Mudbricks, Construction Methods, and Stratigraphic Analysis: A Case Study at Tell Timai (Ancient Thmuis) in the Egyptian Delta

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The Graeco-Roman site of Tell Timai (ancient Thmuis) in Lower Egypt is among the largest urban tells in the Nile Delta, boasting substantial amounts of preserved earthen architecture. Although earthen architecture made up the vast majority of public and domestic structures in ancient Egypt, it still does not receive the same analytical attention from archaeologists as other categories of evidence. This paper presents a case study for the archaeological investigation of the earthen architecture at Tell Timai. The goal was to develop a methodology that can be implemented in the field by excavators with little geoarchaeological training and limited laboratory access in order to generate useful data for determining building stratigraphy and studying construction processes. Through the close examination and sampling of three buildings of different periods and scales, we tested a new field methodology combining geoarchaeological techniques and mensiochronology. The results provide information useful for stratigraphy and phasing as well as for identifying specific patterns of mudbrick manufacturing, production, and construction during the Graeco-Roman period at Tell Timai.[1]

INTRODUCTION

Earthen architecture made up the majority of public and domestic structures in ancient Egypt. Nevertheless, it is Egypt's stone monuments that have traditionally attracted the most attention. While the study of mudbrick architecture in Pharaonic-period Egypt has developed steadily over

[1] We would like to thank the Timai team, especially the students who helped with this research, Natalie Marquez and Casey Preston; the resourceful Lori Lawson; and the *quftis* who tirelessly worked with us, especially our head *qufti*, Abdul Aziz Farouk. We would also like to thank the Ministry of Antiquities and the inspectors who worked at Tell Timai for their continued support; the anonymous reviewers for the *AJA* for their feedback; Serena Love and Lisa-Marie Shillito for the long discussions on geoarchaeology and the extension of analytical methods in the field; and Becky Martin and Nick Hudson for their insightful comments and suggestions on an early draft of this paper. Figures are the authors' unless otherwise noted.

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the last 50 years, progress remains slow.[2] In particular, mudbricks have been underutilized as tools for stratigraphic analysis, and only limited work has been done to explore how methods and manufacturing processes of earthen architecture changed over time.[3] Although often overlooked by archaeologists, mudbricks are complex, multilayered artifacts that can provide technological, cultural, and stratigraphic insights into the built environment. As mudbricks are manufactured objects created by members of the community, they provide relevant information on community practices used in a given period.

The value of geoarchaeological techniques in the analysis of mudbricks as artifacts has been well established in the archaeological literature. For example, analysis of variability in mudbrick morphology and recipes can reveal information about workshops, organization of labor, and environment as well as about the mode of production (e.g., whether mudbrick production is centrally based or household-based).[4] Recent studies in and outside of Egypt have explored some techniques that can be implemented in the field with minimal invasiveness and a small sample size. An example is Love's work at Çatalhöyük that used wet sieving and hydrometer analysis to analyze particle size and applied hydrochloric acid to measure calcium carbonate content.[5] Friesem's study on mudbricks in northern Greece shows the efficacy of geochemical techniques like Fourier-transform infrared spectroscopy (FTIR) in combination with micromorphology.[6] Emery and Morgenstein used geochemical fingerprints analyzed by portable X-ray fluorescence (pXRF) in the analysis of construction techniques.[7]

Yet, such analyses are the exception rather than the norm when it comes to studying the extensive earthen architecture of ancient Egypt. This is partly because of a lack of expertise and partly because of field circumstances. Lab setups and equipment that are usually necessary for the geoarchaeological study of mudbricks are not readily available in Egypt, and current antiquities restrictions do not allow for the export of samples. This has created a challenge for the ongoing archaeological project at Tell Timai (ancient Thmuis) in Lower Egypt, which is among the largest urban tells in the Delta (approximately 90 ha) and boasts substantial amounts of preserved earthen architecture (figs. 1, 2).

