/f 50 µm 1/3	Single spaced porphyric	Calcarenite, micritic and bioclastic limestone (subrounded and subangular). Red clays nodules.	Organic material/ charcoals (**) from 50 to 200 µm and some bone with traces of dissolution.	Brown/red (PPL), clays. Speckled b-fabric.	Traces of dissolution in limestone fr.(+); orthic nodules of Fe (hydr) oxides (++); calcitic hypocoatings in voids (+++) and faecal pellets and passage features (++).
Floor layer preparation	36 (S.5, profile 3)	Granular/channels 20% porosity (compound packing and channels).	c/f 50 µm 1/3	Single spaced porphyric	Micritic and oolitic limestone (subangular and subrounded).	Organic material/ charcoals(**), bones (*), earth raw aggregates (*), pottery (*) and flint (*) with a random arrangement.	Brown/red (PPL), clays. Crystallitic calcitic and speckled b-fabric.	Traces of dissolution in limestone fr.(+); faecal pellets and passage features (++).
	35b (S.2, profile 1)	Granular. 25% porosity (compound packing voids and fissures).	c/f 50 µm 1/2	Single spaced porphyric	Calcarenite (subangular). Cracked gravels with opaque colouration in PPL and isotropic zones in XPL.	Earth aggregates with combustion traces with a random arrangement.	Light brown (PPL). Calcitic crystallitic b-fabric.	Orthic nodules of Fe (hydr)oxides (++); loose continuous and discontinuos infilling of channel by ellipsoids faecal and passage features(+++).
Floor	35a (S.2, profile 1)	Granular/massive. 15 -20% porosity (complex packing voids, compound packing voids, vesicles and fissures).	c/f 50 µm 1/2	Single spaced porphyric	Calcarenite, micritic and oolitic limestone (subangular and subrounded).	Charcoals (**), bones (*), phytoliths (*) and shell fr. and earth aggregates (***). Homogeneous distribution of components.	Brown (PPL). Calcitic crystallitic b-fabric.	Calcitic hypocoatings in voids (+); calcitic and fine material coatings in voids (+); orthic nodules of Fe (hydr)oxides (+); loose continuous and discontinuos infilling of channel by ellipsoids faecal and passage features(++++).
	9b (S.4, profile 3)	Complex/massive. 20% porosity (complex packing voids).	c/f 50 µm 1/3	Single spaced porphyric	Calcarenite, oolithic and micritic limestone (subangular and subrounded). Some cobbles with traces of Fe (hydr)oxides.	Subrounded earth aggregates (*****). Homogeneous distribution of components.	Light dark brown (PPL). Calcitic crystallitic b-fabric.	Fine material hypo/ coatings in aggregates (+); orthic nodules of Fe (hydr)oxides (+); loose continuous and discontinuos infilling of channel by ellipsoids faecal and passage features(++).
Human activity surface	9a (S.4, profile 3)	Platy/granular. 15% porosity (planar, fissures and compound packing voids).	c/f 50 µm 1/3	Single spaced porphyric	Calcarenite, oolithic and micritic limestone (subangular and subrounded).	SU 9a: woody charcoals (***), pale yellow bones (*) in PPL and isotropes in XPL, and bivalve and gastropod shells (*) and subrounded earth aggregates (**).	Light dark brown (PPL). Calcitic crystallitic b-fabric.	Orthic nodules of Fe (hydr)oxides (+); loose continuous and discontinuos infilling of channel by ellipsoids faecal and passage features(++).
Raw earth building material	34 (S.3, profile 2)	Massive/granular. 10% porosity (Compound packing voids).	c/f 50 µm 1/3	Single spaced porphyric	Subrounded micritic limestone.	Bones (*) and earth aggregates (***), anorthic nodules of CaCO3(**).	Brown (PPL). Calcitic crystallitic / Speckled b-fabric.	Calcitic hypocoatings in voids (+++); loose continuous and discontinuos infilling of channel by ellipsoids faecal and passage features (++).
Soil horizon formation (pedogenesis)	33 (S.1, profile 1)	Granular/channel. 25% porosity (Compound packing voids and channels).	c/f 50 µm 1/3	Single spaced porphyric	Calcarenite, oolithic and micritic limestone (subangular and subrounded).	Shell fr (*) and some gastropod. Earth aggregates (**), amorphous organic matter (***) and flint (*).	Dark brown (PPL). Undifferentiated b-fabric / Calcitic crystallitic b-fabric.	Loose continuous infilling (++++) and roots (++).

From both an archaeological and ethnographic perspective, the use of this technique has been documented in a wide range of constructions, such as walls, wall coverings and platforms, though it is less common in the construction of floors (Carbonell-Roca 2024; Wattez *et al.* 2018). This method has been documented micromorphologically at various prehistoric and protohistoric sites, mainly in wall construction contexts, such as the Neolithic sites of La Capoulière (Languedoc-Roussillon, France) (Wattez 2009) and Klimonas (Cyprus) (Mylona *et al.* 2017; Mylona *et al.* 2023), as well as at the protohistoric site of Lattara (Lattes, France) (Roux and Cammas 2010). It has also been identified in the construction of floors at Neolithic sites in France, such as Buchères (Aude) and Bois d'Adrien (Indre-et-Loire) (Wattez *et al.* 2018). Furthermore, this technique has been recognised in areas used for the production of raw earth in the form of balls at the Iron Age site of Vilars d'Arbeca (Lleida, Spain) (Carbonell-Roca 2024; Carbonell-Roca *et al.* 2024). This type of modelling has also been documented macroscopically at the Middle Bronze Age site of Caramoro I (Elche, Alicante) (Pastor *et al.* 2018), among other Bronze Age sites in the southeast (Pastor 2021).

In all cases, the same *chaîne opératoire* is used, which, in summary, consists of kneading hydrated sediment, shaping elements with a tendency towards a circular morphology—or, in the case of the Buchères and Bois d'Adrien soils, a quadrangular morphology—and placing them in a wet or partially dry state, as evidenced by the micromorphological indicators observed.

Another form of modelling distinguished in Closos is the one observed in some reused microaggregates (Type I in section 4.3), also found in SU 36 and SU 9a. While its specific nature is difficult to specify, it may represent direct modelling in which there is a dominance of mineral temper with little porosity, potentially related to the manufacture of furniture elements within the naveta.

A further construction technique seen through localised microaggregates is wattle and daub; a mixed technique in which both raw earth and plants are used (Knoll *et al.*, 2019). It is used as lining and/or reinforcement of plant-framed structures such as walls, partitions or roofs, generally made with clayey sediments and with abundant plant temper (Carbonell-Roca 2024; Mateu 2016; Mateu *et al.* 2022; Matthews 2010). At Closos, we found two types of microaggregates (Type II and Type III, in section 4.3), possibly related to this technique. Although in both the clay fraction is dominant, they differ in the stabiliser used: one shows an increase in the sandy fraction (mainly quartz) and therefore it acts as a mineral temper, while the other is dominated by vegetal temper which, according to the phytoliths found, corresponds to grasses. For the moment, this type of material has been interpreted as part of the Closos roofing and, due to its clayey composition, its origin likely lies in the *terra rossa* soils near the settlement (Albero-Santacreu and Garcia-Amengual 2010).

Traces of occupation in the archaeosedimentary record

From a microstratigraphic point of view, human occupation is evidenced by specific activity surfaces and the presence of localised anthropogenic components.

Occupation surfaces

An occupation surface was identified in SU 9a, related to floor SU 9b. It is situated in the front area, before the naveta, and dates to Phase 2 (*c.* 1000–850 BC). This surface is characterised by the presence of trampling traces typical of the active occupation zone (Gé *et al.* 1993; Macphail and Goldberg 2018). These are represented by sub-horizontal fissural porosity, creating a platy and even granular microstructure. The associated anthropogenic components also exhibit a sub-horizontal orientation and slight fragmentation, further indicating the effects of trampling (Matthews *et al.* 1997). These results are consistent with pollen analysis, also pointing out the abundance of trampling-tolerant taxa in this archaeological level (Picornell-Gelabert and Servera-Vives 2017). The anthropogenic components consist of remains from domestic activities such as woody charcoal, bones, gastropods and possibly bivalve shells.

In contrast, floor SU 35a, located in the rear area of the naveta and contemporary with SU 9b, preserves only the floor itself and would represent a passive area of the occupation; that is, no anthropogenic components associated with domestic activities were observed (Gé *et al.* 1993; Macphail and Goldberg 2018). The absence of an active area (i.e., the occupation surface with its anthropogenic components) could be due to several factors: intense sweeping of this area, which would indicate intensive activity; intentional lowering; or, possibly, post-depositional processes that have affected this surface.

Anthropogenic components

Except for the components located on the occupation surface (SU 9a), all the others appear as a result of their reuse as part of the raw earth temper used in the floors (SU 9b, SU 35a), in other raw earth building material (SU 34), as well as in the floor preparation (SU 35b and SU 36).

Most of these components may come from different domestic activities, including bones, charcoal fragments, malacological remains, phytoliths (especially in SU 35a), some ceramic and flint fragments (particularly in SU 36) and the raw earth microaggregates (located mostly in SU 35a and SU 9b), likely reflecting a greater abundance of this construction material in Phase 2.

Detrital carbonate material has also been found, especially in SU 35b, in the form of gravels with traces of high-intensity combustion, above 700 °C, and possibly with subsequent rewet and recarbonation (Canti 2017). The temperature reached suggests that its origin is more likely to be from combustion, potentially related to specific technological activities.

Constructive evolution of the Naveta I of Closos de Can Gaià

Over the long period of time between the construction and abandonment of the naveta—approximately 700 years (Javaloyas *et al.* 2011)—significant changes can be observed through the microstratigraphic record. These findings complement the overall study of the site and even raise new working hypotheses for future archaeological interventions in other navetas at Closos de Can Gaià.

The Cyclopean construction, as well as the internal structure of the naveta, dates to around 1550 BC. From this first phase, SU 36 has been located, which would have acted as a floor preparation layer. It is made up of detritic material, homogeneous with that of SU 37 of geogenic origin, but with an increase in small anthropogenic components such as bones, flint, subrounded pottery and some microaggregates of raw earth. They are chaotically arranged, which suggests that this may have been an intentional dump-type accumulation. The presence of raw earth indicates its use as a material in domestic architecture of the naveta; however, the scarcity of components in the SU 36 thin section makes it difficult to fully assess the technology used. Since the wattle and daub technique can be seen in the aggregates recovered during the archaeological intervention, we can deduce that this technique was used in the phase 1 of Closos (*c.* 1550–1000 BC).

Directly above this layer there was the stone floor (SU 15), made up of irregular, more or less flat stone slabs of small to medium size, fitted together and levelled with wedges to create a uniform and homogeneous appearance, mainly in the eastern area of the naveta (Javaloyas *et al.* 2007).

From the second phase (*c.* 1000–850 BC), in the peak of the Late Bronze Age, a technological change in building materials took place:

- A diversification of handmade raw earth construction can be observed: the wattle and daub and the cob balls technique.
- The cob balls technique is clearly introduced, especially documented in the floors, using the raw earth kneading in the form of more or less spherical balls, probably made within the settlement itself.
- The use of stone is involved in the construction but plays a more secondary role. In our case, it can be seen that it is part of the floor layer preparation. SU 35b is characterised by a dump-type detrital accumulation, the same as in SU 36, and towards the top, there are some cobbles that fit together to form the base on which the SU 35a floor will rest. On the other hand, floor SU 9b rests precisely on the stone floor of the previous phase. From this, we can deduce that the cobbles or stone floor represented a support base for the earthen kneading of the floor.

Focusing on the studies of the naveta, it has been interpreted that during this phase, the interior no longer functions as a communal or public area, unlike in the previous phase; although there is a transversal wall that more forcefully delimits the exterior from the interior space (Javaloyas *et al.* 2011).

Despite being contemporary, there are differences between the front area of the naveta (SU 9) and the rear area (SU 35), as mentioned above. The fact that perhaps the active zone of the occupation (SU 9a) was located in the front may be because, as an outward passage zone, sweeping may have been less frequent than in the rear area (SU 35a). The latter likely hosted more intensive domestic activity, such as sleeping or resting, requiring more frequent cleaning.

Finally, around *c.* 850 BC, archaeological data indicate the abandonment of the naveta, eventually leading to the roof collapse. In this study, this stage is reflected in two units: SU 34 and SU 33. In SU 34, very massive raw earth building material is observed, which could correspond to a building construction element or part of the roof. Traces of abandonment are evident, especially due to the growth of roots in this same unit, which increases in SU 33 with the formation of a type A soil horizon, from amorphous organic matter. This sequence supports the hypothesis of a progressive abandonment of the site, where the growth of vegetation would have been mixed with the more residual activities of this phase.

Conclusions

The microstratigraphic analysis of Naveta I at Closos de Can Gaià allowed us to determine the importance of the raw earth building materials within the settlement and most probably within Cyclopean architecture as a whole. This study also revalues their complementary use together with stone in these constructions.

The use of raw earth through direct modelling has been found in the phase 1, *c.* 1550–1000 BC, although not very abundantly. In contrast, in the second phase, *c.* 1000–850 BC, raw earth construction becomes more important and probably even more than the use of stone, as far as the internal construction of the naveta is concerned. In fact, the floors are built and made using the cob ball technique, a system already documented across the Mediterranean since Recent Prehistory (Wattez *et al.* 2018). Materials made using the wattle and daub technique—which due to its characteristics makes us consider its use for the infilling of reed and branch frames—are also further consolidated (Friesem *et al.* 2017). In this context, the use of plant material, including both herbaceous and woody, for architectural strategies at Naveta I was documented by macroscopic observation (Garcia-Amengual 2014).

A significant challenge in the characterisation of these earth construction materials has been the postdepositional activity, especially biological, both of the roots and the soil fauna, which accentuates their degradation, typical of temperate regions with certain environmental humidity.

In summary, we believe that micromorphological analysis remains an indispensable tool for in-depth study of anthropogenic sediments such as building materials, their implications for floors and their occupation. This approach has allowed us to document various construction techniques that were imperceptible during fieldwork and macroscopically, thereby reinforcing the need to implement such studies to complement, together with other disciplines, our knowledge of navetiform constructions during the Bronze Age in the Balearic Islands.

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Rare Earth Elements Marking Anthropic Soil Development at the Geoglyphs of Acre (Brazil)

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Abstract: In the western Brazilian Amazon region, in the state of Acre, several earthen structures called 'geoglyphs' have been found. Questions involving the use, extent and geographic distribution of these earthen structures have been investigated by several researchers for about two decades. The first excavation carried out by our team (2022) in the Reserva Extrativista Chico Mendes (RESEX) showed that the archaeological material is limited to a few ceramic sherds and palaeobiological remains. The aim of this study is to test for the first time the potential of rare earth elements to provide proxies for identifying layer development and for distinguishing human-related activities in soil sample sections from two excavated geoglyphs located in RESEX. Forty-five sediment samples were collected from the Antonio y Felipe and Pedro y Nelida geoglyphs. Rare earth element concentrations, together with major elements and cross-referenced with the archaeological record, show that geochemical information can potentially become a complementary tool to better understand the human contribution to the stratigraphic formation in these contexts.

Keywords: Rare earth elements, geoglyphs, chemical elements, earthen structures, soils, Brazilian Amazon.

Resumen: En la región amazónica occidental de Brasil, en el estado de Acre, se han encontrado varias de esas estructuras de tierra que se denominan geoglifos. Las cuestiones relativas al uso, la extensión y la distribución geográfica de estas geoformas arqueológicas han sido investigadas por alrededor de dos décadas. La primera excavación, realizada por nuestro equipo en 2022 en la Reserva Extractivista Chico Mendes (RESEX), mostró que los materiales arqueológicos se limitan a unos pocos fragmentos de cerámicas y restos paleobiológicos. El objetivo de este estudio es probar por primera vez el potencial de los elementos de tierras raras como proxies para identificar el desarrollo de capas y distinguir las actividades humanas relacionadas en la muestra de suelo de los dos sectores excavados en RESEX. Se recogieron 45 muestras de sedimentos de los geoglifos Antonio y Felipe, por un lado, y Pedro y Nélida, por otro. La concentración de elementos de tierras raras junto con los elementos principales recogidos del registro arqueológico muestra que la información geoquímica puede potencialmente convertirse en una herramienta complementaria para comprender mejor la contribución humana a la formación estratigráfica en estos contextos.

Palabras clave: Tierras raras, geoglifos, elementos químicos, estructuras de tierra, suelos, Amazonía brasileña.

Introduction

Earthen structures were built by Neolithic and Copper Age populations in a wide variety of contexts and chronologies from the 6th millennium BC onwards. Several studies have focused on the origin and function of these remains, proposing different hypotheses (Bernabeu *et al.* 2006; Erickson *et al.* 2008; Shaan *et al.* 2012). Some authors support the idea that the shortage of stone in the environment could have given rise to the construction of these ditches; others suggest that the construction was of social significance, in memory of certain people or events of collective importance, or perhaps a manifestation of respect and/or gratitude to their divinities or ancestors. Further hypotheses relate to astronomical concepts, physical and/or symbolic delimitation, or diverse functions such as settlements, ceremonial centres, megaxylic graves and social power management. Practical purposes, such as drainage, irrigation channels or animal husbandry, have also been posited, alongside potential defensive roles.

The Amazon area is characterised by the presence of earthworks initially named ‘geoglyphs’ by the researchers due to the apparent resemblance to the Peruvian geoglyphs of Nazca. These earthen structures have been identified in a wide geographical area, showing the ability of ancient populations to manipulate their surroundings, significantly modify the natural environment and create a long-term landscape. The geoglyphs are primarily found in the western and south-western Amazon (Peripato *et al.* 2023; Prümers *et al.* 2022), including the south-east and south-west of the current Brazilian states of Amazonas, Acre and Rondônia, as well as in the north-western area of Bolivia in the current territory of Beni, covering a region approximately 600 km in length.

This work is focused on the Acre State region (Figure 1), where more than four hundred earthen sites have been identified in deforested areas (Erickson *et al.* 2008; Rampanelli 2016; Schaan *et al.* 2012). Our case studies are located within the Reserva Extrativista Chico Mendes (RESEX), a Brazilian national

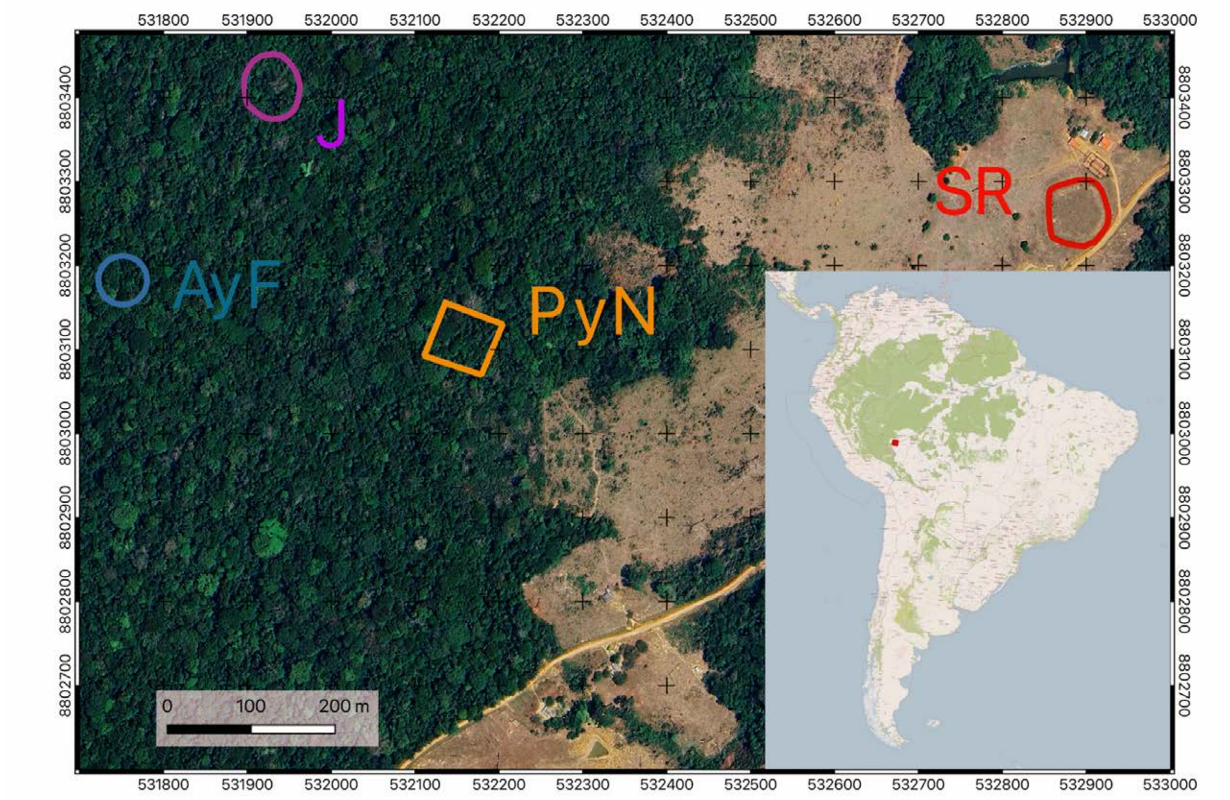

Figure 1. Area of study and sampling section location for the geoglyphs AyF and PyN.

reserve where several earthen structures, such as geoglyphs, have been identified, some of which are dated between 2500 BC and 1400 AD.

These structures are delimited by wide earthworks characterised by different shapes: circular, quadrangular, linear, elliptical and ellipsoid. Some lack a defined shape and are elementary or composed of two or three overlaid forms, either scattered or interconnected by roads or paths. These features are more easily identified through satellite imagery (Rampanelli 2016), having been hidden and covered by the Amazon rainforest for a long time (Peripato *et al.* 2023). Archaeological evidence, such as ceramics, lithic industries and bioarchaeological remains, has been discovered in some of the few already excavated earthen structures. However, questions concerning the functionality and origins of these earthworks remain unanswered, as previous studies have not been able to provide definitive conclusions about their history.

The aim of this study is to test, for the first time, the potential of rare earth elements (REE) to provide proxies for identifying layer development and for distinguishing human-related activities in sediment sample sections from two recently excavated geoglyphs located in RESEX.

REE are a group of seventeen elements with similar chemical properties, classified by the International Union of Pure and Applied Chemistry (IUPAC): lanthanum, the fourteen elements of the lanthanide series, scandium and yttrium. They are ubiquitously found together in geological deposits in measurable quantities. Chemical processes are known to modify REE ratios in sediments. REE analyses have been recently employed to help in the identification of anthropogenic deposits on archaeological sites by comparing the REE values from known anthropogenic stratigraphic units with layers with no evidence of human influence (Gallello *et al.* 2017; 2019a; 2019b; 2021; 2022; Selvaraj *et al.* 2024).