With a continuous history from the Late Pharaonic through the Early Islamic periods, Tell Timai presents an ideal setting for case studies in the construction practices and stratigraphy of earthen architecture. Even a cursory evaluation of the standing remains of the site shows that, for a large part of the site's history, mudbrick was the material of choice both for smaller, domestic structures and for public buildings. That Timai was a city predominantly of brick and not of stone is significant for our understanding of urban environments of Egypt in these periods. Traditionally, scholars have assumed that, in their urban forms, the centers of major cities in Graeco-Roman Egypt "became Hellenized and Romanized."[8] However, as observed by Wilson, historians have asserted a process of Romanization of Egyptian towns based on textual evidence that is far less readily evident in the material culture so far.[9] Our archaeological understanding of urbanism in

[2] General introduction to mudbrick in ancient Egypt: Nims 1950, which focuses on the use of vegetal temper in mudbrick production; Emery 2011a; 2011b. Use of earthen architecture in Pharaonic-period domestic contexts: Clarke and Engelbach 1999; Correas-Amador 2013. Kemp (2000) presents a good summary on the use of mudbrick architecture in ancient Egypt. Lorenzon and Zermani (2016) discuss the specific Timai context and the relevance of earthen architectural practices of the current community. Likewise, Fathy (1969, 1973) and Henein (1988) amply debate earthen construction techniques applied to modern Egyptian architecture and their sustainable, community-oriented characteristics. General introduction to geoarchaeological techniques applied to ancient Egyptian mudbrick architecture: Emery and Morgenstein 2007; Morgenstein and Redmount 1998. Contemporary earthen construction practices in relation to grain size and mudbrick performances: McHenry 1996; Minke 2006; Van Beek and Van Beek 2008.

[3] Dickinson 2014, 61.

[4] Rosen 1986; Marinova et al. 2011; Love 2013a, 268–69; Friesem et al. 2014a, 81–85; Lorenzon and Sadozaï 2018, 9; Lorenzon and Iacovou 2019, 357–59. By the term "recipe" we mean a set of ingredients and procedures used by brickmakers. Although all mudbricks are typically made up of more or less the same core raw ingredients, there can be significant variations in the makeup of the soil and the types and amount of temper. These variations are due to several factors, such as local geology, whether or not the soil was sieved, and adjustments by the brickmaker based on a sense of the soil during the mixing process (Littman et al. 2014, 61).

[5] Love 2012, 2013a, 2017.

[6] Friesem et al. 2014a, 81–85; Friesem et al. 2014b, 558–66.

[7] Emery and Morgenstein 2007, 113–15.

[8] Bagnall and Rathbone 2004, 42.

[9] Wilson 2012, 145. See Littman and Silverstein (2017) for

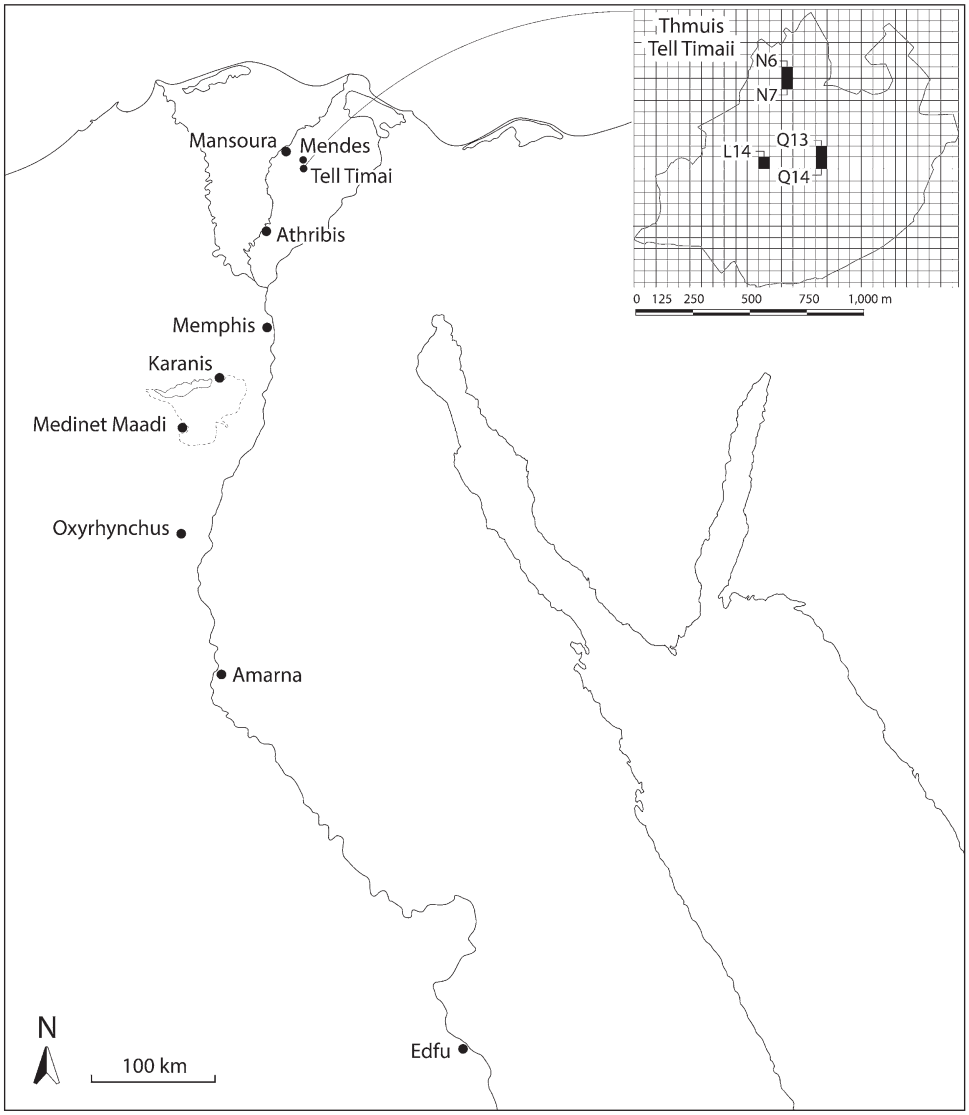

FIG. 1. Map of Egypt with inset of Tell Timai (drawing by N. Hudson).

Egypt during the Graeco-Roman period remains poor, so it is no wonder that scholars have tended to rely on literary and documentary sources (ostraca, epigraphic texts, papyrological texts) in lieu of physical evidence of buildings and towns.[10] Once mapped and analyzed, the mudbrick buildings of Timai will be able to contribute meaningful data to questions of continuity and evolution in indigenous building practices in the urban environments of Graeco-Roman Egypt.

Timai retains a considerable amount of standing architecture, but, absent extensive and long-term archaeological excavation, there is some uncertainty as to what periods of the town's history are reflected in the standing structures. Buildings of various periods are located at similar elevations, and the looting and quarrying of different parts of the site over the past centuries as well as the poor documentation of some of the early explorations mean that Timai has a complicated site-formation history. Like most Delta sites, Timai was subject to extensive quarrying of mudbrick for fertilizer (*sebakh*). Farmers mining for material

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the significance of Timai to the study of ethnicity and material culture in Ptolemaic Egypt.

[10] For the challenges facing the study of urban settlements in Egypt in these periods, see Davoli 2011, 69; McKenzie 2011, 8–18; and Wilson 2012, 138.

FIG. 2. View of mudbrick structures at Tell Timai, looking northwest (G. Bondar).

tended to sift out pottery and leave behind a sherd scatter that can skew the results of survey work.[11] These factors and the large size of the tell make it challenging to get a quick snapshot of the urban structure of Timai at any one period.[12]

In order to improve and accelerate our understanding of the building phases and the construction processes at Timai, we developed a new field method for analyzing earthen architecture. To facilitate analysis, we created a protocol that does not rely heavily on expensive equipment or extensive scientific expertise and that can easily be followed by field staff with little or no geoarchaeological training. Over the course of the 2014 field season, we developed and tested a field methodology combining simple techniques from geoarchaeology and building archaeology. In this undertaking, we were guided by two related questions: Is it possible to quickly and accurately detect distinct mudbrick recipes in the field and correlate them with wall construction methods? And can this information assist in determining the chronological phasing of Timai's buildings? Our primary goal was to find a consistent, reliable method that can be implemented by excavators with limited laboratory access and allow for real-time, stratigraphic feedback about the buildings they are excavating. As a secondary goal, we wanted to regularize a field recording method for earthen building materials in order to contribute to a growing database of information about mudbrick *chaîne opératoire* and construction practices. *Chaîne opératoire* is a framework of analysis that focuses on not only the manufacturing processes of production but also the social acts involved in these processes.[13] The *chaîne opératoire* approach allows researchers to identify the multiple operational steps of production and construction in architecture using the microscopic and macroscopic record. The analysis of the step-by-step process is essential for understanding its variations and the impact of such variations on the production of vernacular architecture in Egypt during the Graeco-Roman period when multiple traditions coexisted.