The data produced during these last years of research have shown the complexity of REE soil geochemistry and, at the same time, the potential of REE to clarify different archaeological issues. For example, REE results obtained in the African subtropical region of Konso (Ethiopia) showed that REE data, when compared with soil organic matter, organic carbon and fire markers, and cross-referenced with archaeobotanical and soil micromorphology data, provided significant information. The REE signatures detected stratigraphic differences defined through field observations and highlighted variations within the same deposits developed by both natural and anthropogenic activities (Gallello *et al.* 2019b).

Our studies confirmed the role of pH as a key driver, together with Fe-oxides and phyllosilicates (rich in silicon and aluminium), as well as carbonates and phosphates, in controlling REE abundances and fractionation. However, depending on the local environment, many other soil components, including organic matter, organic carbon and iron and manganese oxyhydroxides, can play an important role in controlling REE chemistry. The ability of REE to define stratigraphic layers not identified by other chemical elements and the geochemical processes influencing REE concentration make them excellent proxies for human activities in certain contexts, especially when compared with more soluble or mobile markers such as calcium, sodium, strontium and potassium (Gallello *et al.* 2021).

In the investigated geoglyphs, the archaeological record is poorly represented and natural chemical processes are predominant; therefore, to better understand the strata formation in the studied environment, REE parameters were calculated and cross-referenced with the obtained major and trace element data. Finally, a methodological approach based on REE geochemical processes and their drivers (minor and major elements) was developed for the interpretation of potential natural or anthropogenic activities carried out in each studied earthen structure and to identify the nature of the changing patterns. To conclude, the obtained soil data were cross-referenced with the scarce archaeological record composed of ceramic sherds and palaeobiological remains discovered during fieldwork.

Previous studies and working hypotheses

In the Brazilian state of Acre, where most of the earth deposits are located within structures delimited by ditches, the soils are typical of high-rainfall environments and the climatic conditions of tropical and subtropical areas. They are generally very deep, and have been identified as ‘argisols, cambisols, luvisols, gleysols, latosols, vertisols, plinthosols’ and ‘neosols’ (Bardales *et al.* 2010). The pH of the soils in the area is generally acidic, rich in silicon, aluminium and iron oxides (Wadt 2002). A preliminary study in Acre—carried out specifically at the geoglyphs of Severino Calazans, Jacó Sá, JK, Fazenda Atlântica and Cícero Cara de Pau—highlighted that the deposits of the earthen structures were located in the most ancient areas, where developed soils and degraded latosols and argisoils are found (Carmo 2012). The morphological description of the soils at the Fazenda Atlântica and Cícero Cara de Pau deposits enabled the identification of palaeosols with anomalous organic charcoal levels, changes in the texture of the natural characteristics and the presence of archaeological materials in surface and subsurface horizons (Carmo 2012). The soils at the Severino Calazans and Jacó Sá geoglyphs were extremely low in phosphorus. Samples collected in a dark brown soil layer presented a slightly higher concentration (18 mg/kg) compared with other samples collected in reddish layers. Carmo (2012) concluded in her study that the occupation and use of the structures were not of sufficient duration to produce high amounts of phosphorus in the soil under these environmental conditions, which are characterised by rapid nutrient cycling in plants, poor weather conditions and soil leaching. Alternatively, the nature of their use was insufficient to cause significant accumulation and subsequent decomposition of the organic material.

During the last decades, archaeobotanical studies in the Acre region have shed new light on the chronocultural context of the earthen structures. Studies carried out by Ranzi and Aguiar (2004) imply the possibility that these were built before the formation of the forest, when the Amazon consisted of savannah. Carmo (2012) found phytoliths in ceramic fragments, supporting the hypothesis that the ditches were constructed in a palaeoenvironment of grass and non-forest vegetation, very different from the current scenario. The analysed material demonstrated low levels of phytoliths, as shown by the morphotype identified as *bastonete* (Carmo 2012). These morphotypes are taxonomically related to the Poaceae family, which includes phytolith-producing grasses of wide geographical distribution. These data may support the hypothesis that this Amazon region was previously dominated by a relatively open landscape, such as pampas or savannah, with herbaceous plants, especially grasses (Carson *et al.* 2014). Some authors (Lui and Molina 2009) affirm that the region underwent a 'domestication of vegetation', causing significant changes in species distribution. Important changes in the ecology of the landscape included economic reorientations focused on the exploitation of specific plants and animals, including palms, fruit trees, edible roots and aquatic fauna. In addition, this domestication also reveals a heterogeneity associated with the use of plants (edible, medicinal, ritual and for manufacture), found mainly along the major rivers of the region and on the margins of their floodplains. Other evidence for this diverse exploitation is found in the ethnohistorical writings of Cristóbal de Acuña (1641), who described a very varied fauna and flora, emphasising a great variety of animals and food plants (bananas, guavas, pineapples, maize, cocoa and Brazilian chestnuts), as well as highly nutritious roots such as yucca and sweet potato, palms of various genera, coconuts, dates and medicinal plants. All this suggests that prehistoric populations exercised a powerful and continuous influence from the beginning of the Holocene, right to the present day. This conclusion supports the hypothesis that part of what today we see as a 'primary' forest was actually an anthropogenic landscape, the result of conscious or unconscious human management (human manipulation of organic and non-organic components of the environment) for thousands of years (Balée 2013).

Watling *et al.* (2018) suggest that the ancestors of the geoglyph builders were responsible for an intensification of landscape management around 4000 cal BP and a new type of inceptive niche construction in the region. They proposed that geoglyph construction practices created a landscape rich in resources such as palms; consequently, a greater concentration of resources emerged in these areas though a combination of crop cultivation and forest management. This hypothesis is supported by Iriarte *et al.* (2020), who carried out a LIDAR survey and observed distinctive architectural features. Their results suggest the possibility that following the geoglyph culture, the Amazonian region of Acre was not abandoned, but rather a new village-network system flourished. Saunaluoma *et al.* (2021), employing remotely sensed imagery and aerial vehicle surveys, obtained data suggesting that roads connected specific sites across the region. This highlights that in Acre terrestrial movement responded to archaeological evidence of villages interconnected by road networks, as already published by our team (Rampanelli *et al.* 2017). Souza (2022), studying the Acre geoglyph site of Tequinho, suggests that it was a cultural and religious centre, with its roads and paths acting as central elements for ritualistic ceremonies, as well as serving as landscape markers and boundaries.

However, challenging these cultural evolution interpretations, Pärssinen *et al.* (2020) recently provided new evidence of anthropogenic ash and charcoal accumulation in the Acre area dating back to *c.* 10,000 cal BP; furthermore, carbon isotope (δ13C) values suggested no significant changes in climate and vegetation during the Holocene. While Della Libera *et al.* (2022), also employing δ13C record, indicate an overall tendency towards a more humid tropical forest only during the last millennium. Nacimiento *et al.* (2022) collected palaeoecological records from lake sediments containing charcoal and from pollen analyses to understand how human land use affected vegetation during the early to mid-Holocene in the Western Amazon. The authors observed that significant vegetation changes were only found centuries to millennia after the initial human presence, suggesting that the earliest occupants of Amazonia exerted only a gradual change on the forest. The early human occupations across Amazonia occurred mostly in areas bordering savannahs, where fires were a part of the natural vegetation dynamics. In these regions, natural fires were common and cannot be distinguished from anthropogenic fires based solely on charcoal counts.

Alternatively, there are others who support the existence of a symbiosis between humans and the environment. Ponte and Szlafsztein (2022), investigating the dynamics and periodicity of special social events, assumed that over time these human groups in Western Amazonia, including the Acre region, became familiar with the natural characteristics of the region. This familiarity allows them to better understand the ecosystem dynamics, consequently selecting plant species and habitats with greater utilitarian potential for their livelihood. Analyses of the dynamics of socio-spatial events demonstrate that humans have always established relationships with nature through their organisational and productive capacities, the latter conditioned by the available technology. As humanity interacted with the Amazonian natural environment, their knowledge increased, enhancing the conditions that facilitated socio-productive stability. Maezumi *et al.* (2022) suggest that polyculture agroforestry and cultural burning persisted within this system throughout the Holocene.

Likewise, several scholars have focused on the structural characteristics, morphology and function of geoglyphs. For example, Saunaluoma (2014) systematically examined the functions of earthworks, proposing that their uses were as diverse as their architectural forms and that the functionality of their construction varied regionally. Based on the distribution and characteristics of archaeological deposits and features, earthworks in Bolivia appear to have served more diverse and practical functions, whereas the spatial organisation of sites in the Acre region seems to have been more closely associated with ritual activities.

Focusing on the Acre area, Saunaluoma (2014) identified a relatively uniform pattern of earth-engineering and a consistent distribution of cultural deposits across surveyed sites. Geometric earthwork sites typically comprise contiguous ditches and earthen bank structures in a variety of shapes, including circles, squares, rectangles, ellipses, octagons, and 'U' and 'D' forms, with circular and square enclosures being the most common. The best-preserved ditches were originally several metres deep (approximately 2–3 m), exceeding their depth at the time of survey. Individual structures range from a few dozen metres to as much as 400 m in diameter. Sites generally contain one or more distinct enclosures, varying in size and form. Roads frequently connect separate earthworks and link them to a broader network.

The overall density of cultural material—such as ceramics, found fragmented and eroded on the surface—is generally low at geometric earthwork sites, which may indicate that they functioned as non-residential public monuments serving surrounding communities. In some cases, the intentional deposition of ceramics has been documented at the base of ditches and on elevated areas near site entrances. These earthen structures may have functioned as repositories for offerings, potentially used exclusively during specific ceremonial activities conducted at these sites (Saunaluoma 2014).

From a structural perspective, Silva (2019) investigated the construction techniques of these monuments using geomorphological methods. The results indicate that the basal layer consisted of a mound composed of locally sourced material rich in clay and iron nodules, likely employed to reinforce and stabilise the structure. In contrast, the upper layers were constructed using coarser sediments, primarily silt and sand.

Taken together, the evidence presented in previous studies supports diverse hypotheses concerning the development and function of these earthen structures. This lack of consensus highlights the need for additional archaeological data and the application of complementary methodological approaches to better understand their construction, chronology and use.

Materials and methods

Soil samples were collected from the geoglyphs of Antonio y Felipe (AyF) and Pedro y Nelida (PyN), as aforementioned, located in the RESEX area (Figure 1). The earthen structures were discovered by Agustín Diez-Castillo and collaborators during the Hispanic-Brazilian research collaboration that has been active since 2017 (Diez Castillo *et al.* 2017; Rampanelli *et al.* 2017). AyF and PyN are located under the forest canopy and are protected under the jurisdiction of the RESEX. This is an area of high ecological value owned by the Brazilian state, where traditional land uses are allowed for both indigenous communities and traditional settlers (*serengueiros*), allowing for the establishment of a long-term archaeological intervention strategy not conditioned by private landowners. Both earthen structures have been selected for this study because their formal features are characteristic of the area; furthermore, they exhibit an optimal state of conservation and offer logistical advantages, such as the facility of obtaining permits, being within a federal reserve.

The geoglyph called Antonio y Felipe (AyF) is located at geographic coordinates 10.82657° S and 68.70950° W at its central point and has an approximate elevation of 287 m above sea level. It exhibited a circular plan with an approximate diameter of 65 m. The surrounding ditch had a width of 12 m and reached a maximum height of 4 m.

The other documented geoglyph is Pedro y Nelida (PyN). Its central geographic coordinates are 10.82717° S and 68.70581° W, with an approximate elevation of 277 m above sea level. It has a quadrangular plan with visible dimensions of 80 m along its major axis and 60 m along its minor axis. The surrounding ditch also measured 12 m in width and 4 m in height.

The first survey carried out showed that the archaeological material in these geoglyphs is very limited (Rampanelli *et al.* 2017), although some ceramic fragments were recovered, as well as palaeobiological remains, during fieldwork (August 2022).

Sampling

Forty-five samples of sediment were collected from two cross-sections at the geoglyph of Antonio y Felipe (AyF) and from two cross-sections at the geoglyph of Pedro y Nelida (PyN) (Table 1 and Figure 2). About 50 g of sediment were collected from each column from the bottom to the top, at 5 cm intervals. Concerning AyF, ten samples were taken from a cross-section at the bottom of the ditch (AyF2.01-10), characterised by reddish and silty-sandy soil; eight further samples were collected from a cross-section within the interior area (AyF3.01-08), characterised by reddish and silty-sandy soil with laterites. Regarding PyN, the samples came from an excavation in the upper inner area of the geoglyph: 17 from one of the main cross-sections (PyN2.01-17), characterised by reddish and silty-sandy sediments with presence of ceramic sherds and charcoal, and ten from a survey pit in the centre of the same area (PyN1.01-10), in which the sediments are clayey-sandy with laterites and charcoal. The ceramic material recovered from PyN2 is poorly preserved, showing extensive fragmentation and surface erosion, consistent with the preservation patterns commonly observed in ceramics associated with the Acre geoglyphs (Saunaluoma 2014).

Table 1. Sampling data.

Sample	Geoglyph	Location	Relative Depth	Sample	Geoglyph	Location	Relative Depth
AyF2.01	Antonio y Felipe	Bottom of the ditch	-2.60	PyN1.06	Pedro y Nelida	Upper inner area (survey pit)	-2.00
AyF2.02	Antonio y Felipe	Bottom of the ditch	-2.50	PyN1.07	Pedro y Nelida	Upper inner area (survey pit)	-1.90
AyF2.03	Antonio y Felipe	Bottom of the ditch	-2.40	PyN1.08	Pedro y Nelida	Upper inner area (survey pit)	-1.80
AyF2.04	Antonio y Felipe	Bottom of the ditch	-2.30	PyN1.09	Pedro y Nelida	Upper inner area (survey pit)	-1.70
AyF2.05	Antonio y Felipe	Bottom of the ditch	-2.20	PyN1.10	Pedro y Nelida	Upper inner area (survey pit)	-1.60
AyF2.06	Antonio y Felipe	Bottom of the ditch	-2.10	PyN2.17	Pedro y Nelida	Upper inner area	-1.60
AyF2.07	Antonio y Felipe	Bottom of the ditch	-2.00	PyN2.16	Pedro y Nelida	Upper inner area	-1.55
AyF2.08	Antonio y Felipe	Bottom of the ditch	-1.90	PyN2.15	Pedro y Nelida	Upper inner area	-1.50
AyF2.09	Antonio y Felipe	Bottom of the ditch	-1.80	PyN2.14	Pedro y Nelida	Upper inner area	-1.45
AyF2.10	Antonio y Felipe	Bottom of the ditch	-1.70	PyN2.13	Pedro y Nelida	Upper inner area	-1.40
AyF3.01	Antonio y Felipe	Inner area	-1.70	PyN2.12	Pedro y Nelida	Upper inner area	-1.35
AyF3.02	Antonio y Felipe	Inner area	-1.60	PyN2.11	Pedro y Nelida	Upper inner area	-1.30
AyF3.03	Antonio y Felipe	Inner area	-1.50	PyN2.10	Pedro y Nelida	Upper inner area	-1.25
AyF3.04	Antonio y Felipe	Inner area	-1.40	PyN2.09	Pedro y Nelida	Upper inner area	-1.20
AyF3.05	Antonio y Felipe	Inner area	-1.30	PyN2.08	Pedro y Nelida	Upper inner area	-1.15
AyF3.06	Antonio y Felipe	Inner area	-1.20	PyN2.07	Pedro y Nelida	Upper inner area	-1.10
AyF3.07	Antonio y Felipe	Inner area	-1.10	PyN2.06	Pedro y Nelida	Upper inner area	-1.05
AyF3.08	Antonio y Felipe	Inner area	-1.00	PyN2.05	Pedro y Nelida	Upper inner area	-1.00
PyN1.01	Pedro y Nelida	Upper inner area (survey pit)	-2.80	PyN2.04	Pedro y Nelida	Upper inner area	-0.95
PyN1.02	Pedro y Nelida	Upper inner area (survey pit)	-2.50	PyN2.03	Pedro y Nelida	Upper inner area	-0.90
PyN1.03	Pedro y Nelida	Upper inner area (survey pit)	-2.40	PyN2.02	Pedro y Nelida	Upper inner area	-0.85
PyN1.04	Pedro y Nelida	Upper inner area (survey pit)	-2.30	PyN2.01	Pedro y Nelida	Upper inner area	-0.80
PyN1.05	Pedro y Nelida	Upper inner area (survey pit)	-2.10				

Figure 2. Sampled sections for the Geoglyphs AyF (top) and PyN (bottom).

Multielement analysis

Concentrations of major, minor and trace elements, including REE (see Annex 1, Tables A1.1 and A1.2), were determined in the laboratory using portable X-ray fluorescence (pXRF) and inductively coupled plasma mass spectrometry (ICP-MS).

First, the sediment samples were air-dried and sieved to 2 mm. Then, the fine fraction was ground and homogenised using an agate mortar. The pXRF analysis was performed on the sieved samples (< 2 mm) using a Bruker S1 Titan spectrometer equipped with a Rh X-ray tube and a X-Flash® SDD detector. The Geochem-trace calibration was used to obtain Al, Si, K, Ca, Ti, Fe, Rb and Zr concentrations.

Trace element analyses were performed using a Perking Elmer NexION 2000 ICP-MS. Samples were digested in *aqua regia*, adding 1.35 mL of HCl and 0.45 mL of HNO_3 to 0.15 g of powdered sample in a glass tube, subsequently heated in a boiling water bath for about 40 min. Concentrations of Li, Be, V, Cr, Mn, Co, Ni, Zn, Sr, Mo, Cd, Ba, Tl, Pb, Bi, U, REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu), Sc and Y were determined in the solution. Further details regarding the analytical method can be found in Gallello *et al.* (2022). The NIM-GBW07408 soil certified reference material was analysed by both pXRF and ICP-MS to test the accuracy and precision of the analyses.

Data analysis

As a first test, the data obtained from the excavated profiles were explored to understand if REE are able to shed light on the function of the studied earthen structures, and to develop hypotheses regarding the identification of natural and anthropogenic layers. To do so, principal component analysis (PCA) was employed to explore the geochemical datasets, reducing the number of variables. PCA was carried out using all samples as observations and all elemental concentrations as variables. Variables were z-scored prior to the analysis.

Data analysis was carried out using R (version 4.4.1; R Core Team, 2024), employing the following R packages: factoextra (version 1.0.7; Kassambara and Mundt 2020), corrplot (version 0.92; Wei and Simko 2021) and ggplot2 (version 3.5.1; Wickham 2016).

Rare earth elements (REE) parameters

REE concentrations obtained from the analysed sediment samples were normalised, and ratios such as La_n/Yb_n, La_n/Sm_n and Sm_n/Yb_n were used to determine relative REE enrichment or depletion. Ce and Eu anomalies were calculated to evaluate differences between measured concentrations and those expected from neighbouring REE.

These anomalies are calculated, resulting from differential reactions associated with reduction-oxidation (Ce^{3+} or $^{4+}$ and Eu^{2+} or $^{3+}$), using formulae from Gallello *et al.* (2021), detailed below. Anomalies are considered positive or negative depending on whether the values are above or below 1, respectively. Finally, the fractionation (Gallello *et al.* 2019) of light REE (LREE: La to Nd), medium REE (MREE: Sm to Ho) and heavy REE (HREE: Er to Lu) was evaluated.

In order to calculate these ratios, normalised concentrations need to be used. In the formulae, these concentrations are written as 'X_n', corresponding to the normalised concentration of an element X by the Post Archean Australian Shale (PAAS) values reported by Taylor and McLennan (1985) as follows.

$$\left[X_n\right] = \frac{[X]_{raw}}{PAAS_X}$$

Where $[X]_{raw}$ corresponds to the concentration of the element X after ICP-MS analysis and $PAAS_X$ corresponds to the PAAS value of the element X.

Those normalised concentrations are then used to calculate anomalies and fractionation with the formulae as follows.

Anomalies from Gallello *et al.* (2021):

$$\frac{Ce_n}{Ce^*} \frac{Eu_n}{Eu^*}$$

$$Ce^* = \frac{La_n}{2} + \frac{Pr_n}{2} \text{and} Eu^* = \frac{Sm_n}{2} + \frac{Gd_n}{2}$$

Fractionations:

$$\frac{LREE}{HREE} = \frac{La_n}{Yb_n}; \frac{LREE}{MREE} = \frac{La_n}{Sm_n}; \frac{MREE}{HREE} = \frac{Sm_n}{Yb_n}$$

Correlations between REE and other elements were also tested to identify significant drivers (i.e., elements) affecting REE chemistry in the different materials. The interpretation of these results could potentially provide important information about the consistency of the mechanisms influencing REE chemistry in the studied sections.

Results and discussion

Data exploration

As can be observed in the score plot (Figure 3), samples from AyF and from PyN can be distinguished: most of the samples from PyN have higher scores along the positive PC1 axis and lower ones along the negative PC2 axis than those from AyF (except some samples from PyN2). It is worth noting that, considering the two geoglyphs, the samples collected from different cross-sections fall in different areas of the diagram. Indeed, samples from AyF2 (bottom of the ditch) have higher negative PC1 and positive PC2 scores than those from AyF3 (inner area). Similarly, samples from PyN2 (upper inner area) show higher PC2 scores and, in most of the cases, higher PC1 scores than those from PyN1 (upper inner area – survey pit).

The loadings plots for PC1 (Figure 3b) and for PC2 (Figure 3c) indicate the main features of the different classes of samples. Samples from PyN show higher levels of Al, Ti, Zr and Mo than AyF, while the latter show higher concentrations of K, Rb, Be, Co, Ni, Zn, Cd and Ba. For other elements, dissimilarities are fuzzier and involve inner differences between the cross-sections of each geoglyph. Concerning major element levels, we can observe that cross-section PyN2 has higher Si levels than the others, as well as low Ca ones, which in most of the cases remain below the limit of detection (see Annex 1, Table A1.1). On the other hand, PyN1 has the highest Fe concentrations. As regards trace elements, PyN1 shows the highest concentrations for V, Cr and Bi, and the lowest for Mn, while PyN2 has low amounts of Pb. Total REE levels (see Annex 1, Table A1.2) are lower in AyF2 and PyN2 than in the other columns of their respective geoglyph, although for PyN these differences are more blurred. The loadings for PC2 suggest that scores along this dimension are also influenced by REE fractionation. First, PyN is characterised by strong positive Ce anomalies, especially for lower strata of PyN2 (PyN2.02-07), compared to AyF. Light REE are enriched over HREE, but this enrichment is less intense in AyF3, while MREE enrichment over HREE is more intense in PyN than in AyF. On the other hand, LREE are not enriched compared to MREE in any of the columns, and Eu anomalies are not present.