We tested our method in three buildings of different periods and scales. These buildings were chosen because they either had been recently excavated or had been identified for future excavation (more on

[11] Moeller 2016, 54. See Wilson (2012) and Lorenzon and Zermani (2016, 185) regarding the current state of fieldwork and mudbrick preservation in the Delta.

[12] This is a problem not just at Timai. One of the major factors holding back archaeologists' ability to study urbanism in Graeco-Roman Egypt is the difficulty of distinguishing the occupation phases and strata among structures visible at the surface (Davoli 2011, 72).

[13] Leroi-Gourhan 1964, 164; Haudricourt 1987, 107–10; Ingold 2001, 19–22; Roux 2016, 102.

this below). The number of buildings and samples was restricted by time and permit limitations. Although the results should be considered preliminary, they are nonetheless promising. First, we were able to provide useful data that supplemented and clarified other tentative phasing and diachronic (i.e., ceramic) information available for the buildings in question. Second, we were able to show that similar recipes and construction techniques were used for both a small-scale domestic building and a large-scale monumental building. This was in contrast to what we had assumed about construction practices at Timai. While we expected to find varying qualities of bricks used in domestic construction, we assumed that comparatively higher-quality bricks would have been used for public buildings. We conclude that employing this methodology along with traditional field methods of analysis has the potential to improve our understanding of the structures on the tell, in terms both of their dating and building history and of the community practices behind their construction.

SITE BACKGROUND

The site of Tell Timai, located in the Daqaliyah province in the northeastern Nile Delta (30°56'21" N, 31°31'00"E) approximately 17 km southeast of Mansoura, is bordered by the towns of Kafr El-Amir (to the northwest) and Timai el-Amdid (to the northeast; fig. 3). Known in antiquity as Thmuis (in Greek) and Tamawy (in Egyptian), ancient Timai was situated on the Mendesian branch of the Nile. Literary, papyrological, and archaeological evidence points to Timai's prosperity throughout the Hellenistic, Roman, and Byzantine periods. In particular, the discovery by early visitors to the site of numerous marble statues, high-quality mosaics (including the famous mosaic signed by the artist Sophilos), and carbonized papyri attests to its economic prominence during the Ptolemaic and Roman periods.[14] In his broad historical survey of Egypt, Ammianus Marcellinus (writing in the late fourth century CE) lists Thmuis as among the "greatest cities" in Egypt, a group that included Oxyrynchos, Memphis, and Athribis.[15] Later sources attest to Timai as an episcopal seat (it appears on the sixth-century CE Madaba map) and as one of the centers of the first Christian revolt against Arab occupation.[16] Timai's significance seems to have decreased during the Early Islamic period; by about the ninth or 10th century, the tell appears to have been abandoned.[17]

Although the predominance of evidence from Timai is from the Graeco-Roman period, it would be a mistake to think of the site as a Greek or Roman settlement in Egypt. Rather, the settlement was likely an extension of the much older city of Mendes (modern Tell el-Rub'a) to the north; only approximately 500 m separates the two sites, and it is likely that in antiquity the towns were contiguous. The history of Mendes spans the Predynastic through the Roman periods; the city was especially prominent from the beginning of the seventh century BCE onward, when it was one of the largest and most prosperous port cities in the Nile Delta.[18] The date of the expansion to Timai is unconfirmed, but according to Herodotus (2.66), Timai was established as a separate administrative entity by the fifth century BCE, which agrees with the earliest diagnostic ceramic evidence so far excavated.[19] Archaeological evidence suggests that Timai supplanted Mendes in economic status as early as the Mid to Late Hellenistic period, and literary sources confirm that Timai was the nome capital no later than the second century CE (and perhaps considerably earlier). It has been suggested that Timai grew as a result of the movement of the Mendesian branch of the Nile southward, leading to a population shift away from Mendes.[20]

Although Timai has been largely unoccupied since its abandonment in the Early Islamic period, the site has not garnered much attention from archaeologists, in contrast to nearby Mendes. The discovery in 1890 of papyri in what was thought to have been a public archive building brought about a mission to Timai by the Egypt Exploration Fund in 1892 that was primarily focused on the recovery of papyri.[21] This project made little headway, and the remaining papyri from the building found their way into the scholarly record

[14] For a complete list of ancient textual sources relating to Timai and an account of early explorations at the site, see de Meulenaere and Mackay 1976. For the mosaics, see Daszewski 1985, 14–58. The carbonized papyri from Thmuis are distributed among various collections around the world. See Blouin (2014, 45–70) for a thorough overview of the history and contents of these documents.

[15] Amm. Marc. 22.16.6.

[16] Blouin 2014, 80–81.

[17] Littman and Silverstein 2007.

[18] Redford 2010; Blouin 2014, 72–76.

[19] Hudson 2016a, 75.

[20] Blouin 2014, 90–98.

[21] Naville 1892–1893; Blouin 2014, 45–70.

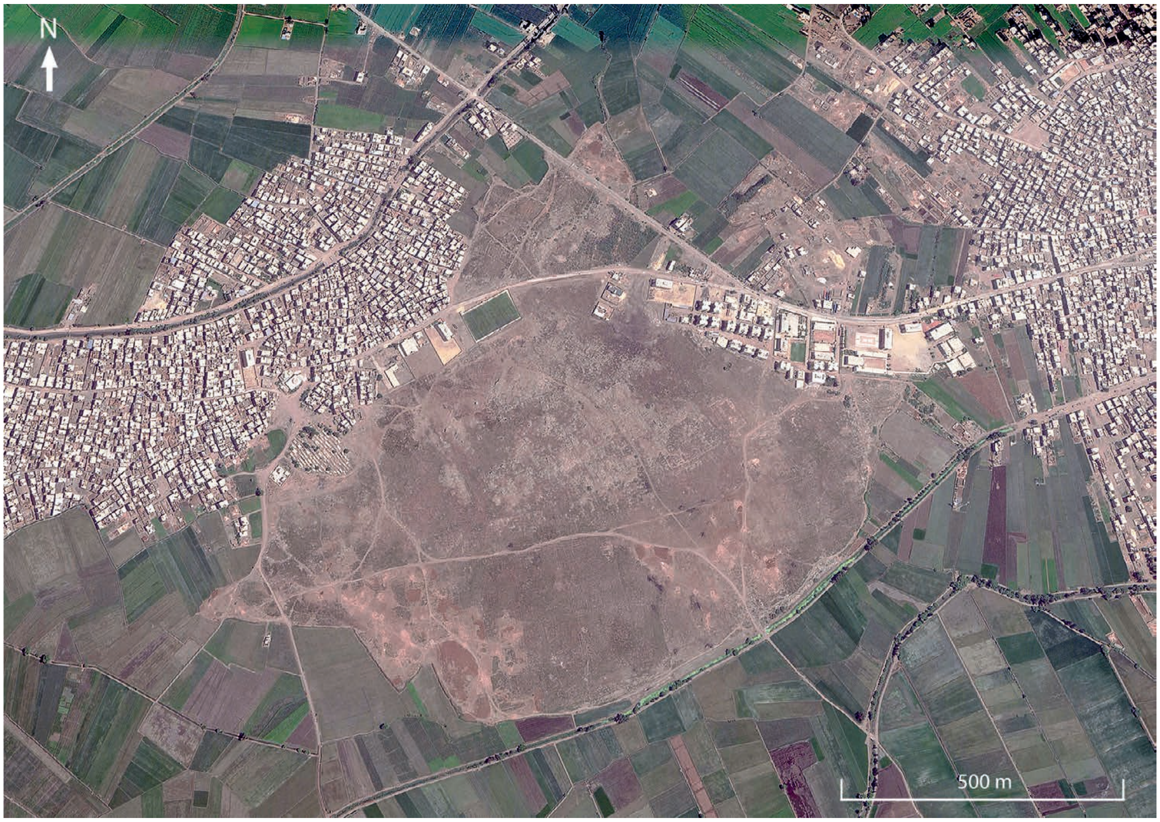

FIG. 3. Satellite view of Timai (Google, © 2019 Maxar Technologies, © CNES / Airbus).