Correlations among elemental concentrations and REE parameters in the four cross-sections are shown in Figure 4. The drivers for REE levels seem to vary slightly between geoglyphs and between columns

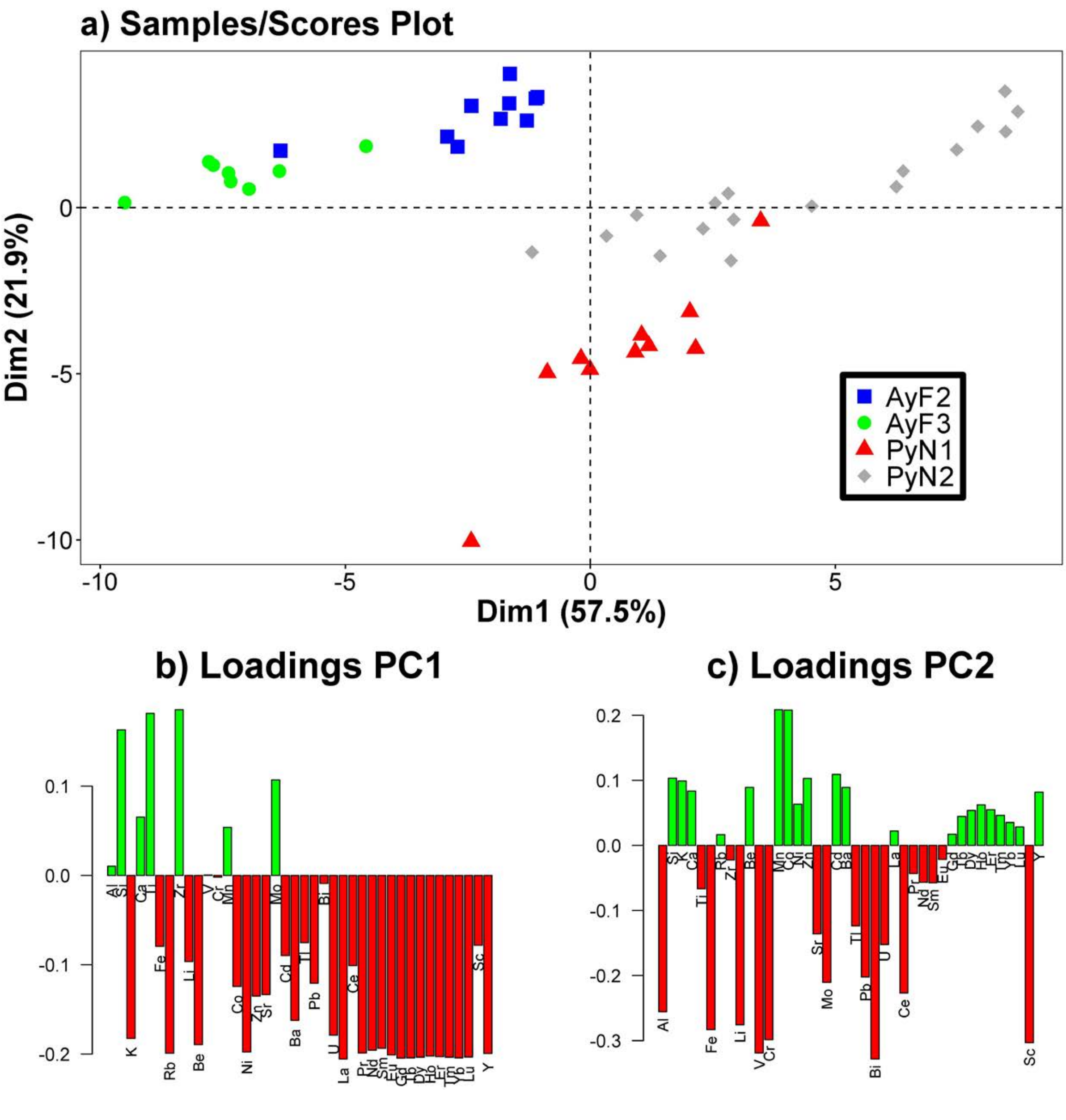

Figure 3. Samples/scores plot (a) of PCA and variables/loadings plots for PC1 (b) and PC2 (c).

within the same geoglyph. The total amount of REE (TREE) is positively correlated with Fe in all columns and with Sr in AyF2-3 and in PyN1. For PyN2 and AyF2, it shows a moderate positive correlation with K. In PyN2, levels of REE also seem to be driven by Al in the positive direction and by Si, Ca, Ti and Mn in the negative one. Ce anomalies have negative correlations with Fe for both PyN1 and PyN2, while they are moderately positively correlated with Mn for PyN2 and negatively for PyN1. In PyN2, they show strong positive correlations also with Si and Ti, while a moderate negative correlation can be observed with Al. No significant correlations have been found between the selected elements and the parameters for LREE enrichment in PyN1. On the other hand, La_n/Yb_n and La_n/Sm_n are correlated in a positive direction with Mn in AyF2, and the latter is negatively correlated with Fe. For AyF3, positive correlations can be observed between La_n/Yb_n and Sr, and between La_n/Sm_n and Ca. In PyN2, strong positive correlations

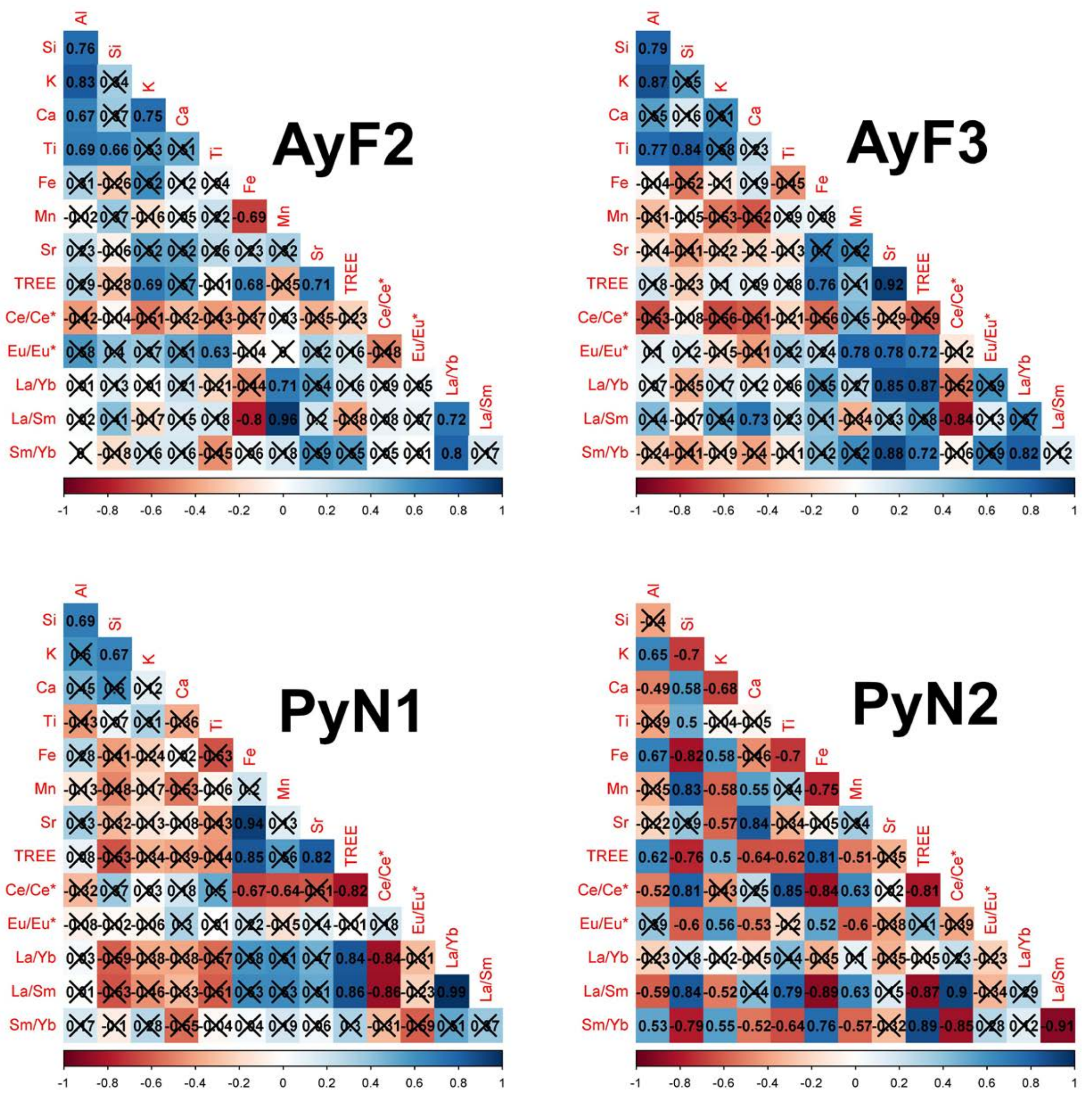

Figure 4. Pearson correlation coefficients (r) for REE parameters and elemental concentrations. Non-significant coefficients (p > 0.05) are barred.

are present between La_n/Sm_n and Si, Ti, and a strong negative correlation with Fe, while moderate correlations seem to be present with Al and K (negative) and with Mn (positive). Significant correlations for Sm_n/Yb_n were found only for AyF3 and PyN2. In particular, MREE enrichment over HREE is driven by Sr for AyF3, whereas it shows strong positive correlations with Fe and strong negative ones with Si in PyN2. In the same column, moderate positive correlations are present between Sm_n/Yb_n, and Al and K, and moderate negative correlations between this ratio and Ca, Ti and Mn.

Comparing the columns from the geoglyphs permits to better highlight some patterns. As can be observed in the boxplot graphs (Figure 5), the survey pit sediments (PyN1), which allegedly contain

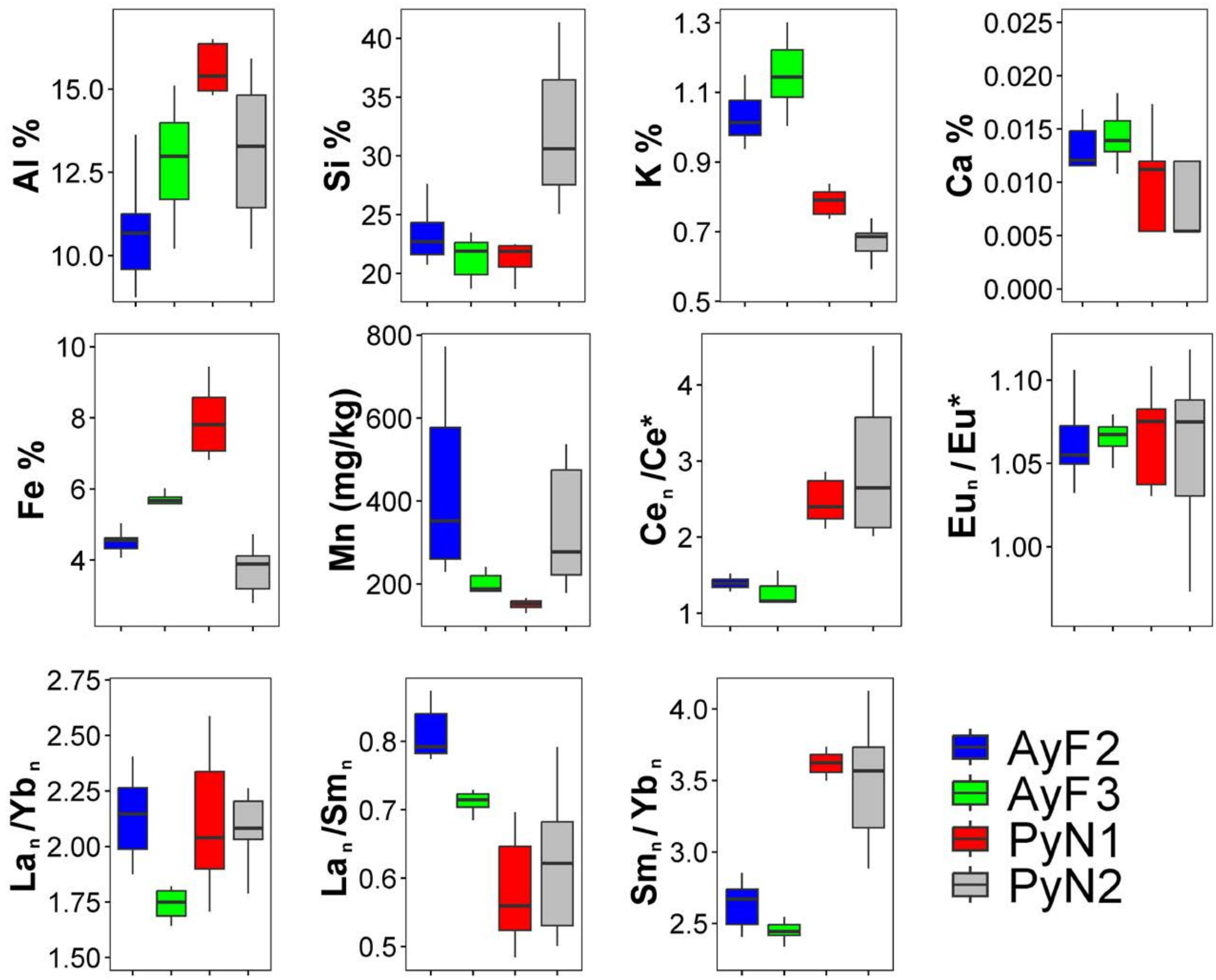

Figure 5. Distributions of elemental concentrations and REE parameters in the four columns (outliers were not considered).

natural strata, show the highest enrichment of Al and Fe and the lowest concentrations for Mn. In contrast, PyN2, an area where remains of human activities (ceramic sherds and charcoals) were found, has the highest levels of Si and the lowest of K and Fe. PyN2 also displays the levels with the highest positive anomalies for Ce and the highest positive enrichment of MREE over HREE.

REE chemical processes in AyF and PyN samples

These preliminary chemical data show that differences among geoglyphs and their related sections are probably based mainly on natural processes. However, some human-induced chemical processes have taken place and have contributed to strata formation.

The soils in the studied area are composed of reddish silty-sandy material and, as suggested by previous works, the pH of the soils in the area is generally acidic, and as confirmed by our study, it is rich in silicon, aluminium and iron oxides (Wadt 2002). The obtained data are also in accordance with those already observed in the soils of the geoglyphs of Severino Calazans and Jacó Sá low, which are poor in phosphorus (Carmo 2012).

In general, as already observed in Brazilian mangrove soils, REE depletion and fractionation are driven by clay minerals (Andrade *et al*. 2022). In our studied sections, natural soil samples from PyN1 (survey pit) show higher concentrations of REE, especially at the bottom of the pit, compared to most of the samples from PyN2, where archaeological material was found. This may be because REE are retained onto the clay mineral phases (Gallello *et al*. 2019), resulting in higher concentrations of REE in the PyN1. Furthermore, both geoglyph AyF and PyN sections present positive Ce anomalies, typical of clays rich in Fe (Pattan *et al.* 2005). However, AyF2 and AyF3 present higher levels of Sr and Ca than PyN, being those elements markers of carbonate phases (Gallello *et al.* 2019), and higher concentrations of K, maybe in this case related to the aluminosilicates, thus influencing the REE behaviour as reflected in the lower values of the Ce anomaly and Sm_n/Yb_n. Most of the samples present neutral Eu anomalies, possibly related to the dominance of silicates (Si and Al are the most abundant elements) in the studied soil fraction (Cuadro *et al*. 2023).

While AyF2, AyF3 and PyN1 chemical profiles are probably influenced by natural processes, PyN2, which is the only section related to ceramic sherds and charcoal, presents the highest Si concentrations. Given that Si levels are not correlated with those of Al, this is maybe related to the presence of phytoliths, as suggested by Carmo's (2012) work, which found them associated with ceramic fragments and/or authigenic amorphous silica and Si-rich clay minerals, possibly originating from the precipitation of biogenic silica from vegetal remains (Karkanas 2010).

These data suggest that Si in PyN2 could be related to human activities and, consequently, the REE concentrations, fractionations and anomalies employed could mark the human contribution to the soil formation and development. However, although ceramic fragments and charcoal have been found within these geometric earthworks, their function remains unknown. One possible explanation for the presence of these remains, following Saunaluoma (2014), is that those materials are associated with waste used for offerings during specific ritual practices.

Conclusions

Rare earth elements soil analyses have been employed for the first time in the geoglyphs of Antonio y Felipe and of Pedro y Nelida, located in the RESEX area. The obtained data show the potential of REE to identify anthropogenic deposits in a very complex environment and in sites with a scarce archaeological record.

The sediments from sections AyF2, AyF3 and PyN1 appear to be primarily controlled by natural sedimentary processes, suggesting that REE are preferentially retained within clay mineral phases. This retention likely explains the lower REE concentrations observed in PyN2 (with the presence of ceramic sherds and charcoals) compared to the other sections lacking such remains.

Moreover, PyN2 exhibits the strongest positive Ce anomalies and a marked enrichment of middle rare earth elements relative to heavy rare earth elements. The elevated Si concentrations in PyN2, which do not correlate with Al, may indicate the presence of biogenic silica derived from plant remains. This suggests that Si enrichment in PyN2 could be linked to anthropogenic inputs. Overall, REE concentrations, fractionation patterns and anomaly signatures in PyN2 likely reflect human influence on soil development and formation processes.

Finally, REE concentrations, fractionations and anomalies—cross-referenced with major and minor elements and archaeological record—provide innovative proxies for determining past human activities compatible with anthropogenic waste in the studied PyN earthwork, in line with the hypothesis that the geoglyphs located in the Acre state (Brazil), where those earth structures are frequently found, may have been used during ceremonial activities.

The potential of REE as a key tool for understanding the history of these archaeological remains needs further exploration. The obtained results have demonstrated the important role of REE in clarifying pivotal issues, such as the understanding of the human contribution to the development of archaeological strata in the studied area. However, this approach needs to be further optimised to reach a better comprehension of the anthropogenic activities in the earthen structures employing REE chemistry and identifying its drivers to provide a new tool for understanding contexts characterised by a scarce amount of remains, where the traditional geochemical and archaeological methods have not proven to be sufficiently reliable.

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Table A1.1. Concentrations of major elements and trace elements expressed as percentage (from Al to Fe) or mg/kg (from Rb to U).

Samples	Al	Si	K	Ca	Ti	Fe	Rb	Zr	Li	Be	V	Cr	Mn	Co	Ni	Zn	Sr	Mo	Cd	Ba	Tl	Pb	Bi	
AyF2.01	11.72	21.88	1.15	0.02	0.61	5.03	52	307	1.39	0.613	52.4	21.3	368	4.31	8.87	40.2	7.22	0.403	0.029	31.0	0.075	15.8	0.110	5.67
AyF2.02	11.24	22.79	1.08	0.02	0.59	4.60	51	317	1.05	0.574	45.2	14.6	229	3.43	6.76	6.00	5.85	0.301	0.018	17.7	0.055	12.0	0.097	4.68
AyF2.03	11.26	22.63	1.06	0.01	0.60	4.64	49	318	1.05	0.533	49.2	23.1	258	3.44	6.70	4.52	5.81	0.347	0.022	23.0	0.060	13.1	0.110	4.75
AyF2.04	8.74	20.73	0.94	<LD	0.57	4.56	47	328	0.984	0.392	42.8	17.4	266	3.36	6.09	90.7	5.83	0.407	0.017	19.5	0.058	11.0	0.081	4.47
AyF2.05	11.18	25.01	1.02	0.01	0.61	4.54	50	366	0.899	0.479	43.1	15.0	259	3.73	6.26	33.5	5.36	0.220	0.012	19.0	0.061	11.5	0.083	4.49
AyF2.06	9.42	21.53	0.97	0.01	0.61	4.32	55	353	0.952	0.539	48.9	16.5	336	4.38	7.03	83.2	5.98	0.265	0.021	22.4	0.071	11.8	0.097	4.95
AyF2.07	10.10	23.09	1.01	<LD	0.60	4.63	55	389	0.815	0.406	46.2	23.4	469	5.42	6.22	55.1	5.60	0.255	0.029	17.8	0.063	12.8	0.092	4.41
AyF2.08	13.62	27.62	1.09	0.02	0.62	4.33	51	384	0.920	0.409	43.0	12.5	613	5.36	6.63	43.4	6.15	0.433	0.030	23.4	0.085	13.7	0.089	4.26
AyF2.09	8.80	21.37	0.96	0.01	0.59	4.13	51	342	0.933	0.454	42.1	14.4	682	5.23	6.32	49.3	5.96	0.382	0.073	21.7	0.070	13.6	0.082	4.24
AyF2.10	10.15	24.75	1.00	0.01	0.61	4.06	49	344	1.02	0.396	43.4	13.2	772	5.17	6.68	37.4	6.49	0.509	0.038	25.4	0.076	14.1	0.079	4.47
Mean	*10.6*	*23*	*1.03*	*0.014*	*0.601*	*4.5*	*51*	*345*	*51*	*0.48*	*46*	*17*	*425*	*4.4*	*6.8*	*44*	*6.0*	*0.35*	*0.029*	*22*	*0.067*	*12.9*	*0.092*	*4.6*
s	*1.5*	*2*	*0.07*	*0.002*	*0.015*	*0.3*	*2*	*28*	*2*	*0.08*	*3*	*4*	*198*	*0.9*	*0.8*	*28*	*0.5*	*0.09*	*0.017*	*4*	*0.010*	*1.4*	*0.011*	*0.4*
AyF3.01	14.63	22.02	1.30	0.02	0.61	5.64	59	303	1.91	0.655	51.8	17.8	183	3.73	8.49	42.4	7.98	0.353	0.020	36.8	0.082	13.6	0.106	6.03
AyF3.02	15.10	23.45	1.25	0.01	0.60	5.60	66	310	1.79	0.607	56.9	21.2	184	3.64	8.11	47.7	8.02	0.606	0.031	35.8	0.086	13.7	0.160	5.95
AyF3.03	12.30	20.12	1.21	0.01	0.59	5.56	63	363	1.99	0.616	53.4	17.1	183	3.61	8.31	50.9	8.48	0.305	0.025	36.2	0.080	13.6	0.126	5.81
AyF3.04	13.78	22.38	1.14	0.02	0.59	5.70	65	357	2.07	0.569	57.0	28.3	181	3.52	8.20	40.9	7.71	0.180	0.021	34.0	0.082	13.8	0.110	6.10
AyF3.05	13.66	21.76	1.15	0.01	0.60	6.02	64	357	2.61	0.605	62.2	28.1	241	3.96	8.87	28.8	10.2	0.414	0.030	49.6	0.110	16.8	0.125	6.51
AyF3.06	10.20	18.69	1.04	0.01	0.56	5.93	63	357	1.97	0.463	56.9	33.3	193	3.19	7.29	33.5	8.11	0.239	0.039	40.4	0.083	13.9	0.122	5.48
AyF3.07	10.30	19.28	1.00	0.01	0.57	5.71	64	320	2.16	0.545	60.3	31.4	222	3.47	7.87	38.6	9.38	0.441	0.034	44.6	0.102	15.0	0.134	5.76
AyF3.08	12.15	23.43	1.10	0.01	0.61	5.00	58	270	1.54	0.443	48.4	18.4	219	3.54	6.80	46.5	7.14	0.270	0.032	33.9	0.079	12.1	0.102	5.30
Mean	*12.8*	*21.4*	*1.15*	*0.015*	*0.590*	*5.6*	*63*	*330*	*2.0*	*0.56*	*56*	*24*	*201*	*3.6*	*8.0*	*41*	*8.4*	*0.35*	*0.029*	*39*	*0.088*	*14.1*	*0.123*	*5.9*
s	*1.9*	*1.8*	*0.10*	*0.003*	*0.018*	*0.3*	*3*	*34*	*0.3*	*0.08*	*4*	*7*	*23*	*0.2*	*0.7*	*7*	*1.0*	*0.13*	*0.007*	*6*	*0.012*	*1.4*	*0.018*	*0.4*
PyN1.01	15.93	20.71	0.74	0.01	0.71	8.66	43	528	3.56	0.272	144	39.6	160	1.76	5.53	13.7	7.24	0.453	<LD	12.9	0.098	15.6	0.227	5.15
PyN1.02	14.81	18.68	0.76	0.01	0.73	9.44	47	454	3.15	0.242	167	66.9	162	1.83	5.04	18.0	8.18	0.500	0.022	17.1	0.099	18.1	0.214	6.06
PyN1.03	16.50	19.44	0.75	0.01	0.71	12.20	43	436	3.32	0.312	272	116.9	152	1.98	5.95	26.7	10.8	1.617	0.025	18.8	0.108	25.2	0.393	8.09
PyN1.04	15.48	20.51	0.82	<LD	0.77	8.30	45	498	2.49	0.222	160	65.9	151	1.73	4.97	18.9	7.49	1.008	0.018	14.2	0.091	16.4	0.249	5.59
PyN1.05	19.43	26.38	0.84	0.01	0.74	6.81	41	557	2.39	0.199	143	63.9	156	1.63	4.50	18.9	7.02	0.626	0.024	14.0	0.087	14.8	0.212	4.74

Samples	Al	Si	K	Ca	Ti	Fe	Rb	Zr	Li	Be	V	Cr	Mn	Co	Ni	Zn	Sr	Mo	Cd	Ba	Tl	Pb	Bi	
PyN1.06	14.89	21.90	0.80	<LD	0.81	7.04	43	539	2.41	0.197	152	65.8	167	1.72	4.94	20.5	7.16	1.103	0.014	16.3	0.090	14.6	0.248	5.01
PyN1.07	15.11	21.92	0.80	<LD	0.75	7.15	43	498	2.09	0.185	122	56.6	150	1.55	4.06	5.09	6.15	0.843	0.012	15.8	0.081	12.8	0.198	4.24
PyN1.08	15.30	22.49	0.79	<LD	0.78	7.31	44	562	2.07	0.233	170	72.3	131	1.47	4.28	15.6	7.91	0.732	0.017	19.7	0.078	16.0	0.214	4.96
PyN1.09	18.79	27.21	0.82	0.04	0.74	8.32	40	512	1.74	0.230	161	82.9	130	1.24	3.52	2.95	7.33	0.889	0.013	17.2	0.073	15.1	0.213	4.41
PyN1.10	12.75	21.83	0.74	0.02	0.77	4.77	38	575	1.81	0.111	59.9	20.0	142	1.52	3.72	10.7	4.68	0.661	<LD	15.5	0.069	8.24	0.136	3.67
Mean	*16*	*22*	*0.78*	*0.017*	*0.75*	*8*	*43*	*516*	*2.5*	*0.22*	*155*	*65*	*150*	*1.6*	*4.6*	*15*	*7.4*	*0.8*	*0.018*	*16*	*0.087*	*16*	*0.23*	*5.2*
s	*2*	*3*	*0.04*	*0.011*	*0.03*	*2*	*3*	*46*	*0.6*	*0.05*	*52*	*25*	*13*	*0.2*	*0.8*	*7*	*1.6*	*0.3*	*0.005*	*2*	*0.012*	*4*	*0.07*	*1.2*
PyN2.01	10.20	38.80	0.54	0.15	0.76	3.19	17	678	0.449	0.052	47.4	25.9	513	1.67	2.80	<LD	7.37	0.740	0.029	23.0	0.032	8.04	0.078	1.57
PyN2.02	11.44	37.42	0.62	0.05	0.90	2.95	22	828	0.428	0.097	44.8	19.8	493	1.83	2.64	<LD	5.61	0.771	0.014	16.2	0.032	8.27	0.083	1.90
PyN2.03	14.48	41.35	0.69	0.04	0.97	2.94	20	804	0.526	0.065	44.7	18.6	537	2.12	2.89	<LD	5.53	0.878	0.016	18.1	0.036	8.97	0.104	2.28
PyN2.04	11.10	36.46	0.63	0.02	0.98	2.79	22	933	0.596	0.071	44.1	15.7	517	2.35	3.19	<LD	4.94	0.644	0.014	16.6	0.044	9.55	0.084	2.65
PyN2.05	13.28	36.90	0.67	0.01	0.95	3.25	23	858	0.613	0.083	46.9	19.5	413	2.06	2.81	<LD	4.87	0.711	0.020	15.3	0.045	9.73	0.095	2.58
PyN2.06	10.97	34.99	0.59	<LD	0.88	3.08	25	890	0.817	0.103	54.2	18.4	358	2.35	3.42	<LD	4.98	0.924	0.015	13.6	0.053	9.67	0.124	3.16
PyN2.07	11.34	30.59	0.69	<LD	0.96	3.49	27	856	0.819	0.085	58.4	28.6	253	1.90	2.91	<LD	4.66	0.823	0.013	13.2	0.049	10.3	0.124	3.09
PyN2.08	12.14	27.12	0.72	<LD	0.94	3.88	29	734	1.25	0.110	58.2	21.9	226	1.91	3.71	3.88	4.95	0.923	0.014	16.6	0.064	9.33	0.134	3.37
PyN2.09	14.82	33.32	0.64	<LD	0.83	4.06	32	763	1.49	0.154	61.2	23.1	226	1.99	3.87	<LD	5.14	0.609	0.017	20.8	0.075	10.2	0.125	4.05
PyN2.10	12.92	28.53	0.67	<LD	0.78	4.11	33	646	1.66	0.172	60.9	21.6	278	2.07	4.22	28.2	5.19	0.530	0.020	23.3	0.078	11.2	0.124	4.34
PyN2.11	14.74	28.69	0.70	<LD	0.77	4.16	36	567	1.81	0.164	57.5	16.6	475	2.10	4.28	<LD	5.00	0.524	0.019	23.6	0.283	11.7	0.148	4.40
PyN2.12	14.97	32.09	0.67	<LD	0.73	4.05	33	584	1.74	0.173	67.4	19.9	416	2.10	4.10	12.6	5.48	0.984	0.029	22.0	0.118	11.3	0.161	4.19
PyN2.13	15.28	27.56	0.74	<LD	0.80	3.83	33	604	1.21	0.079	51.2	16.1	222	1.64	3.24	11.9	4.31	0.430	0.012	14.1	0.081	7.95	0.116	3.16
PyN2.14	12.00	25.75	0.69	0.01	0.75	3.94	34	610	1.36	0.128	58.0	17.2	203	1.80	3.76	<LD	4.93	0.707	0.013	18.2	0.079	8.49	0.139	3.57
PyN2.15	15.01	25.05	0.79	<LD	0.81	4.44	36	633	1.59	0.144	66.2	23.1	178	1.66	3.76	<LD	5.29	0.561	0.011	17.5	0.079	9.40	0.143	3.76
PyN2.16	15.91	26.74	0.70	<LD	0.76	4.72	38	586	1.63	0.146	82.6	27.1	189	1.74	4.06	<LD	5.67	0.768	0.018	19.0	0.077	10.6	0.174	4.24
PyN2.17	14.09	29.06	0.69	<LD	0.76	4.65	37	622	1.71	0.158	103	29.9	179	1.72	3.99	<LD	5.68	0.973	0.011	17.4	0.083	10.3	0.187	4.00
Mean	*13.2*	*32*	*0.67*	*0.05*	*0.84*	*3.7*	*29*	*717*	*1.2*	*0.12*	*59*	*21*	*334*	*1.9*	*3.5*	*14*	*5.3*	*0.74*	*0.017*	*18*	*0.08*	*9.7*	*0.13*	*3.3*
s	*1.8*	*5*	*0.06*	*0.05*	*0.09*	*0.6*	*7*	*123*	*0.5*	*0.04*	*15*	*4*	*136*	*0.2*	*0.6*	*10*	*0.7*	*0.17*	*0.005*	*3*	*0.06*	*1.1*	*0.03*	*0.9*

Table A1.2. Concentrations of REE, expressed as mg/kg, and REE parameters.

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y	TREE	Cen/Ce*	Eun/Eu*	Lan/Ybn	Lan/Smn	Smn/Ybn
AyF2.01	21.2	59.4	5.20	20.7	4.00	0.833	3.29	0.417	2.26	0.373	0.951	0.121	0.720	0.097	6.88	9.09	120	1.30	1.07	2.17	0.78	2.78
AyF2.02	16.6	49.5	4.07	16.3	3.12	0.646	2.63	0.335	1.81	0.306	0.788	0.096	0.578	0.080	5.81	7.46	97	1.38	1.05	2.12	0.79	2.69
AyF2.03	15.9	49.0	3.91	15.4	2.97	0.635	2.56	0.325	1.78	0.292	0.734	0.096	0.566	0.078	5.98	7.13	94	1.43	1.07	2.07	0.79	2.63
AyF2.04	14.8	46.2	3.62	14.1	2.81	0.563	2.23	0.294	1.53	0.255	0.629	0.079	0.493	0.065	5.22	6.01	88	1.45	1.05	2.21	0.77	2.85
AyF2.05	13.3	42.8	3.26	12.7	2.52	0.530	2.19	0.277	1.53	0.251	0.634	0.085	0.524	0.070	5.18	6.26	81	1.49	1.05	1.87	0.78	2.40
AyF2.06	14.2	40.3	3.38	13.2	2.63	0.571	2.26	0.287	1.58	0.267	0.659	0.086	0.537	0.071	5.37	6.62	80	1.34	1.09	1.94	0.79	2.45
AyF2.07	12.3	35.6	2.98	11.6	2.27	0.467	1.97	0.250	1.37	0.240	0.603	0.080	0.463	0.060	5.06	5.81	70	1.35	1.03	1.96	0.80	2.44
AyF2.08	14.8	40.0	3.46	13.5	2.55	0.556	2.16	0.277	1.52	0.250	0.647	0.083	0.477	0.066	4.75	6.21	80	1.29	1.11	2.28	0.85	2.68
AyF2.09	14.1	41.7	3.33	13.0	2.39	0.494	2.06	0.255	1.37	0.230	0.571	0.071	0.449	0.059	4.92	5.65	80	1.40	1.04	2.31	0.87	2.66
AyF2.10	14.3	45.4	3.30	12.5	2.40	0.487	1.92	0.253	1.28	0.214	0.530	0.069	0.437	0.056	5.20	5.16	83	1.52	1.06	2.40	0.87	2.75
Mean	*15*	*45*	*3.7*	*14*	*2.8*	*0.58*	*2.3*	*0.30*	*1.6*	*0.27*	*0.67*	*0.087*	*0.52*	*0.070*	*5.4*	*6.5*	*87*	*1.39*	*1.06*	*2.13*	*0.81*	*2.63*
s	*2*	*7*	*0.6*	*3*	*0.5*	*0.11*	*0.4*	*0.05*	*0.3*	*0.05*	*0.12*	*0.015*	*0.08*	*0.012*	*0.6*	*1.1*	*14*	*0.08*	*0.02*	*0.17*	*0.04*	*0.15*
AyF3.01	20.5	52.0	5.23	20.9	4.14	0.874	3.62	0.467	2.48	0.442	1.12	0.146	0.854	0.119	7.19	10.8	113	1.15	1.05	1.77	0.73	2.42
AyF3.02	19.7	50.6	5.10	20.2	4.10	0.869	3.52	0.443	2.45	0.424	1.08	0.139	0.837	0.116	7.10	10.6	110	1.16	1.07	1.73	0.71	2.45
AyF3.03	20.6	51.5	5.29	21.4	4.17	0.897	3.66	0.474	2.56	0.436	1.10	0.143	0.842	0.116	7.06	10.8	113	1.14	1.07	1.80	0.73	2.48
AyF3.04	19.9	49.7	5.06	20.7	4.06	0.869	3.58	0.457	2.49	0.433	1.09	0.143	0.870	0.122	7.53	10.8	109	1.14	1.06	1.69	0.72	2.34
AyF3.05	22.8	58.6	5.95	23.8	4.69	1.026	4.00	0.510	2.75	0.476	1.19	0.155	0.921	0.129	8.00	11.2	127	1.16	1.10	1.82	0.72	2.55
AyF3.06	17.9	53.4	4.62	18.8	3.81	0.793	3.28	0.417	2.24	0.382	0.994	0.127	0.782	0.107	7.19	9.03	108	1.35	1.05	1.69	0.69	2.43
AyF3.07	18.8	57.9	4.93	19.8	3.89	0.838	3.37	0.446	2.27	0.381	0.956	0.129	0.770	0.107	7.58	8.84	115	1.38	1.08	1.80	0.71	2.53
AyF3.08	15.3	52.9	3.96	16.1	3.30	0.697	2.81	0.371	2.01	0.339	0.839	0.113	0.688	0.098	6.55	8.10	100	1.56	1.07	1.64	0.68	2.40
Mean	*19*	*53*	*5.0*	*20*	*4.0*	*0.86*	*3.5*	*0.45*	*2.4*	*0.41*	*1.05*	*0.14*	*0.82*	*0.114*	*7.3*	*10.0*	*112*	*1.25*	*1.07*	*1.74*	*0.71*	*2.45*
s	*2*	*3*	*0.6*	*2*	*0.4*	*0.09*	*0.3*	*0.04*	*0.2*	*0.04*	*0.11*	*0.01*	*0.07*	*0.010*	*0.4*	*1.2*	*8*	*0.16*	*0.02*	*0.07*	*0.02*	*0.07*
PyN1.01	12.6	66.3	3.54	14.3	2.66	0.484	1.76	0.195	1.00	0.166	0.437	0.061	0.358	0.052	11.1	3.70	104	2.27	1.04	2.59	0.70	3.72
PyN1.02	12.4	62.0	3.65	14.7	2.77	0.506	1.84	0.202	1.05	0.165	0.443	0.061	0.386	0.053	10.8	3.63	100	2.11	1.04	2.36	0.66	3.59
PyN1.03	13.9	72.1	4.04	16.6	3.10	0.595	1.99	0.225	1.14	0.184	0.487	0.066	0.436	0.057	13.8	4.08	115	2.20	1.11	2.35	0.66	3.55
PyN1.04	11.5	61.9	3.46	14.5	2.75	0.520	1.83	0.203	1.04	0.165	0.434	0.061	0.369	0.055	10.1	3.38	99	2.24	1.07	2.30	0.62	3.73
PyN1.05	10.1	56.3	3.18	13.2	2.54	0.461	1.66	0.176	0.954	0.148	0.378	0.052	0.346	0.051	9.23	2.96	90	2.26	1.04	2.16	0.59	3.68

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y	TREE	Cen/Ce*	Eun/Eu*	Lan/Ybn	Lan/Smn	Smn/Ybn
PyN1.06	9.65	60.7	3.10	12.8	2.67	0.491	1.66	0.191	0.961	0.151	0.402	0.055	0.375	0.051	9.55	2.98	93	2.52	1.08	1.90	0.53	3.57
PyN1.07	8.01	56.4	2.65	11.1	2.25	0.421	1.45	0.159	0.861	0.134	0.343	0.049	0.307	0.042	8.50	2.51	84	2.77	1.08	1.92	0.53	3.65
PyN1.08	8.42	59.0	2.76	11.5	2.40	0.431	1.55	0.176	0.895	0.141	0.369	0.052	0.326	0.046	9.37	2.64	88	2.78	1.03	1.90	0.52	3.68
PyN1.09	7.65	51.9	2.57	10.7	2.33	0.439	1.49	0.166	0.835	0.132	0.345	0.045	0.330	0.045	8.26	2.44	79	2.65	1.09	1.71	0.48	3.52
PyN1.10	7.03	50.4	2.28	9.60	1.98	0.374	1.29	0.147	0.731	0.114	0.298	0.041	0.283	0.037	7.04	2.20	75	2.86	1.08	1.83	0.52	3.50
Mean	*10*	*60*	*3.1*	*12.9*	*2.5*	*0.47*	*1.7*	*0.18*	*0.95*	*0.15*	*0.39*	*0.054*	*0.35*	*0.049*	*9.8*	*3.1*	*93*	*2.47*	*1.06*	*2.10*	*0.58*	*3.62*
s	*2*	*6*	*0.6*	*2.2*	*0.3*	*0.06*	*0.2*	*0.02*	*0.12*	*0.02*	*0.06*	*0.008*	*0.04*	*0.006*	*1.9*	*0.6*	*12*	*0.28*	*0.03*	*0.29*	*0.07*	*0.08*
PyN2.01	2.06	13.6	0.537	2.14	0.446	0.075	0.287	0.035	0.179	0.030	0.081	0.012	0.075	0.009	2.33	0.608	20	2.97	0.97	2.03	0.68	2.99
PyN2.02	1.88	16.2	0.439	1.70	0.350	0.072	0.265	0.031	0.171	0.029	0.074	0.010	0.077	0.011	2.45	0.530	21	4.11	1.10	1.79	0.79	2.26
PyN2.03	2.31	21.1	0.566	2.29	0.445	0.086	0.337	0.041	0.225	0.037	0.093	0.014	0.077	0.012	3.10	0.681	28	4.25	1.03	2.20	0.76	2.88
PyN2.04	3.03	30.4	0.789	3.11	0.639	0.118	0.446	0.054	0.274	0.045	0.112	0.018	0.107	0.013	3.75	0.864	39	4.51	1.03	2.08	0.70	2.98
PyN2.05	3.48	34.1	0.924	3.49	0.718	0.140	0.539	0.060	0.333	0.055	0.129	0.018	0.113	0.017	4.15	1.04	44	4.36	1.05	2.26	0.71	3.17
PyN2.06	5.29	43.5	1.47	5.76	1.14	0.211	0.829	0.093	0.483	0.074	0.190	0.026	0.175	0.023	5.17	1.55	59	3.57	1.01	2.23	0.68	3.26
PyN2.07	5.34	41.8	1.51	5.95	1.21	0.220	0.836	0.093	0.512	0.079	0.201	0.027	0.180	0.025	5.12	1.60	58	3.37	1.02	2.18	0.65	3.36
PyN2.08	7.54	50.9	2.14	8.59	1.69	0.335	1.17	0.136	0.706	0.117	0.299	0.039	0.251	0.037	6.15	2.33	74	2.90	1.11	2.21	0.66	3.37
PyN2.09	9.66	60.5	2.89	11.7	2.29	0.450	1.60	0.176	0.931	0.148	0.380	0.054	0.321	0.046	7.44	3.04	91	2.61	1.09	2.22	0.62	3.56
PyN2.10	11.6	68.5	3.65	15.2	3.02	0.574	1.99	0.224	1.18	0.181	0.463	0.062	0.406	0.055	8.16	3.75	107	2.40	1.09	2.10	0.56	3.72
PyN2.11	14.0	77.0	4.78	19.6	4.11	0.739	2.60	0.296	1.50	0.236	0.591	0.079	0.498	0.077	9.61	4.57	126	2.13	1.04	2.07	0.50	4.13
PyN2.12	12.7	67.6	4.21	17.8	3.54	0.643	2.29	0.252	1.31	0.202	0.553	0.068	0.455	0.061	8.22	4.06	112	2.09	1.04	2.06	0.53	3.89
PyN2.13	9.62	49.4	3.21	13.4	2.67	0.494	1.68	0.184	0.928	0.154	0.385	0.055	0.358	0.047	6.51	2.94	83	2.01	1.08	1.98	0.53	3.73
PyN2.14	9.60	49.0	3.17	13.5	2.66	0.513	1.69	0.177	0.928	0.147	0.385	0.051	0.327	0.048	7.14	2.87	82	2.01	1.12	2.16	0.53	4.06
PyN2.15	9.58	50.1	3.17	13.2	2.65	0.495	1.71	0.188	0.929	0.146	0.398	0.051	0.342	0.053	7.46	2.92	83	2.06	1.07	2.06	0.53	3.88
PyN2.16	9.99	58.0	3.44	14.5	2.94	0.558	1.92	0.220	1.08	0.171	0.451	0.060	0.412	0.053	8.14	3.17	94	2.23	1.09	1.79	0.50	3.57
PyN2.17	7.96	53.3	2.62	11.0	2.32	0.433	1.49	0.171	0.839	0.135	0.350	0.050	0.323	0.048	7.64	2.58	81	2.65	1.08	1.82	0.51	3.59
Mean	*7*	*46*	*2.3*	*10*	*1.9*	*0.4*	*1.3*	*0.14*	*0.7*	*0.12*	*0.30*	*0.04*	*0.26*	*0.04*	*6.0*	*2.3*	*71*	*2.95*	*1.06*	*2.07*	*0.62*	*3.44*
s	*4*	*18*	*1.4*	*6*	*1.2*	*0.2*	*0.7*	*0.08*	*0.4*	*0.06*	*0.17*	*0.02*	*0.14*	*0.02*	*2.2*	*1.3*	*32*	*0.90*	*0.04*	*0.15*	*0.10*	*0.48*

Note: TREE = REE sum (from La to Yb).

A Geometric and Constructive Approach to Self-Supporting Domes and Vaults in the Architecture of the Ancient Near East

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Abstract: Among the various roofing alternatives available for earthen buildings in the ancient world, certain types of domes and vaults were the most economical and simplest to construct. Of these, stone, adobe and brick vaults built without formwork were the most common in the Ancient Near East. The challenge is that, in addition to the difficulty of identifying them within the archaeological record, it is necessary to evaluate different factors in order to extract the cultural readings associated with each variant, such as the historical and archaeological context, the construction process, the geometry, the mechanical functioning or their possible symbolic meaning. Among all these issues, this brief article invites us to incorporate the underlying construction logic of each type of dome and vault built without formwork into our interpretations of these architectural elements.

Keywords: Adobe; Archaeology of architecture; Mesopotamian vault; Protohistory; Tell al-Rimah.

Resumen: Entre todas las alternativas de cubrimiento disponibles para los edificios de tierra en el mundo antiguo, algunos tipos de cúpulas y bóvedas se presentan como las opciones más económicas y sencillas de construir. De estas, las bóvedas de piedra, adobe y ladrillos construidas sin cimbra fueron de las más arraigadas en el Próximo Oriente Antiguo. El problema es que, además de la dificultad para identificarlas a partir del registro arqueológico, es necesario evaluar distintos factores para extraer las lecturas culturales asociadas a cada variante, como son el contexto histórico y arqueológico, el proceso constructivo, la geometría, el funcionamiento mecánico o su posible carga simbólica. Entre todas estas cuestiones, este breve artículo invita a incorporar la lógica constructiva subyacente a cada tipo de cúpula y bóveda construida sin cimbra a las lecturas que hagamos de dichos elementos.

Palabras clave: Adobe; Arqueología de la arquitectura; Bóveda Mesopotámica; Protohistoria; Tell al-Rimah.

Introduction

In the field of archaeology dedicated to the study of earthen architecture, roofs are the structural elements most prone to degradation, loss and collapse (Friesem *et al.* 2014), which means that the evidence necessary for their identification is not always preserved. In addition, the study of these variants has often relied on terminology that is either imprecise or fails to fully reflect the reality of construction. This has meant that, for their description and characterisation in prehistoric and protohistoric periods, parallels are frequently overused as a key factor in the reconstruction of roofing systems (Carranza *et al.* 2023). This situation can lead to a simplification of the interpretative possibilities of roofs, an element that carries a significant amount of information about human activity (Deffontaines 1972: 62; Rapoport 1969: 34) and which responds to both social aspects and various technical and environmental factors (Besenval 1984: 168). In this way, roofs are the structural elements that provide the greatest protection to a space, transforming it into an enclosed and functional area, while also significantly expanding the usable surface area of a building. Consequently, they play a crucial role in defining the habitability of an architectural space and all the activities associated with a building.

Thus, in this paper we will briefly analyse the main variables of domes and vaults built without formwork or auxiliary support elements that were used in the Ancient Near East. We will highlight some of the most relevant terminological and conceptual inaccuracies and reflect on the construction logic inherent to each of them, as well as describe the bonding patterns used to tackle the geometric challenges associated with the shape of the floor plans. To this end, these variants have been geometrically simplified in order to present clear and accessible visual diagrams, and the construction process has been described on the basis of several notable examples from the Eastern Mediterranean and the Ancient Near East.

Although it is necessary to evaluate different characteristics—such as the historical and archaeological context, the construction process, the geometry, the mechanical functioning or the possible symbolic significance of the different roofs—we consider the approach presented here to be a fundamental basis for future work, since in the ancient world, construction challenges took precedence, including the choice materials, rigging and balance. Balance, for its part, depends on geometry. In other words, architecture in the ancient world followed the principle that 'A safe state of equilibrium is achieved through correct geometry' (Huerta 2001: 47), which was achieved through empirical experience and crystallised within different construction traditions.

Basic concepts regarding the relationship between arches, domes and vaults

Structural building systems (which include roofing), defined as those capable of withstanding forces without deformation or collapse, can be classified into two main categories: lintel systems and curved systems (i.e., the family comprising arches, domes and vaults). Consequently, two methods can be used to bridge the distance between two supports: the first, by using a solid piece resting on two jambs (lintel); the second, by arranging smaller pieces that rest on top of each other until they reach the supports (masonry structures). In terms of their mechanical behaviour, lintels are pieces that work under bending—on one side under tension and on the other under compression—whereas masonry structures function solely under compression. Therefore, masonry roofs represented a highly significant invention in the history of architecture, as they enabled the creation of large openings in walls and the safe covering of large spaces. Without them, the only feasible solution without using perishable materials or intermediate supports was to install a solid piece larger than the opening to be covered, with all the limitations and constraints that this entailed.

Among the variety of roofing alternatives, domes and vaults were widely used in the Ancient Near East (Besenval 1984; Dalley 2017; Dieter 2003; El-Naggar 1999; Norton 1997; Spencer 1979) due to the wide range of advantages and alternatives they offered, such as versatility and adaptability to all types of contexts and needs. In addition, they provided the possibility of enclosing spaces with pieces smaller than the span to be covered (typical of masonry structures) and are notable for their ability to distribute weight more efficiently than lintel systems. This enabled them to cover larger spaces without the risk of failure, regardless of the type of floor plan, whether circular or quadrangular. Similarly, the absence of intermediate supports simplifies the design and increases structural efficiency. To all this must be added aspects such as thermal efficiency, the most significant example of which is found in domes of furnaces, a technology that has hardly changed throughout history.

When analysing vaults, it is also essential to consider the interrelationship between the three fundamental types of curved roofing in architecture: arches, domes and vaults. All three exhibit similarities and differences in their characteristics. First, in terms of function, arches are used to cover a span between two supports, while domes are used to cover round or polygonal spaces. In contrast, vaults are capable of covering square or rectangular spaces, or even spanning areas of unlimited length. In terms of their composition, they are formed by joining pieces that are smaller than the span they cover (masonry structures). These pieces are characterised by their ability to work under compression, which results in the transfer of forces to the supports or lateral abutments. Finally, from the perspective of the most basic geometry, the vault can be defined as the longitudinal projection of an arch, while the dome originates from rotating an arch on its own axis. However, it is important to emphasise that this is merely a geometric definition, given that the arch is the most basic element of the family, although historically, the arch did not necessarily constitute the basic figure from which the design of domes and vaults was developed.

From a construction point of view, these systems can be divided into those that require an auxiliary structure during their construction and those that do not. Such support structure, usually in the form of scaffolding, is used to hold the pieces in place during the construction of arches, vaults and domes, and once the structure is completed, it is no longer necessary in most cases (Fortea and López Bernal 2012: 29). In other words, this auxiliary structure disappears, making it impossible to determine its original appearance or even if it existed, despite it being one of the most important strategies in the history of architecture. In fact, as a temporary element, the auxiliary structure allowed for the emergence of the arch, to the point that it is now an essential element for any reinforced concrete construction. However, a key point is that the auxiliary structure can exceed the structure it supports in both cost and complexity, which is why throughout history alternatives have been sought to dispense with it (Huerta 2012: 11), or even reusable materials such as adobe or bricks have been used (Beek 1987). Thus, self-supporting domes and vaults—capable of dispensing with such supports—were widely used in the Ancient Near East in a multitude of contexts and constructions, standing out as a resource that the Byzantine world knew how to exploit later on and becoming common throughout most of the Mediterranean world (Choisy 1883 [1997]; Huerta 2012: 11).

However, it should be borne in mind that the development of each variant presented did not necessarily occur in a single isolated area; instead, it could have been a multifocal innovation involving several evolutionary convergences. Similarly, caution should be exercised when drawing diffusionist or causal conclusions, as chronologies and complexity are not necessarily linked to a specific evolutionary sequence. With regard to this issue—and leaving aside case studies focused on specific solutions (e.g. Baudouin *et al.* 2022)—the reconstruction of the evolutionary sequence of arches, domes and vaults in the Ancient Near East has been addressed on only a few occasions. Notably, the article by Oates (1973), the notes by van Beek (1987) and the works by Besenval for Mesopotamia (1984) and El-Naggar for Egypt (1999) are the only ones to have dealt with the subject in some depth, albeit without chronological objectives. More recently, Valentini's research (2002) stands as the primary study addressing the emergence of the vault in search of an evolutionary sequence. However, further and more extensive work remains necessary to study this type of structure across broader chronological frameworks.

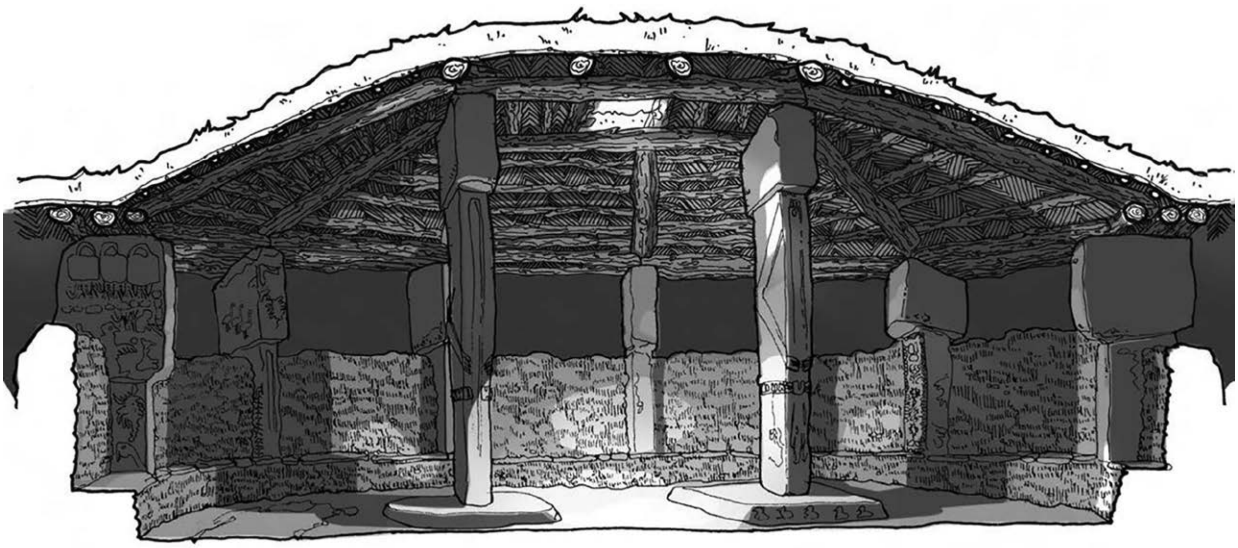

Figure 1. Göbekli Tepe Enclosure D roof design, proven to be 'implausible' (Newman and Ainsworth 2024).

Covering of circular plans

Circular or semi-circular plans, present since the Early Neolithic period in the Near East (Akkermans 2010: 26), could be covered with either plant material or lintel systems. Kathleen Kenyon already identified these roofs in the oldest settlement of Jericho (Tell el-Sultan) (PPNA 8500–7500) (Kenyon and Holland 1981: 60 plates 44a, 152), associated with the early stages of sedentism and agrarian populations. Similar roofs have been proposed in later works for other early sites such as Wadi Hammeh (Goring-Morris and Belfer-Cohen 2008), Göbekli Tepe (Banning 2011) (Figure 1), Karahan Tepe (Newman and Ainsworth 2024) or Jerf el-Ahmar (Haklay and Gopher 2020). However, all these cases would fall within the group of geometrically curved but not functionally vaulted roofs.

Based on the above point, we highlight the Halaf period sites in northern Mesopotamia—dated to approximately the 6th millennium BC—due to the influence of the work carried out at Tell Arpachiyah by Mallowan and Cruikshank (1935). It was at this time, when the first extensive research focusing on this period was carried out, that the name *tholoi* was proposed, given their apparent similarity to Mycenaean tombs, to designate the circular or 'keyhole-shaped' architecture that characterised them (Ipek 2019: 18; Stein 2019: 3). From this point onwards, the widespread belief took hold that many of these *tholoi* were covered by adobe domes or 'false domes', although vegetated roofs were not ruled out (Figure 2) (Akkermans 2010: 22; Campbell 1992: 182).

Since then, historiography has used the term 'false' or 'pseudo' to define those arches, domes and vaults constructed using horizontal courses with cantilevered pieces—a phenomenon that clearly indicates the terminological problem already highlighted above (Villalobos 2011). This issue is particularly relevant to the discipline of archaeology, as it is common to use the term 'false vault' to refer to a dome with horizontal courses. This represents one of the most important and widely used construction techniques in the history of the ancient world, including the Ancient Near East and the prehistoric Mediterranean. However, contrary to popular belief, in most cases such a structure is neither false nor a vault. In this sense, the problem lies in using the term 'false' or 'pseudo' to define a type of horizontal course construction simply because it is built without formwork, a meaningless distinction, since a specific construction element remains what it is regardless of the process by which it was made. This

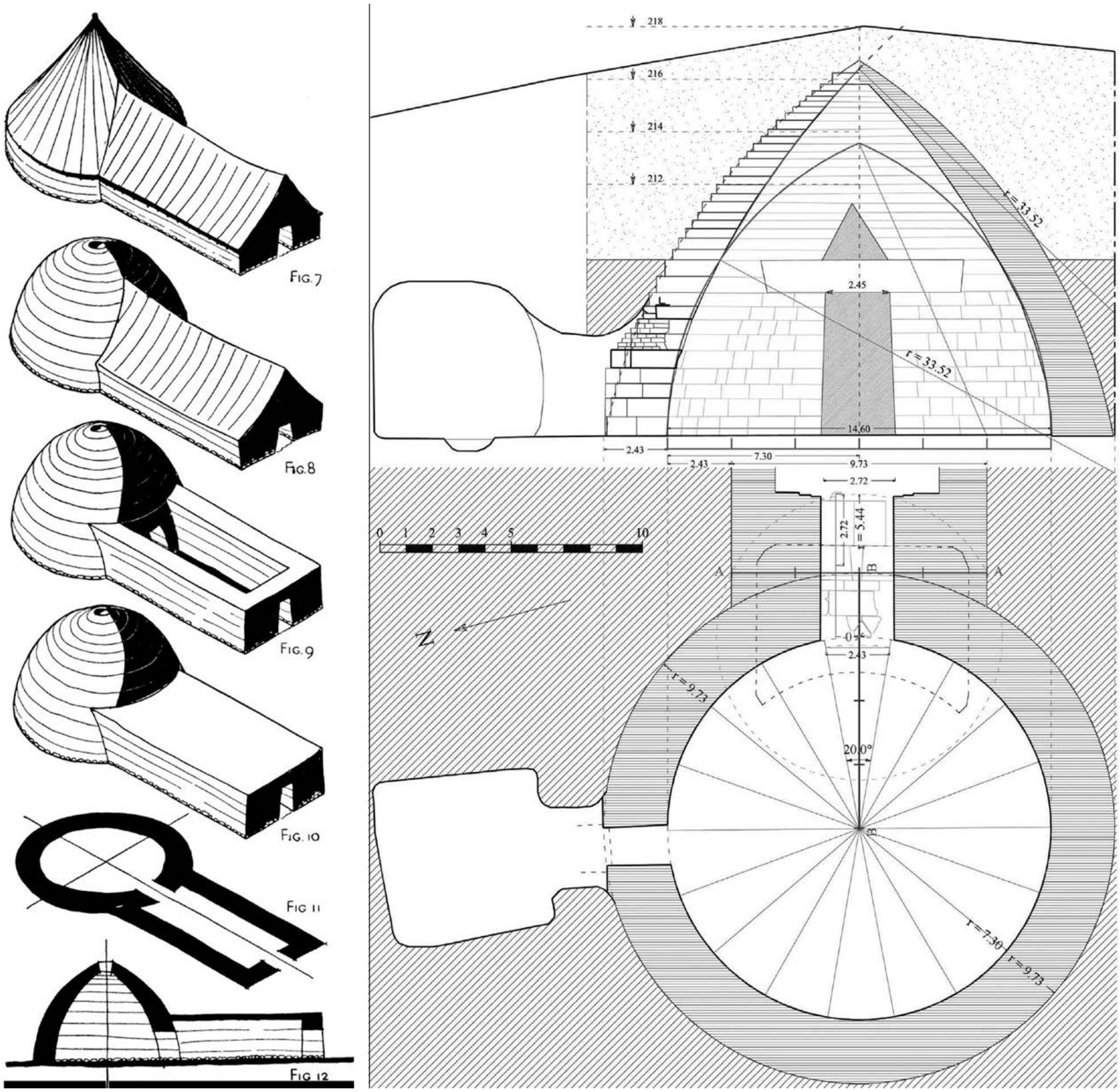

Figure 2. Left: Reconstruction of the elevations and roofs of the *tholos* with stone foundations (Mallowan and Cruikshank 1935: 28). Right: Geometrical relationships and dimensions of the main hall of the Treasury of Atreus (Como 2007).

same logic applies to any construction element; for example, a wall remains a wall regardless of how its bricks are laid or the technique used.

The widespread presence of this type of structure in archaeological contexts has led to numerous studies analysing the structural or mechanical behaviour of domes and vaults built with horizontal rows, including studies of Mycenaean and Minoan *tholoi* (Benvenuto and Corradi 1987; Cavanagh and Laxon 1981; Como 2007; Girella *et al.* 2013) or Sardinian *nuraghi* (Cappai and Pulina 2018; Mirabella and Spina 2001; Tran *et al.* 2025) as the main case studies, though a consensus on their functioning has yet to be reached. However, a key issue regarding the rigging and construction of these domes and vaults is that, in order to close the structure using the same pieces employed in the wall, the circular courses must

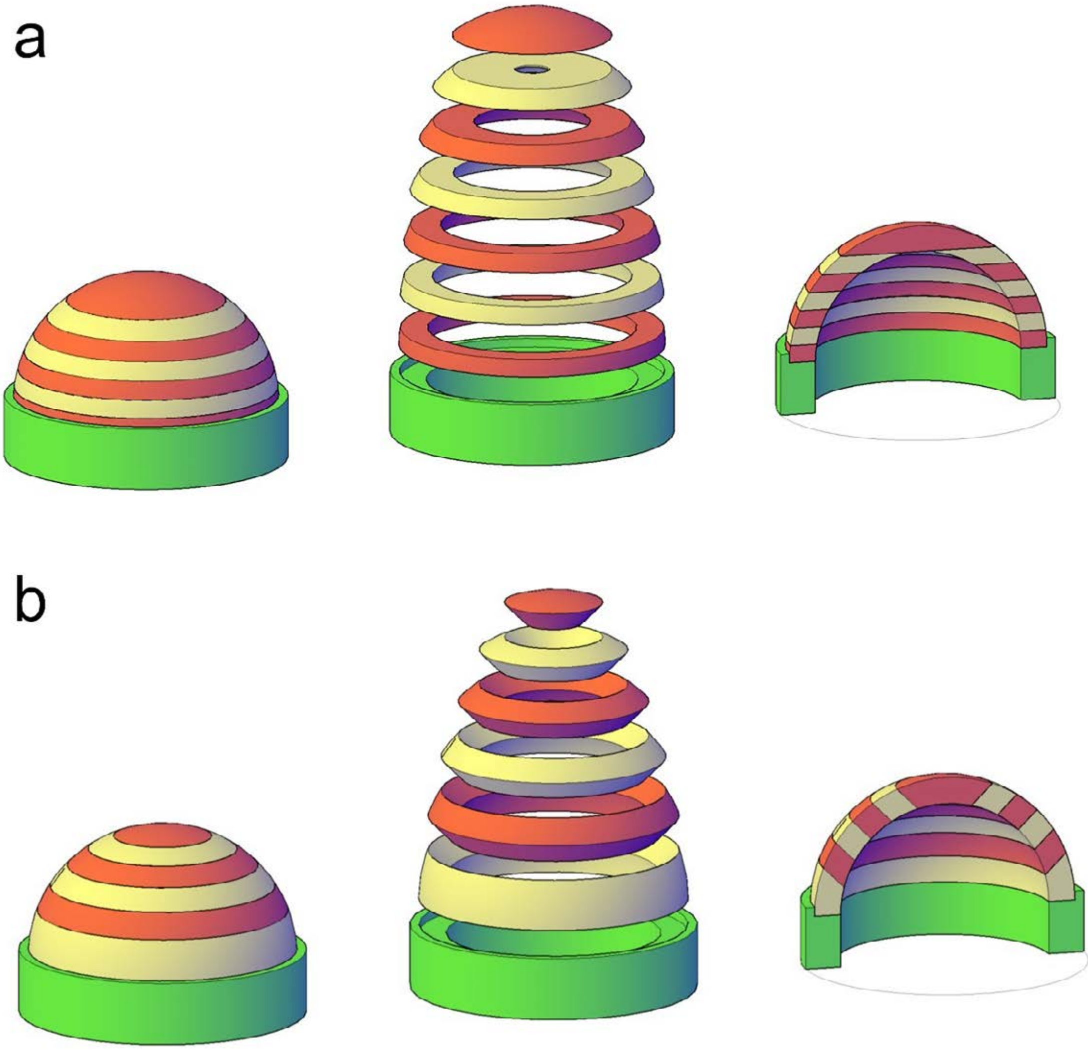

Figure 3. a) Detail and section of a hemispherical dome with horizontal courses. b) Detail and section of a hemispherical dome with inclined courses.

be closed inwards—gradually bringing the courses of bricks closer together. However, to prevent these sections from collapsing, a counterweight must be used, making the construction process fundamental. The most representative example of these domes in the ancient world is the Mycenaean *tholoi*, among which the Treasury of Atreus stands out for its historical and archaeological importance (Figure 2). This is clearly evident in the work of Como (2006, 2007, 2009) in which, following in the footsteps of previous research (Como 2006: 777 with bibliography), he studied their architectural and geometric characteristics, as well as their mechanical functioning and fundamental construction process, which aligns with the counterweight principle described above and can be extended to other domes that share this type of structure. Among his various conclusions, the researcher also raised the possibility that domes were invented before arches (Como 2006: 789), a working hypothesis that would be interesting to further investigate.

In short, we believe that the concept 'false vault' should be abandoned when referring to horizontal courses, since this feature is simply one of the variety of construction techniques that characterise domes and vaults and, as previously stated, does not define one type of masonry or another. Therefore, we believe archaeological practice must discard the term 'false' when describing a bonding pattern and covering system that was so widely used in the ancient world. This is all the more important given that, regardless of how they were constructed, as Heymann demonstrated in his 'Stone Skeleton' (1995), all vaulted structures face gravity in the same way.

Apart from the strategy mentioned above, there are other possible solutions for covering circular plans. First, there are hemispherical domes with horizontal courses (Figure 3a). In these structures, the upper courses protrude from the lower ones, which means that the pieces in each ascending course must be longer than the length of the lower course to allow for overturning without collapsing. This difficulty is often solved by building a cone instead of a hemisphere, or an ellipsoid as an intermediate solution. However, it is impossible to build a dome with a hemispherical section using adobe or bricks in horizontal courses unless moulds of different lengths are manufactured, a practice that, for the moment, has not been documented in the Ancient Near East. Therefore, if we want to build such a dome using adobe or bricks of uniform size, we must find other ways to fit the pieces together. The solution lies in arranging the bricks together using inclined courses, an important innovation in the history of architecture (Figure 3b). Once the key to the angle of the masonry was found, the formula could be replicated and disseminated.

From circle to square

From approximately 9000 BC onwards, circular floor plans began to be replaced by quadrangular ones in various areas of the Near East, although this was a gradual process (Akkermans 2010: 26) and circular floor plans were not abandoned, as shown by the architecture of the Halaf period. Consequently, the aim in these rectilinear cases was to enclose the space of a square or rectangular floor plan using pieces smaller than the span of the room itself and without resorting to wooden elements, such as auxiliary structures or trusses, or mortar. This could be achieved by using inclined masonry courses. However, covering a square-based space requires solving other important problems to apply the technique observed in the hemispherical dome (Figure 3), as we must transition from a square base to a circular one before applying the technique described above. Thus, the problem is reduced to how to obtain a circle from a square as the courses ascend, with the four corners being the critical points. This adaptation of the square to an upper circle was solved by means of pendentives, resulting in a continuous surface without edges, although their exact origin remains unclear and other alternatives may have existed (Figure 4).

The problem becomes more complicated when the space to be covered is rectangular, which requires the construction of a vault if one wishes to avoid using lintels or plant elements. Therefore, the same pendentive-based technique can be used as in the case just mentioned, but now without ending in a hemispherical dome; since the space is rectangular, it cannot be closed with circular rings. Once again, we must find another bond for the pieces (bricks or adobe). This leads once more to the use of inclined courses, but not arranged in horizontal circles, but rather in inclined circles that start from the two smaller ends until they meet in the centre. The geometric result is a continuous surface without edges in which the centre of the vault is the highest point, as in the case of the semicircular dome, resulting in a seamless, continuous surface.

The best-studied example of this construction solution comes from Tell al-Rimah (Karana in the Paleo-Babylonian period), southwest of Nineveh, in what is now northern Iraq (Kawami 1982). Among the various discoveries made (Oates 1965, 1966, 1966, 1967, 1968, 1970, 1972), the remains of a monumental building in the Babylonian tradition dating from around 1800 BC, when the area was part of the Assyrian

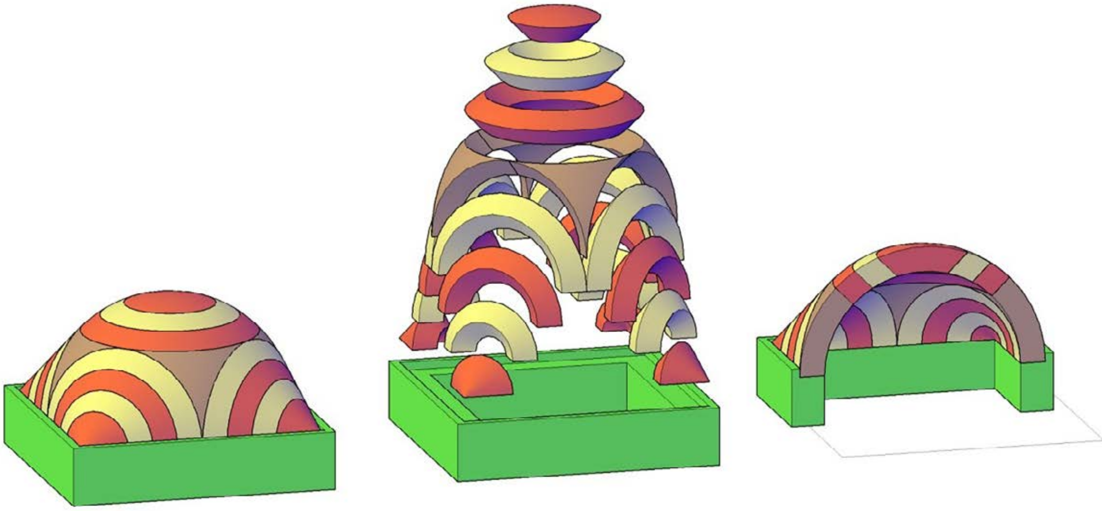

Figure 4. Detail and section of a dome with a square base and inclined courses.

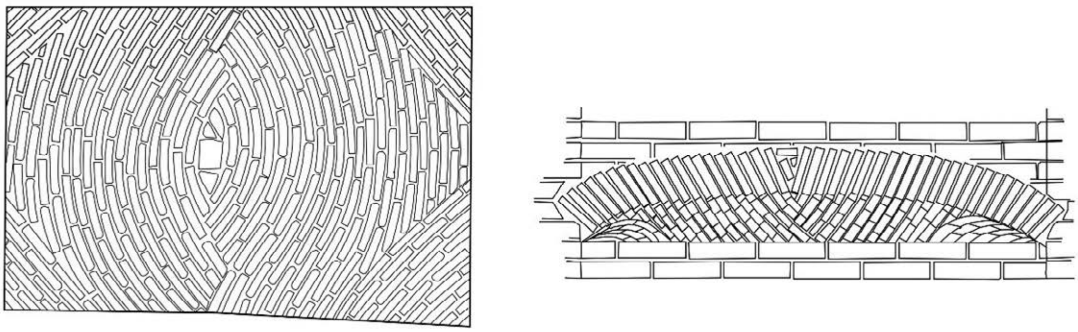

Figure 5. Vault of Tell al-Rimah. Reproduced from the original by Oates (1970: 21-22, 1990: 402 fig. 7).

Empire of Shamshi-Adad I, stand out (Liverani 2011: 35). Most interesting for our work is the unusual discovery of several rectangular-based vaults that would not have required an auxiliary structure for their construction, as they used inclined courses (Oates 1970: 14; plate V fig. a; plate VI fig. d; plate VII) (Figure 5). Oates had already published a series of interpretations in line with our own view regarding this type of vault:

The reason for the use of vaulting rather than the more common joist and matting roof may have been a shortage of suitable timber in this area, although the technique seems to have been handled with assurance by the builders and must have been familiar to them elsewhere (Oates 1965: 69).

Geometrically, it is an extremely complex shape. The entire perimeter, on all four sides, is at the same level and rises towards the centre, reaching the maximum height of the arch without having any edges.

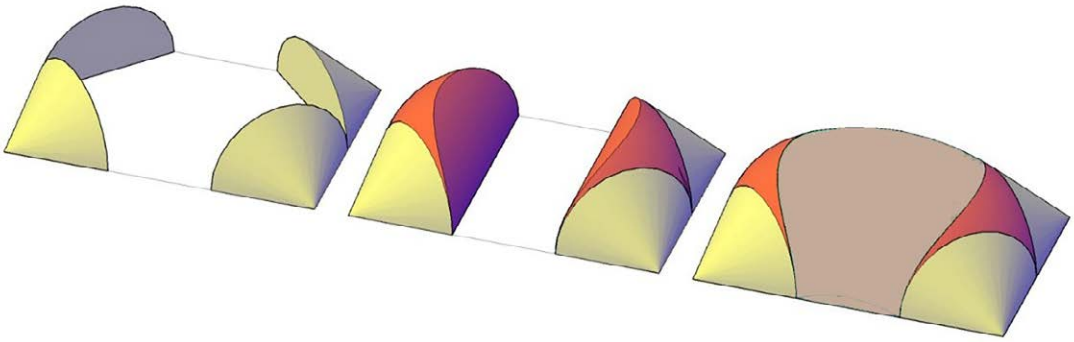

Figure 6. Detail of the geometric figures that comprise the vault of Tell al-Rimah.

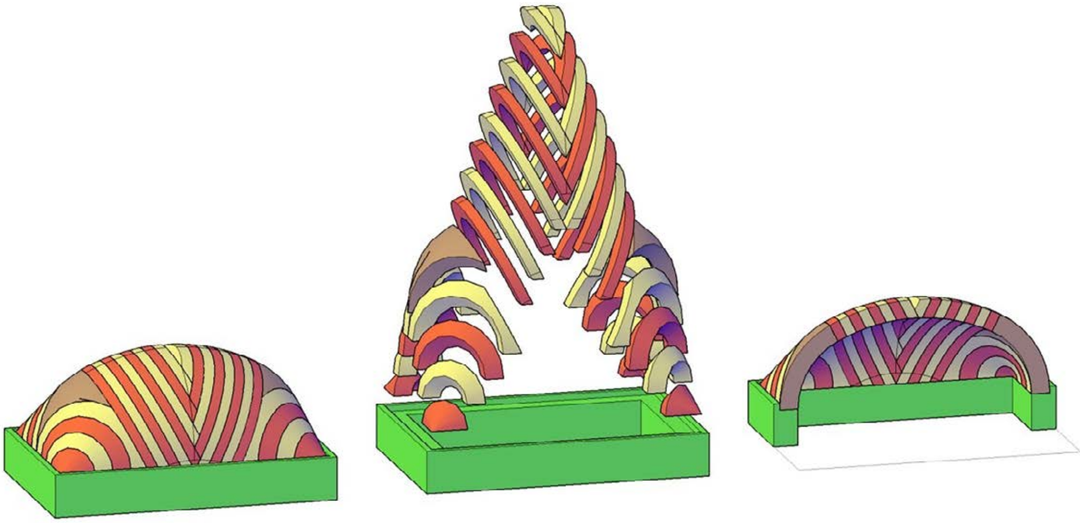

Figure 7. Detail and section of the Mesopotamian vault.

Notably, no single, simple geometric shape meets these conditions; instead, a set of basic geometric shapes must be joined together. The solution is presented below, although we must bear in mind that, as the rest of the examples in this work, this is an idealised model. It eliminates the irregularity typical of earthen architecture in order to clearly show the geometric decomposition (Figure 6). Piece 1 (yellow) consists of semi-cones with an elliptical cross-section that form the trumpets. Part 2 (orange) is an ellipse of revolution, and part 3 (brown) is part of a toroid of revolution. The section of the soffit through the trumpets at the vertices is a straight line, which is not very recommendable for structural behaviour, based on our experience. Therefore, these vaults perform effectively when they are lowered, but they work with greater difficulty the more they sag. Constructionally, the process can be divided into two phases. In the first stage, the corners—which, as mentioned above, are semi-conical in shape—are built. This part does not require an auxiliary structure because it originates directly from the walls. The second phase consists of curved courses and sloping bricks. It begins at both ends at the same time until closing in the centre. These courses, laid as described above, also do not depend on auxiliary structures, as each course rests on the previous one. As mentioned, this is a significant advancement in construction technology, as it represents a great saving in both cost and construction time.

Having analysed the model and evaluated its origin according to the archaeological evidence available to date, it seems more logical to employ the term 'Mesopotamian vault' to identify this type of constructive solution. With this name, we intend to define a type of vault with its own constructive and technical conditions and characteristics: 1) the fact that it starts on all four sides at the same height, 2) the use of conical pendentives, 3) the use of inclined courses and 4) the existence of a higher central point (Figure 7). Therefore, its geometrical and constructive characteristics, its exceptional architectural features and the historical context in which it is located merit the development of more in-depth studies than those conducted so far.

The Mesopotamian vault exemplifies one of the strategies used to cover a rectangular base without the need for auxiliary wooden elements or falsework during construction. This is because—although it is a vault with a unique curvature, without edges, and whose bases are at the same level—the bricks are arranged in such a way that they remain self-supporting throughout the process.

The Nubian vault

Another important variant for covering rectangular floor plans, widely used in Egypt and the Ancient Near East (Besenval 1984; El-Naggar 1999), is the so-called barrel vault with sloping rows, commonly known in literature as the Nubian Vault, pitched-brick vault, *de hiladas inclinadas* (in Spanish) or *à tranches inclinées* (in French). In this case, it is worth noting the influence of Hassan Fathy's famous New Gourna Project on the outskirts of Cairo in the 1940s, an experience recounted in his book *Construire avec le people, histoire d'un village d'Égypte: Gourna'* (1969). Fathy's ambitious social project introduced, revived and modernised certain construction techniques, including the so-called 'Nubian vault', which was clearly inspired by the Theban warehouses of the Ramesseum (Fathy 1969 [2021], 28). This type of vault stands out as the oldest documented vault in ancient Egypt (tomb 3500 in the Saqqara necropolis, 1st Dynasty, 4th millennium BC) (Emery 1958) and as the most representative type of vault in Pharaonic Egypt (El-Naggar 1999: 349), although the case of the Ramesseum warehouses (19th Dynasty, New Kingdom, *c.* 13–12th century BC) has been studied in greater depth (Dervy and Elyamani 2016).

Thus, from a geometric point of view, if we section the vault described at Tell al-Rimah at both ends, we obtain an approximation of a barrel vault—or what would be a barrel vault that does not require an auxiliary structure, since the conical rows of bricks are arranged at an angle, making them self-supporting. If we removed the highest central point of this, we would obtain a continuous barrel vault with unlimited length (Figure 8).

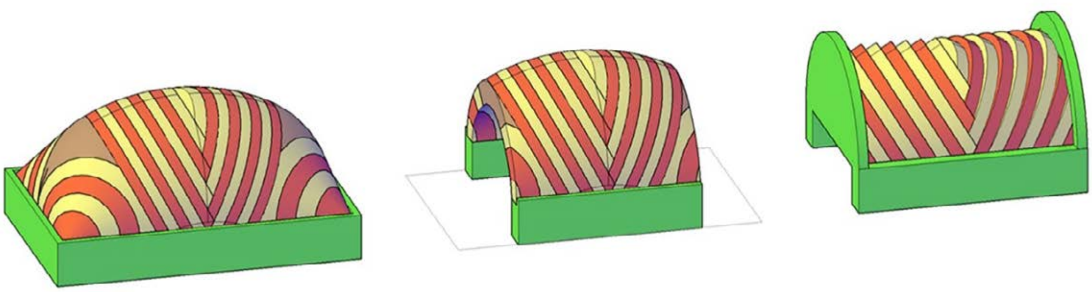

Figure 8. Hypothetical evolutionary stages from the Mesopotamian vault to the Nubian vault.

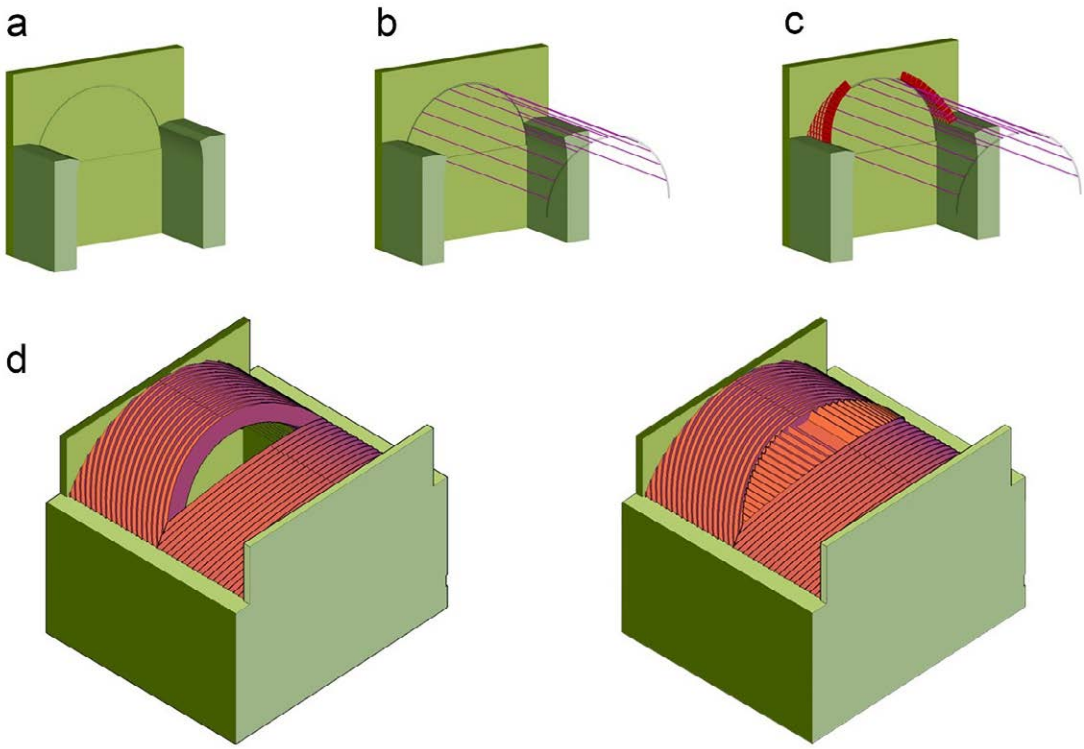

Figure 9. Construction stages of a Nubian vault.

The principles of this vaulting system were described in detail by Auguste Choisy (1883, 1904), upon whose work we will make some constructive notes. More recent sources include explanations by Fathy (1951), Besenval (1984), El-Naggar (1999) and Goyon (*et al.* 2004). Monnier's contribution to the design and construction of these vaults (2015) is also significant. However, given its importance, we consider it necessary to describe in detail the different stages of its execution (Figure 9):

Raising the support walls at the ends (short), as they are necessary as starting points. In addition, although not strictly necessary, the long walls can be curved inwards, which slightly reduces the width of the span.

The section of the vault is traced on the two short support walls and horizontal ropes are placed from one trace to another, although a mobile truss could also be used. These ropes serve to guide the operator, so the more ropes there are, the less likely it is that mistakes will be made. The important thing is that these guides will determine the actual cross-section of the vault.

The bricks or adobe are laid starting from the top of the long wall at both ends, with a gentle slope—the degree of inclination will depend on the qualities of the mortar and the weight of the pieces—until reaching the back wall, following the guides naturally. Once the first course has been completed from end to end, the next course is laid on top of the previous one instead of on the wall, and so on until both ends are joined.

Although the previous step can be carried out starting from a single short wall and extending the courses to the opposite wall, it is more common to start from both short walls simultaneously. This allows two work teams to advance at the same time, until they meet at the centre point. It is at this meeting point that different types of rigging can be used. The important thing is to close the eye or opening so that the vault is completely sealed.

The important thing about this structure, in addition to the use of sloping rows, is its geometry (Huerta 2004 with bibliography), formed by the inner and outer curves of the vault, whose height is only conditioned by the width of the walls responsible for supporting the forces and light of the room. These forces must be counteracted, for which there are different strategies, such as the construction of contiguous vaults that neutralise each other's forces, through the use of tie rods, buttresses or the widening of the walls (Fortea and López Bernal 2012: 35–41). To calculate this last option—which relates the necessary thickness of walls and pilasters to the dimensions of an arch or vault—we have the rule popularised (but not invented) by François N. Blondel in his *Cours d'Architecture* (1675–1683) at the end of the 17th century. This rule provides the maximum possible dimensions of an arch based on the thickness of the abutments that support it and the span between them; or, conversely, it determines how wide the abutments must be in order to safely construct an arch of a given height.

What does not influence this—and this must be made clear—is the internal composition once completed. In other words, the masonry or material used is not important for its functioning, as it is sufficient that there are no gaps between the components for the compressive stresses to circulate once the work is completed. Furthermore, these stresses are very low, which means that the compressive strength requirements of the elements we use are extremely low. This is another important aspect, as it is one of the most common misconceptions in archaeological literature. Contrary to this belief, the span of vaults and arches is not limited in any way by the greater or lesser compressive strength of adobe or brick.

Conclusions

In this brief paper, we have sought to highlight the importance of understanding how each of the most common types of domes and vaults was constructed in the Ancient Near East and much of the prehistoric and protohistoric Mediterranean, which involves reconstructing part of the operational gestures required to build the edifications. This approach enables us to evaluate aspects such as the specialisation of builders or the management of technical and material resources, as well as to investigate the different building traditions within which it was decided to use one option or another. However, as has been repeated throughout this work, for a deeper understanding, it will be necessary to compare both the construction process and geometry discussed here, as well as the mechanical functioning, the symbolic significance of each solution and the specific historical and archaeological context of each case study.

Incorporating construction logic can also help us to correctly interpret the construction remains found in archaeological contexts or, at least, to assess a wider range of options that may have been present in the buildings. This relates to the frequent assumption regarding the apparent difficulty of constructing domes and vaults. However, as we have attempted to demonstrate, these would not be a complex technical resource once the formula is known. Thus, the correct differentiation between the types of roofs is a key aspect, since the mechanical behaviour of flat roofs is very different from that of domes and vaults, as are their construction process and the materials used. This distinction also carries important historical and cultural implications. Furthermore, we must remember that in a building, all the construction elements are interrelated, so that the presence of a specific roof system conditions the rest of the architectural elements. Similarly, the misidentification of one of them will cause problems or inaccuracies in the interpretation of the rest of these construction elements.

The aim has been to lay the foundations for studying these structures in archaeological contexts, providing a necessary critical perspective while also proposing new lines of research. Therefore, it is a good time to begin designing a working protocol to identify and interpret the domes and vaults used in earthen architecture in the archaeological record, as they may go unnoticed either because they are not considered as options or because the level of destruction of the architectural structures prevents their recognition. This problem, the lack of unified methodologies, extends to much of the earthen architecture in pre-Roman and pre-Hellenistic contexts, so it will be one of the main tasks we will be working on in the coming years. Likewise, it is important to trace the evolution and spread of this type of roofing throughout the Mediterranean. Therefore, this work opens the door to further studies that will undoubtedly shed light on the historical process associated with this type of structure.

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Building a Mesolithic Hut. A Social Interaction Analysis of Coordinated Engagement with the Material Environment

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Abstract: This contribution addresses the interactional and collaborative processes occurring during the reconstruction of a prehistoric building. Our aim is to explore possibilities for inferring prehistoric building practices and space usage through the analysis of present-day interactions. Thus, we seek an interdisciplinary exchange to explore common theoretical ground and to refine our methodology. The project featured here uses space-based multimodal interaction analysis to study the interactional appropriation of past architectural spaces. In interaction analysis, the structure of architecture and landscape is considered a resource that participants can draw upon when organising their social activities. The analysis is based on audiovisual recordings of the building of a Mesolithic-style hut by a group of experts and laypeople during a citizen science event at FU Berlin. The recordings document three perspectives: the external observer's perspective (static camera), the internal observer's perspective (mobile camera) and the internal participant's perspective (bodycams). This allows for the analysis of interactional strategies that participants employ during the building process, including joint decision-making, giving instructions and coordinating actions. The analysis reveals the sequential integration of verbal, embodied, material and spatial resources in the building process, shedding light on the social and communal aspects of creating a common *here* for participants.

Keywords: Interaction, space, *origo*, multimodality, sociality.

Zusammenfassung: Dieser Beitrag thematisiert die interaktionalen und kollaborativen Prozesse, die während der Rekonstruktion einer prähistorischen Struktur zu beobachten sind. Unser Ziel ist es, die Möglichkeiten zur Untersuchung prähistorischer Bauprozesse und Raumnutzung durch die Analyse moderner Interaktionen auszuloten. Daher suchen wir den interdisziplinären Austausch, um gemeinsame theoretische Grundlagen zu erkunden und unsere Methodologie zu verfeinern. Das hier vorgestellte Projekt bedient sich der multimodalen raumbasierten Interaktionsanalyse, um die interaktionale Aneignung vergangener architektonischer Räume zu untersuchen. In interaktionsanalytischen Studien werden die Strukturen von Architektur und Landschaft als eine Ressource gesehen, die Teilnehmer:innen für die Organisation ihrer sozialen Aktivitäten nutzen. Die Analyse basiert auf audiovisuellen Aufnahmen des Bauprozesses, bei dem Laien unter Anleitung von Expert:innen eine Hütte im mesolithischen Stil im Rahmen eines Citizen Science Events an der FU Berlin errichteten. Die Aufnahmen dokumentieren drei Perspektiven: die externe Beobachterperspektive mit einer statischen Kamera, die interne Beobachterperspektive mit einer mobilen Kamera und die interne Teilnehmer:innenperspektive mit Körperkameras. Dies erlaubt die Analyse interaktionaler Strategien, die Teilnehmer:innen im Bauprozess anwenden, wie gemeinsames Entscheiden, Instruieren und Kollaborieren. Die Analyse zeigt, dass verbale, körperliche, materielle und räumliche Ressourcen sequenziell in den Bauprozess integriert werden und die damit verbundenen sozialen und kommunalen Aspekte der Herstellung eines den Teilnehmer:innen gemeinsames *Hier*.

Schlagwörter: Interaktion, Raum, *origo*, Multimodalität, Sozialität.

Introduction

We live in a world largely built by humans which is interwoven with the sociocultural practices of the people that inhabit it together, day by day. We have no direct access to the beginnings of the relationship between human interactional practices and the emergence of built structures. In this contribution, we aim to open a narrow empirical window onto these beginnings by illustrating the analysis of video-recorded interaction and fine-grained multimodal transcripts of the collaborative construction of a simple structure: a prehistoric-style hut built by experts and lay participants. Can we, by analysing such practices and their relationship with the built environment, make inferences about the prehistoric forms of use of built spaces? If so, we need detailed empirical knowledge about the interactive use of modern everyday environments. With this contribution, we would like to invite researchers from archaeology to join us in exploring the potential of multimodal space-based interaction analysis as a methodological tool and theoretical framework for the investigation of interaction in the past, in particular in and with prehistoric structures and buildings.

In this contribution, we would like to introduce an approach that was developed in the social sciences and ethnomethodology (Garfinkel 1984) and draws on subsequent, but related, developments such as conversation analysis (Sacks 1992) and interaction analysis (LeBaron and Streeck 1997). The approach is called multimodal space-based interaction analysis (Hausendorf *et al.* 2016; Jucker *et al.* 2018) and aims at reconstructing the ways in which participants construct and integrate the material and spatial affordances of their physical environment into the sequential organisation of their interactions—i.e. how they are 'doing space' (Jucker *et al.* 2018). Studies in this field primarily focus on social interaction in modern, architecturally modified spaces. These spaces are seen as manifestations of culturally transmitted and sedimented interactional orientations—i.e. they reflect cultural practices of designing and using space in the accomplishment of social interactional aims (Wilton 2025).

By taking an ethnomethodological perspective, we focus on how participants in an interaction produce social order in their everyday activities, and how they draw on various resources, such as talk, embodied actions and spatial and material affordances for cooperative action and meaning-making (Ciolek and Kendon 1980, Streeck *et al.* 2013). Traditionally, conversation analysis focuses on a variety of everyday social activities that range from conversations at the coffee table, encounters in public, workplace interaction and specialised ways of interaction, for example in dancing lessons or while jogging together. An important insight of conversation analytic work is that cooperative action is ordered; specifically, that it is ordered sequentially, by each contribution building on the previous one and preparing the ground for the next contribution. As Schegloff and Sacks (1973: 299) put it: 'a pervasively relevant issue (for participants) about utterances in conversation is "why that now?"'. This is particularly obvious with contributions produced by different participants that are dependent on each other and paired, such as greeting and return greeting, or question and answer (Schegloff and Sacks 1973). Thus, interaction unfolds in time and intersubjectively between participants, reflecting *their* understanding of social and interactional order.

As each contribution to an interaction needs to make sense as it happens, participants in social interaction are required to make their understanding of the situation recognisable to the other participants to achieve meaningful cooperative action. This display is also accessible to the researchers, who then reconstruct the types of actions, including actions that are performed through speaking (*speech acts*), the (sequential) organisation of those actions and the achievement of intersubjectivity within social interactions. The aim of conversation analytic research is not to say anything about what happens in the minds of the interactants, what they think, believe or want at a particular moment—rather, interpretations are based on what is displayed by them to the others for interpretation in the interaction (Birkner *et al.* 2020: 18, Deppermann 2008: 50).

Our approach pays attention to the material environment in which interaction happens and the role this environment plays in the constitution, organisation and maintenance of social interaction. We postulate with Hausendorf (2013) that all social interaction—in its basic face-to-face form—is situationally anchored in a specific material setting. In order for people to engage in and accomplish a joint activity, they need to be aware of each other as potential interactants (co-orientation) and they need to find means of coordinating their interactional activities. To accomplish situational anchoring, participants orient towards environmental affordances (Gibson 1977), defined as the (material) properties that an object or a space offers to potential users; for instance, a flat surface provides support for sitting on. Thus, any particular space provides information on the kinds of interactions that are possible or even likely in that environment (Hausendorf 2013: 295, Hausendorf and Kesselheim 2013). Regular users of architecturally structured spaces are usually familiar with the orientations and interactional possibilities which a particular space offers—Hausendorf and Schmitt (2016: 28) call this *social topography* (*Sozialtopographie*). Modern urban citizens, for instance, generally know how to behave in public buildings like schools, shops, markets and in traffic, and are familiar with the kinds of interactions that typically happen there, in particular if they have been primarily socialised in those environments.

In contrast, familiarity with many past architectural structures, such as historical buildings and monuments, and their original uses might be largely absent for modern users (Wilton 2023). We can no longer observe or consult the societies that designed and used these environments, and their knowledge of how to use and behave in a particular setting is mostly lost. However, following Goodwin (2018), we take into consideration that actions in the present are shaped by the actions of predecessors whenever we use material objects that have their origin in the past. Every time an object, like a spoon or a hammer, or an architectural space, such as a house or a workplace, that has been designed or made by people in the past is used by modern people, it influences present-day actions: '(...) even the most mundane local sequences of action frequently incorporate, and accumulatively operate on, resources and solutions created by actors no longer present, but that structure the current landscape for action' (Goodwin 2018: 246). Ethnomethodological conversation and interaction analysis aim to uncover the fundamental processes of sense-making, particularly in seemingly mundane, familiar settings.

The above discussion demonstrates the potential of combining insights from EMCA and archaeology to analyse social organisation, interaction and meaning-making. Insights from both interaction analysis and archaeology can inform our knowledge of architecture and building as a social activity through time.

Methodology

Our data are audiovisual recordings of naturally occurring interactions in non-experimental settings (Mondada 2014). The activity we focus on is the construction of a Mesolithic-style hut under the guidance of experts in archaeology and ancient technology and with the help of volunteers, students and citizens as part of a citizen science event. We recorded specific phases of the building process from three different perspectives: 1) the external observer's perspective with a static camera that captures the overall setup from a distance, like a bystander who is not involved in the activity; 2) the internal observer's perspective with a mobile camera that records the building process, like a member of the team who is watching but not directly involved in the activity, and 3) the internal participant's perspective with body cameras that document the view of (some of) the participants who are actively involved in the building. The videos were transcribed using a combination of GAT2 (Selting *et al.* 2010) and multimodal transcription conventions (Mondada 2017). Analysis of the sequential organisation of coordinated action requires the use of both the recording and the transcript for each analysed sequence.

For this contribution, we introduce data to explore empirically how people 'begin' architecture by defining the boundaries of a structure with a focus on cooperative action. This step is not only relevant from an evolutionary perspective; the practice of 'beginning something' in a wider sense can be seen as a vital phase for human sociality in general and has, therefore, been researched extensively in interactional studies (e.g. Schegloff and Sacks 1973). To exemplify how we approach the data, we will present two transcripts of two related activities and our observations regarding our question of how constructing a building is interactionally accomplished (for a full interactional analysis, see Wilton 2025).

In our example, people are engaged in this building activity with the aim of recreating a structure that can be assumed to be a Mesolithic shelter or workplace (Milner *et al.* 2018). Reconstructions are an important aspect of archaeological investigation, in particular as part of experimental research into production processes and use-wear analyses (Moser 1993). While it is clear that modern people approach such tasks with different mindsets, bodily experiences and knowledge repertoires than prehistoric people, we believe that modern reconstructions and the creative process they constitute are a possible way to methodologically approach the social components of past building processes. By analysing a process of reconstruction, we hope to make inferences about possible and plausible past construction processes and their social organisation. It is important to note, however, that we do not collect archaeological data in the strict sense, but interactional data that emerge in an archaeology-related context.

Extract I: defining the outline

In this extract (see figure 1 below), two participants in the interaction define the outline of the future hut on the ground. Participant 1 (PA1) suggests using sand as a material to mark the boundary. She uses a string and a scratching tool to scratch a circular shape into the grassy ground and asks Participant 2 (PA2) to scatter sand along the scratched line. While they do so, PA1 loses her grip on the string twice, meaning she has to recover it before continuing.

From this extract, we can make the following preliminary observations:

The establishment of a boundary of the future structure is identified as a fundamental and foundational step in the building process. Participants solve the task of establishing such a boundary for the structure *ad hoc* and with locally available materials. To mark the circle of a suitable size that the team had established earlier in the process, a pin is fixed to the middle of the circle and its circumference is drawn by scratching the ground with a sharp implement attached by a string to the pin. Additionally, PA1 suggests marking the faint scratched line with sand to make it more visible. The execution of the marking is done cooperatively between PA1 and PA2 and is established very quickly. PA1 scratches a faint line into the grassy ground—its visibility is only very local and potentially transient. It becomes clear that the scratched line is intended for PA2 to notice and to build her action of distributing sand upon it. The line on the ground becomes a significant boundary the minute it is established, to which participants subsequently orient their actions. As such, the line is both a symbol of the (future) border and the border itself.

It is interesting to note that the participants choose sand for a more pronounced marking of the line: a material that is not linear (such as long twigs or a length of string) but malleable into a linear shape and of visible contrast to the grassy and earthen surface. Nevertheless, the marking can certainly not be expected to be permanent; this means that the whole action is locally and temporally restricted and anticipates further action to follow very soon. The choice of material is noteworthy: it is transient and embedded in the sequence of events, as it will disappear soon. Like most auxiliary items used in

```
(01) PA1: ‡((NAME)) would YOU take (.) the sand,
          ‡looks at PA2-->
(02) PA1: +and i_ll show how #(-),
          +points fingers at ground in circular movement->
          ------>
```


```
     fig                     #
(03) PA2: *mHM,*
          *nods*
     pa1  ----->
          ----->
(04) PA1: the ‡the CIR+*cle,+*
          ----------->+bends down+
          --->‡looks down------>>
     pa2              *bends down*
```

Planning of the shape

```
(05) PA1: +*and you,
     pa1  +moves scraper and string in a line ->
     pa2   *takes sand------------------------->
(06) PA1: you (TAKE the sand) okay?
          -->
     pa2  -->
(07)       (3.0)+
     pa1  -->+
     pa2  -->
(08) PA1: +whoops.+*
          +readjusts string+
     pa2  ------->*
(09)      #+*(5.0)
     pa1  +moves scraper and string----------->
     pa2   *trickles sand on line--->
```

```
     fig  #
(10) PA1: naja-
          ah well
          -->
     pa2  -->
(11) PA1: *n bisschen weiter außerhalb,+
          a litte bit further outside
          ---------------------------->+
     pa2  *moves bag closer and takes sand->
(12) PA1: +HOA!?+
          +loses string+
     pa2  ------------->
(13) PA1: +dieses DING,+
           this thing
          +readjusts string+
     pa2  ----------------->
(14)      +(8.0)
     pa1  +moves scraper and string-->>
     pa2  ->*trickles sand---------->>
```

Co-ordinated co-operative action

```
(15) PA1: i think- (--)-
(16)      the mesolithic- (2.0)
(17)      were not so exact too [he he];
(18) PA2:                       [<<:-)>hmhm>]
```

Verbal comment on connection to past

Figure 1. Multimodal transcript of Extract I: defining the outline.
Transcription conventions for these videos are provided in Appendix I.

construction, it is not visible in the end product. Considering that these items have an important role in the building process, it is worth focusing more on such materials in the analysis.

Participants coordinate their actions through verbal explication. PA1 explains the way tasks are shared (lines 01–04) while moving from depicting the future shape (she moves her hands in a circle) to preparing her part in the action by starting to look and bend down (line 04). PA2 immediately joins her by bending down and getting ready to attend to her task. This close alignment of the verbalisation and the actions of the participants becomes visible when PA2 takes some sand from the bag even before PA1 repeats her instructions (line 07). The subsequent implementation of the joint action does not require any more verbal coordination but is done through mutual bodily orientation towards each other and the emerging border.

The participants make explicit verbal reference to the past ('The mesolithic were not so exact too', lines 15–17). The participants' own experience during the action (precision is not possible as the tools prove somewhat difficult to handle) is related to and projected onto the process of building in the past. Through verbalisation/explicit comment, it becomes available to others for commenting and reflecting upon. This makes the building of a reconstruction an activity both of the present and of the past—assumptions about past building processes and techniques employed by predecessors are developed and verbalised during embodied action, showing how bodily experience generates insights and stimulates reflection on predecessors' actions and practices.

During the following stages of the building process, two further instances reveal an orientation towards a boundary: the construction of the domed roof of the hut by the joining of two hazel rods and the construction of the entrance. We will discuss some observations of the roof construction in more detail in the following section. For a full analysis of both instances, see Wilton (2025).

Extract II: joining the roof

In this extract (see figure 2 below), participants turn the two-dimensional boundary of the circle on the ground into a three-dimensional structure by joining the first two hazel rods used to support the domed structure of the hut. This phase was filmed from three different perspectives (external observer, internal observer and participant). We can see how the moment of joining the rods is a collaborative achievement, as none of the three perspectives allows any one person to make a judgment about the exact position of the middle of the roof. PA2 is on a ladder, while PA1 bends the rods that are secured in the ground towards her for joining. To make sure that the joint is in the right place for the overall design of the structure (the 'middle'), PA2 enlists the help of PA1 and PA4, whose positions relative to the joined rods allow an assessment of their proper alignment.

From this section, we can make the following preliminary observations:

Like in the first example, the participants are engaged in the joint action of establishing a boundary—this time, it is the outer boundary of the domed cover that will define the hut's three-dimensional appearance. It anticipates the entirety of the structure and its (closed) boundaries, separating an 'inside' from an 'outside'. To do this, the participants use materials selected specifically for the task (hazel rods) that will be part of the permanent structure of the hut. The negotiations accompanying the correct positioning of the joint (in the middle of the roof) point to further actions that will build upon the action of the first joining.

With the extension of the layout into a structure, the participants establish a three-dimensional space within the environment to which they now orient their actions and movements. PA2 relies on PA1 and PA4 to give her information about the overall appearance of the structure, as, from her perspective, she

```
(01) PA2: ‡und jetzt,
           and now
     pa1  ‡at branch->
(02) PA1: *DE::R und der gegenüberliegenDE,‡*
           this one and the one opposite
     pa1                                -->‡
     pa2  *moves right arm towards first branch*

(03)      +‡*(5.0)
     pa1  +moves branch to PA2->
           ‡at both branches--->
     pa2    *joins branches---->
(04) PA1: joa-+‡*
     pa1  --->+
          ---->‡
     pa2  ----->*
(05)      +‡(2.0)
     pa1  +moves to edge of circle->
           ‡at branches and PA2---->
(06) PA3: &can i have the: (.) KNIFE?+‡&
     pa1                          -->+
                                   -->‡
     pa4  &walks to edge of circle---->&
(07) PA2: +‡@&can you have a+ LOOK?‡
     pa1  +rubs palms+
           ‡at PA3 and PA4‡
     pa3    @walks to PA4->
     pa4     &hands knife to PA3->
(08) PA3: [inaudible 2.5 seconds]@
     pa3                      -->@
     pa4  -->
(09) PA2: [‡*WHEther it's in the middle (.) here?]‡*
     pa1   ‡at PA2------------------------------->‡
     pa2    *points at ground moving hand in circle*
     pa4  -->
(10) PA3: +‡(the OTHer one)+&
     pa1  +takes step back and puts palms together+
           ‡at branch joint->
     pa4                 -->&
(11) PA2:  +more [or LESS,]+
     pa1   +steps forward and raises arm+
           -->
(12) PA4:       &[oh (so)]&
                &hands other knife to PA3&
     pa1   -->
(13) PA1: +&yeah,
     pa1  +points at middle of branches->
          -->
     pa4   &walks to PA1 and PA2->
(14) PA1: i think the middle is like right here,+‡
     pa1                                    -->+
                                             -->‡
     pa4  -->
(15) PA2: ‡*Okay;‡&
     pa1  ‡at ground‡
     pa2   *takes leather strap from shoulder and ties it around branches->>
     pa4  ------->&
(16)      +‡&(4.0)
     pa1  +walks to edge of circle
           ‡at branches->>
     pa4    &holds branches together-->>
(17)      +(2.0)
     pa1  +walks around PA2 and PA4->
(16) PA2: okay;+
     pa1  ---->+
(17)       (2.5)
(18) PA2: Okay;
```

Co-ordinated joint action of determining the middle of the domed structure

Figure 2. Multimodal transcript of Extract II: joining the roof.

cannot judge the symmetry of the arrangement in full. PA1 offers his advice on the task at hand, but the most reliable are views from the outside of the structure that encompass the whole picture.

We can see quite clearly how the steps in the construction of the three-dimensional structure of the hut are joint, coordinated processes that require participants to take up and align individual perspectives to achieve a stable structure. They accomplish this without any specific tools for measuring, positioning or securing the materials, thus showing that the process of construction is fundamentally interactional and collaborative (Murphy 2004). This insight might be useful in informing the archaeological analysis of structural remains and their sequential deposition.

Discussion

The analysis sheds empirical light on how participants literally 'make space'. Participants use tools to help them do so: the piece of string attached to a peg in the centre of the future hut enables PA1 to maintain the circular shape envisaged for the structure. With this, she draws on a specialised solution for marking a circle on the ground that is based on predecessors' design and requires only simple tools. Essentially, '[w]orking with, and transforming, materials inherited from our predecessors is central to the accumulative organization of human action, culture, and society' (Goodwin 2018: 245).

We can see quite clearly that joining the roof—at least in this case—is a cooperative activity that requires, or is easier to accomplish with, at least two people: one for holding the rods together in the desired shape and one for tying the rods at different points to get an even curve. For reasons of space, we did not discuss the construction of the entrance here, but we can see in all three instances that participants engage in the separation of a *here* from a *there*, showing a concern for spatial arrangements and the ensuing liminality. In the extracts discussed above, the boundary separated an inside from an outside, and with the subsequent construction of the roof as a boundary, a below is separated from an above. Some theorists of architecture regard this kind of separation as the foundational act of architecture (Baecker 1990; Cache 1995). Through drawing the outline and joining the roof, participants establish the structure step by step as an external, material arrangement that gradually produces a physically and spatially distinct here and there. This differentiation constitutes the basic condition for a common here that can subsequently be inhabited and socially shared.

The establishment of a common *here* is also significant in linguistic theory. It marks the centre of the social situation (the *origo* in linguistic terminology) from which deixis—the linguistic, but also gestural reference to objects in the environment—becomes possible in the first place (Bühler 1990). It is thus the place from which the world is seen and—from a social constructivist perspective—constructed and negotiated linguistically. The common *here* thus serves as a basis for the anchoring of a social situation as postulated by Hausendorf (see above), which is fundamental to both linguistic and architectural theory. Moreover, the above analysis shows that during the building process, participants create the *here* together: during their activity, they establish and maintain a common interactional space that is influenced by the affordances of the emergent structure and the joint tasks that need to be carried out together. At the same time, they need to work towards a shared imagined space-to-be (see Bühler 1990 and his concept of imaginary deixis) until that space materialises in some way. For this, the idea of the future dimensions and boundaries of the building needs to be maintained during the interaction (Wilton 2025). Thus, by engaging with their material and spatial environment during the building process, participants create a new *origo* with linguistic, ideational and material resources that emerges in their shared deictic world.

Finally, the extracts shed empirical light on *ad hoc* coordination as one of the basic processes necessary for any building activity. Participants engage with each other and with the materials at hand by finely adjusting their coordinated embodied and verbalised conduct. In their actions, the participants treat the material and the shapes and environments they create with them as prerequisites for subsequent actions. Every step in the building process builds on the steps before and anticipates what will follow. Thus, joint building activities establish a sequence of actions in which tasks are jointly negotiated. Building a structure of this kind then becomes an inherently communal, social and sequentially unfolding activity.

Such an analysis of the sequential organisation of interaction when creating built environments does not only shed light on the way sociality operates in modern times—in our case, during the reconstruction of a prehistoric hut—but it also opens the possibility of gaining insights into past building processes. It is evident that the activity presented here cannot simply be mapped onto or projected into the prehistoric past, but the insight that such enterprises are accomplished as a joint social activity certainly needs to be considered when analysing past building processes. When analysing social actions in material environments, functional and pragmatic aspects, such as protection from weather, danger or temperatures, might dominate our perception of what 'making space' is about. Similarly, choices like the distance between rods, the symmetry of the roof or the location of the entrance seem to follow primarily functional reasons of stability, endurance and accessibility. However, we believe that a detailed analysis of the interactional processes can uncover how a sense of place-making, of creating an inside and outside, a *here* and *there* coupled with an awareness of aesthetic and stylistic aspects, is part of fundamental social processes of the relationship between humans and their material environment.

Based on the above observations, we ask the following questions that we would like to further explore in collaboration with archaeology:

Does the archaeological record tell us something about the significance of establishing boundaries during building processes, and if so, in what way? Can such evolving boundaries be understood as moments of transition or liminality, and might they leave material traces of a shared *origo*—that is, a spatial centre that enables joint orientation and that constitutes a prerequisite for spoken interaction and the emergence of language?

Can we see traces of the sequentiality of the building process in the archaeological record and, if so, what can this tell us about building as a fundamentally social, cooperative activity unfolding over time?

A fine-grained analysis of the social organisation of building may allow insights into the creation and function of early buildings and architectural structures, while at the same time shedding light on general aspects of social organisation. A focus on the role of objects and environments in interaction places an emphasis on the material that archaeology can support and benefit from. If you are interested in exploring how our approach can complement archaeological investigations into prehistoric structures and building processes, please do not hesitate to contact us.

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Table 1. Transcription conventions, adapted from Selting *et al.* (2011) and Mondada (2016).

Sequential structure	
[ ]	Overlap and simultaneous talk
=	Fast, immediate continuation with a new turn or segment (latching)
Pauses	
(.)	Micro pause, estimated, up to 0.2 sec. duration
(0.5)/(2.0)	Measured pause of approx. 0.5–2.0 sec. duration (to the tenth of a second)
Other segmental conventions	
::	Lengthening, approx. 0.5–0.8 sec.
Accentuation	
SYLlable	Focus accent
Final pitch movements of intonation phrases	
?	Rising to high
,	Rising to mid
–	Level
;	Falling to mid
.	Falling to low
Multimodal elements	
* *	Gestures and descriptions of embodied actions are delimited between
+ +	two identical symbols (one symbol per participant)
Δ Δ	and are synchronized with corresponding stretches of talk
*--->	The action described continues across subsequent lines
---->*	until the same symbol is reached.
>>	The action described begins before the excerpt's beginning.
--->>	The action described continues after the excerpt's end.
ric	Participant doing the embodied action is identified when (s)he is not the speaker.
fig	The exact moment at which a screen shot has been taken
#	is indicated with a specific symbol showing its position within the turn at talk.

The EARTHERITAGE Project.
Earthen Heritage in the Eastern Mediterranean between Archaeology and Sustainability

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Abstract: This paper presents the EARTHERITAGE Project, a two-year research programme focused on the analysis, documentation and development of preservation strategies for earthen architectural heritage in the Eastern Mediterranean, with particular attention to the island of Cyprus. The project was grounded in a synergic dialogue between archaeological, geoarchaeological and architectural approaches, involving multiscalar analyses of prehistoric earthen architectural evidence across the island. Research activities integrated archaeological and geoarchaeological investigations of prehistoric earthen building materials with detailed geomorphological and pedological studies of the natural environment of southern Cyprus, selected as the main study area. The resulting dataset supported a programme of technical experimentation on implemented earthen products, informed by ancient construction practices and local raw materials. Experimental analyses are currently ongoing and aim to contribute to the development of a research framework for evaluating the potential use of these materials as sustainable solutions for the conservation and preservation of archaeological earthen structures in Cyprus.

Keywords: Earthen Architecture, Prehistoric Cyprus, Cultural Heritage, Eastern Mediterranean, Geoarchaeology.

Riepilogo: Il Progetto EARTHERITAGE qui presentato rappresenta un programma di ricerca biennale i cui obiettivi primari sono l'analisi, la documentazione e lo sviluppo di strategie di conservazione del patrimonio architettonico in terra cruda nell'area del Mediterraneo orientale, con particolare attenzione all'isola di Cipro. Il progetto promuove un dialogo sinergico tra approcci archeologici, geoarcheologici ed architettonici, e si è focalizzato su un'analisi multiscala delle evidenze in terra cruda relative all'architettura preistorica sull'isola. Le attività di ricerca hanno integrato indagini archeologiche e geoarcheologiche sui materiali da costruzione preistorici con

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studi geomorfologici e pedologici dell'ambiente naturale della regione meridionale costiera di Cipro, selezionata come regione-chiave per lo sviluppo dell'indagine. I dati ottenuti dall'integrazione delle analisi archeologiche e geoarcheologiche hanno supportato un programma di sperimentazione tecnica su prodotti in terra cruda realizzati secondo pratiche costruttive antiche e materiali locali. Le analisi sperimentali sono attualmente in corso e mirano a contribuire allo sviluppo di un quadro di ricerca finalizzato a valutare il potenziale impiego di questi materiali come soluzioni sostenibili per la conservazione del patrimonio architettonico in terra cruda nell'area del Mediterraneo orientale.

Parole chiave: Architettura di terra, Cipro preistorica, Patrimonio culturale, Mediterraneo orientale, Geoarcheologia.

Introduction

Over the past decade, the rich archaeological and vernacular earthen architectural heritage of the Eastern Mediterranean has been the focus of interdisciplinary research involving archaeologists, geoarchaeologists and architects. A wide range of methodological applications has been developed to investigate this architectural legacy. These include environmental and geoarchaeological studies aimed at reconstructing the formation, use and degradation processes of earthen structures in both archaeological and vernacular contexts (e.g. Friesem *et al.* 2011, 2013), as well as analytical and compositional studies of mudbricks and earthen construction materials addressed to examine properties and technological choices (e.g. Devolder and Lorenzon 2019; Lorenzon 2024; Love 2012; Nodarou *et al.* 2008). In parallel, research programmes and conservation initiatives have addressed the protection and enhancement of the earthen Mediterranean landscape (e.g. Achenza and Sanna 2011; Costi de Castrillo *et al.* 2017; Germanà 2013), while experimental and interdisciplinary approaches have been increasingly employed to test sustainable solutions for the preservation of ancient and modern earthen architecture (e.g. Sadozaï and Gandreau 2020). Together, these studies have highlighted the need for multiscalar and integrative frameworks capable of bridging material analysis, environmental context and conservation practice.

Thanks to its rich archaeological and vernacular earthen architectural heritage, Cyprus represents a key case study for advancing current knowledge on earthen architectural practices in the Eastern Mediterranean. In particular, the southern region of the island offers significant potential for investigating long-term continuities and transformations in earthen building traditions across prehistoric, historic and modern contexts. The local geology, characterised by white chalk and marl of the Pachna Formation (Noller 2009), has created favourable conditions for earth-based construction practices. In fact, soils and bedrock derivatives have been traditionally exploited for wall construction, roof systems and surface finishes, resulting in a diversified but technologically coherent earthen architectural tradition. The widespread use of *Havara* (surficial, soft and carbonaceous, clastic rock) and *Kafkalla* (calcium-rich duricrust of pedogenic origin) (Schirmer 1998) constitutes the primary material basis of earthen architecture on the island from the Neolithic period onwards.

Interdisciplinary investigations of archaeological and vernacular earthen structures in southern Cyprus have already demonstrated the analytical potential of combined archaeological, architectural and geoarchaeological approaches (Amadio 2024; Gkouma *et al.* 2021; Lorenzon and Iacovou 2019; Lorenzon *et al.* 2023; Hourani 2003, 2011; Mylona *et al.* 2023, 2021; Philokyprou 2018; Philokyprou and Limbouri-Kozakou 2015; Philokyprou *et al.* 2017). These studies have underscored the strong interdependence between geological resources, construction techniques and architectural performance, while also revealing the vulnerability of earthen structures to environmental and anthropogenic degradation**.** Nevertheless, despite the growing body of research, systematic and comparative investigations that explicitly integrate material characterisation, environmental analysis, experimental replication and conservation-oriented testing remain limited.

Within this research landscape, the EARTHERITAGE Project was carried out between February 2024 and February 2026 and was conceived to address this gap by developing a multiscalar and interdisciplinary framework for the study of earthen architecture in Cyprus. The project builds upon a long-term research trajectory at the Middle Bronze Age site of Erimi-*Laonin tou Porakou* (henceforth Erimi-*LtP*), where preliminary archaeological and geoarchaeological investigations of earthen materials have been conducted since 2013 (see Amadio 2017: 259-276, 2024). By combining archaeological and geoarchaeological analyses of prehistoric earthen buildings with detailed geomorphological and pedological investigations of the surrounding landscape, the project generated a comprehensive dataset on raw material procurement, material selection and construction practices. This dataset encompasses a wide range of earthen architectural components, including mudbricks, roofing materials and plasters applied to floor and wall surfaces. This formed the basis for targeted experimental programmes aimed at implementing and testing earthen products derived from local materials, with the explicit goal of evaluating their suitability for sustainable conservation and preservation strategies.

In doing so, the project contributes not only to the reconstruction of past building knowledge but also to the development of context-sensitive approaches for safeguarding earthen architectural heritage in Cyprus and more broadly in the Eastern Mediterranean.

Research framework and analytical approach

This study builds on the research activities carried out within a two-year programme dedicated to advancing current knowledge of earthen architecture in Cyprus. The research was centred on the integrated analysis, documentation and conservation-oriented assessment of earthen architectural heritage, combining archaeological, geoarchaeological and architectural perspectives. A multiscalar analytical framework was applied to prehistoric earthen architecture from the Middle Bronze Age site of Erimi-*LtP* (*c*. 1950–1650 BC) (Bombardieri 2017) (Figure 1), selected as a key case study due to the good preservation of its earthen structures. The research was conducted within the framework of the EARTHERITAGE Project. Activities were developed as a joint research initiative involving the Universities of Siena, Genova and Palermo, each contributing complementary expertise in archaeological investigation, geoarchaeological analysis and architectural and material studies. This institutional collaboration enabled the integration of field-based observations, laboratory analyses and applied architectural research within a coherent methodological framework.

The analytical strategy adopted in this study is structured around three interconnected sets of approaches, designed to address earthen architecture as both a material and cultural phenomenon and as a resource for sustainable heritage preservation. These approaches combine (1) archaeological and geoarchaeological analyses of earthen building materials and construction techniques, (2) geomorphological and pedological investigations aimed at reconstructing the environmental context of raw material procurement and (3) experimental and architectural studies focused on the implementation and testing of earthen products for conservation purposes. Together, these methods allow for the examination of production choices, technological knowledge and material performance, while also assessing the potential transferability of past building practices to present-day conservation strategies (Figure 2).

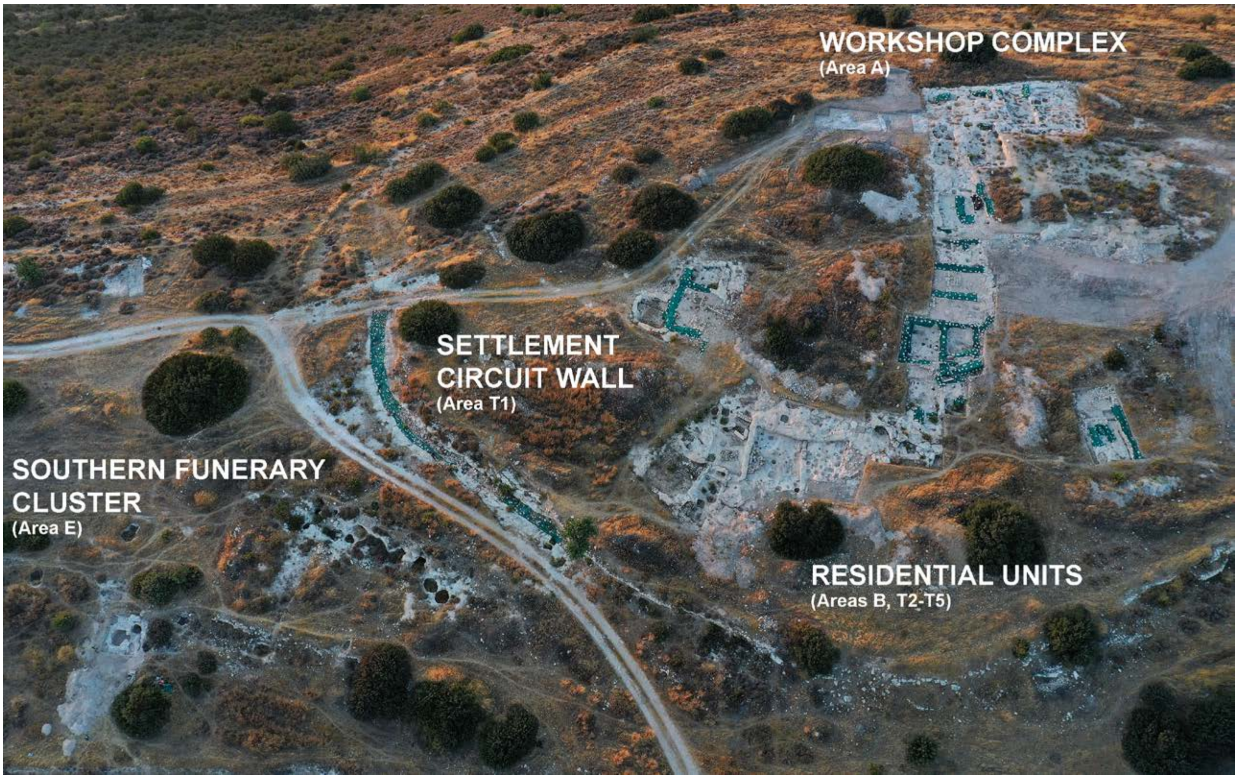

Figure 1. Aerial photograph of Middle Bronze Age Erimi, in the Kouris Valley, Cyprus (Erimi Archaeological Project Archive).

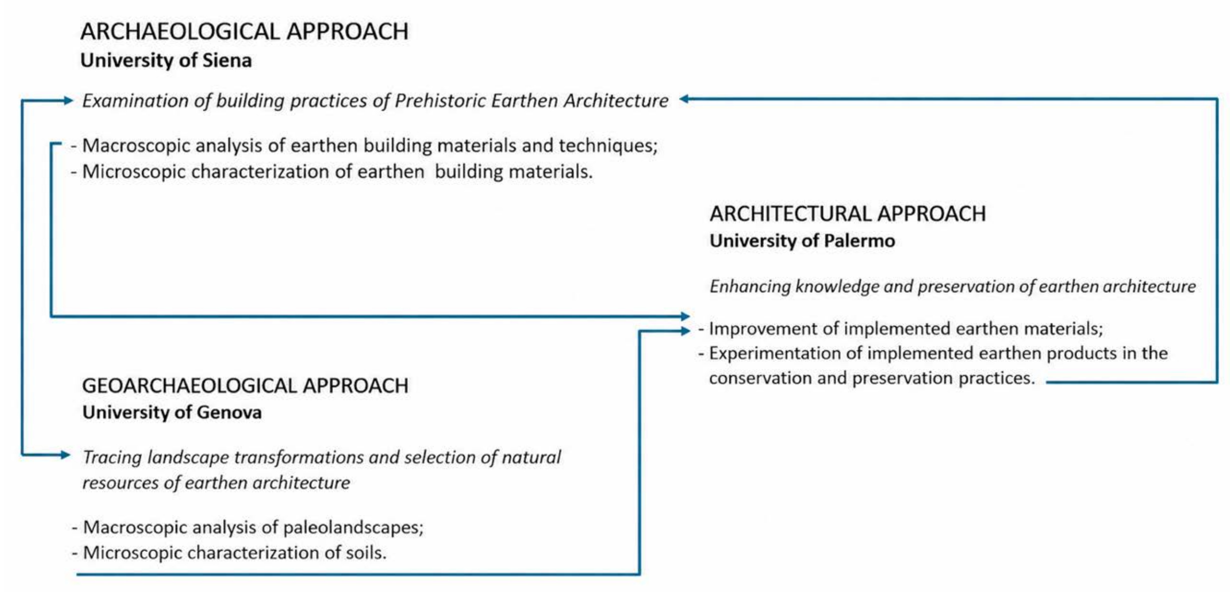

Figure 2. Graphs showing the three intertwined research approaches applied in this study.

Figure 3. Macroscopic analysis and documentation of mudbrick samples during fieldwork activities (EARTHERITAGE Project Archive).

Archaeological and material analytical approach

The archaeological component of this study focuses on the scientific examination of earthen architectural remains preserved in the prehistoric archaeological record of Cyprus. The Middle Bronze Age site of Erimi-*LtP* constitutes the primary context of investigation, serving as both a case study for the analysis of ancient earthen construction practices and a reference framework for evaluating preservation and conservation strategies. Rather than being treated solely as a conservation target, Erimi-*LtP* is approached as an analytical laboratory for examining the materials, techniques and organisational choices underpinning earthen architecture in antiquity.

Archaeological analyses were structured according to multiple and increasing scales of observation and combined in-field recording with laboratory-based investigations. Fieldwork activities included systematic macroscopic examination and documentation of prehistoric earthen structures at Erimi-*LtP*, with particular attention to construction techniques, architectural layouts and the main constitutive elements of walls, floors and associated features (Figure 3). This phase aimed to reconstruct technological practices and material choices related to the production and use of mudbricks and other earthen building materials, such as plasters and roofing components. Observations from Erimi-*LtP* were contextualised through comparison with published evidence from other prehistoric sites in Cyprus and the wider Eastern Mediterranean.

Field investigations also involved a targeted sampling strategy designed to capture variability in production modes and construction practices. Earthen building materials were sampled from both domestic units and productive or communal architectural contexts within the settlement. This comparative approach allowed for the examination of potential differences between household-level

Figure 4. Micromorphological sampling of a paleosol buried by a *Havara* deposit in the Kouris Valley during the geoarchaeological activities (EARTHERITAGE Project Archive).

and supra-household or communal building practices, contributing to broader discussions on labour organisation and social dynamics within Middle Bronze Age communities on the island. Archaeological fieldwork and sampling were carried out in close coordination with geological investigations, enabling continuous data exchange and the refinement of in-field analytical strategies.

Macroscopic observations were complemented by high-resolution laboratory analyses aimed at achieving a comprehensive characterisation of the sampled earthen materials. These analyses included: (a) micromorphological investigation of thin sections (Figure 4), (b) particle size analysis, (c) elemental characterisation through X-Ray Fluorescence (XRF) and Electron Microscopy coupled with Energy Dispersive Spectroscopy (SEM–EDS), and (d) mineralogical and molecular analyses using X-Ray Diffraction (XRD) and Fourier-Transform Infrared Spectroscopy (FTIR). The integration of these methods enabled the reconstruction of raw material selection, preparation techniques and manufacturing processes, providing a robust analytical basis for interpreting technological knowledge and construction practices in prehistoric Cypriot earthen architecture.

Geoarchaeological and landscape analytical approach

The geoarchaeological component of this study investigates human-environment interactions within the broader landscape of the Kouris Valley, where Erimi-*LtP* is located. Geomorphological and pedo-stratigraphic analyses were employed to reconstruct landscape evolution, sedimentary processes and soil formation dynamics relevant to both settlement development and raw material procurement.

The geomorphological analysis involved the production of a standardised geomorphological map, developed within a GIS environment combining the interpretation of stereo-aerial photographs and field survey in the selected area to characterise the different morphologies. This mapping strategy enabled the identification of landforms generated by fluvial, colluvial and other surface processes, the assessment of the spatial distribution of erosional and depositional dynamics, and the reconstruction of palaeo-landscape evolution during the Holocene. Chronological constraints on sedimentary processes were obtained through the combined use of artefacts embedded within alluvial and colluvial deposits as relative chronological markers and selected radiocarbon analyses, providing numeric age estimates for major landscape formation and infill events.

Soil chronosequences and toposequences (catenas) were analysed to establish stratigraphic control and to correlate geomorphic units across the study area. In parallel, statistical analyses of spatial relationships between archaeological site locations and mapped geomorphic units were conducted to assess potential correlations between settlement patterns and specific landscape features. These procedures allowed for the integration of geomorphological data with archaeological evidence at a regional scale.

Geomorphological results were combined with newly acquired pedological data to construct a pedo-landscape map illustrating the spatial and temporal distribution of soils within the Kouris Valley. This dataset provided a key reference framework for evaluating the provenance of raw materials used in earthen architectural structures at Erimi-*LtP*. Soil samples collected from stratigraphically described horizons (Figure 4) were analysed using a suite of complementary laboratory techniques, including soil micromorphology, particle size distribution, pH, total carbonate content, total organic carbon and nitrogen, cation exchange capacity and concentrations of extracted chemical elements, as well as micromorphological, XRD and SEM-EDS analyses.

The resulting pedological and geochemical data were systematically compared with analytical results obtained from archaeological earthen materials. This integrated approach enabled the identification of shared compositional and mineralogical signatures, contributing to the reconstruction of raw material sourcing strategies and to the definition of the geological 'fingerprint' of earthen building materials used in Middle Bronze Age Cyprus.

Architectural and experimental conservation approach

The architectural component of this study integrates technical experimentation on earthen materials with applied testing of their use in conservation and preservation practices. These two dimensions are closely interrelated and were developed to bridge material performance studies with conservation-oriented architectural applications. At a technical level, the research focused on improving the mechanical behaviour and durability of earthen bricks, while at a technological level, it explored the applicability of the resulting materials within experimental conservation contexts.

Technical experimentation was directed at enhancing the mechanical strength and reducing the vulnerability of earthen bricks through the controlled addition of stabilising agents to the raw earth mixtures. Building on previous research, this study investigated the use of nanoparticles as stabilisers, with particular attention to Laponite®, a 'natural-synthetic' layered silicate (Scalisi and Sposito 2015). Two stabilising formulations were tested: a commercially available laponite and a laboratory-modified variant obtained through chemical surface treatment. In order to maintain a sustainability-oriented approach, chitosan was selected as a green polycation derived from renewable resources and industrial by-products of shrimp processing (Aguilar *et al.* 2016; Cavallaro *et al.* 2021; Zavaleta *et al.* 2024).

Hybrid laponite-chitosan nanomaterials were prepared following ratios defined by surface charge measurements and colloidal stability analyses of the mixtures. Experimental protocols were grounded in the characterisation of both raw natural materials and archaeological samples, ensuring methodological consistency with traditional earthen construction practices. Experimental brick specimens were produced using two manufacturing techniques: hand-moulded bricks formed by placing the mixture into moulds and compacting it manually, and compressed blocks manufactured using mechanical presses. All soil types employed in the experiments were sampled from the Kouris Valley area in southern Cyprus, ensuring coherence with the geological and pedological context of the archaeological case study.

The experimental samples were subjected to a series of physical and mechanical tests, and the results were compared both across sample types and with reference values reported in the literature. Material durability was assessed through exposure to natural weathering agents and through accelerated ageing tests conducted under controlled laboratory conditions. Following ageing procedures, specimens were re-tested to evaluate changes in physical and mechanical performance relative to unaged samples.

The results provide a basis for defining future directions in the sustainable conservation and valorisation of earthen heritage in Cyprus and the wider Eastern Mediterranean.

Results

The integrated archaeological, geoarchaeological and architectural analyses produced a coherent and multi-layered dataset that significantly advances current understanding of earthen construction practices in prehistoric Cyprus. Archaeological and material analyses of the Middle Bronze Age architecture at Erimi-*LtP* documented a high degree of technological consistency in the selection, preparation and use of earthen materials, while also revealing variability linked to functional contexts and construction scales (Amadio *et al.* forthcoming).

Geoarchaeological investigations in the Kouris Valley resulted in a detailed reconstruction of the geomorphological and pedological framework of the area (Rellini *et al.* forthcoming). The combined geomorphological mapping, soil analyses and stratigraphic correlations clarified Holocene landscape evolution and sedimentary dynamics, providing essential contextual data for interpreting settlement location, raw material availability and post-depositional processes. The pedo-landscape reconstruction demonstrated a strong correspondence between locally available soil resources and the compositional characteristics of archaeological earthen building materials, allowing for the definition of a geological and geochemical fingerprint for raw material procurement strategies (Ghislandi *et al.* forthcoming).

Experimental and architectural investigations are currently generating a growing body of data on the performance of stabilised compressed earthen blocks. Preliminary observations emerging from the analytical programme and the reviewed literature indicate measurable improvements in mechanical behaviour and durability, particularly in terms of compressive strength and resistance to weathering, depending on the adopted mix design and stabilisation strategy (Germanà and D'Amore 2025). These trends are being further examined through ongoing laboratory testing to better characterise material responses under standard conditions. Architectural experimentation at Erimi is ongoing and is conceived as an exploratory assessment of the potential applicability of the experimental materials within conservation-oriented archaeological contexts.

Conclusive remarks

Overall, the results highlight the potential analytical value of a multiscalar and interdisciplinary methodological framework for the study of earthen architecture. The integration of material characterisation, geoarchaeological landscape analysis and experimental conservation-oriented research enables a more contextualised interpretation of earthen building materials and construction practices, relating technological choices to environmental settings and architectural performance. While architectural experimentation and material performance assessments are still in progress, the ongoing experimental work is expected to contribute comparative data relevant to discussions of material compatibility and durability in conservation contexts. Taken together, these results support the applicability of integrated approaches for improving both archaeological interpretation and the development of informed, context-sensitive strategies for the conservation of earthen architectural heritage in Cyprus and the wider Eastern Mediterranean.

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Productive and Social Practices in Prehistoric and Protohistoric Earthen Building presents new perspectives on one of the most widespread yet historically undervalued forms of construction. Bringing together contributions from leading researchers, the volume explores the production, use and social significance of earthen architecture across a wide range of prehistoric and protohistoric contexts.

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