via the black market. When the discoveries of papyri dried up, the site was once again largely ignored except for occasional unauthorized digging. The next organized mission was from New York University in 1965 and 1966. This team carried out a survey and corings in order to attempt a preliminary map of the ruins and an understanding of the chronology.[22] More recently, a series of unpublished salvage operations were carried out by Egypt's Supreme Council of Antiquities (now called the Ministry of Antiquities) on the northern edges of the site in response to planned expansion of the nearby towns.[23]

Current Archaeological Expedition

Since 2009, a team from the University of Hawaii, led by Robert Littman and Jay Silverstein, in collaboration with the Ministry of Antiquities, has been carrying out a variety of exploration activities at the site. These include survey through magnetometry and aerial photography, considerable salvage and rescue work in cooperation with the ministry, test units and soundings in the center of the tell, preservation case studies, and more comprehensive excavation in the northern spur of the tell.[24]

Beginning in 2013, one of the main research goals of the Tell Timai expedition has been the documentation, analysis, and preservation of the extensive standing mudbrick remains. This work has included the geochemical study of the materials of the ancient buildings and also the study of modern vernacular architectural

[22] Ochsenschlager 1967, 1971.

[23] Littman and Silverstein 2007; Winter et al. 2015, 74.

[24] Final reports detailing these activities are still in progress. However, several publications on recovered material and preservation activities have appeared in recent years. For recent excavations in the northern part of the site, see Littman and Silverstein 2017, 193–200. For pottery: Hudson 2014a; 2014b; 2016a; 2016b. Site preservation and cultural heritage management: Littman et al. 2014; Lorenzon et al. 2014; Lorenzon and Zermani 2016. Terracotta figurines: Bennett 2014; Bennett et al. 2016. Diet in the first century BCE: Winter et al. 2015. Identification of a Roman-era glass oven: Gentelli and Medhat 2017. For a study on clay as a raw material: Hudson et al. 2018.

practices nearby. The project has engaged the local community to formulate the best preservation strategy for the site in light of the growth of the surrounding towns.[25] Minimally invasive approaches have been employed in order to understand the core issues affecting the buildings (such as erosion, salt efflorescing, and fissuring) and to support the preservation efforts.

Previous Research

In an initial pilot project in 2011–2012, geochemical analyses were performed at Timai on mudbricks and sediment sources using pXRF and X-ray powder diffraction (XRD) to assess the correlation between raw sources and earthen architecture. Unfortunately, due to circumstances beyond the project's control, these results were never published.[26] The preliminary lab reports, however, revealed high homogeneity of the Timai sediment with the local mudbricks. Specifically, the XRF data indicate homogeneous values for silica and oxides (e.g., iron oxide, aluminum oxide). The presence of both montmorillonite and illite in the samples also suggests commonality of clay typology between raw sources and earthen building materials. It should be noted that chemical homogeneity between bricks can also be a reflection of recycled mudbricks, whereby mudbricks were broken down by builders in antiquity and the material reused for new bricks. It is also quite common in the contemporary earthen architecture of the region for builders to cut into ancient or abandoned houses (or even from the interior partitions of domestic structures still in use) to obtain new material for the manufacture of mudbrick and mud plaster.[27] This phenomenon has been attested at other Egyptian sites.[28]

STUDY AREA

This case study includes three buildings located in two different areas of the site and representing a wide chronological span: the Hellenistic building in N6/N7, located in the northern part of the tell, and the Q13-1 and L14 structures, located in the central part of the tell.[29]

These three buildings were chosen for the following reasons. First, they were being excavated or undergoing conservation and thus already covered by the existing site permit. As this was a side project, it was important to not take away resources or focus from the season's primary goals. Second, we had reason to believe that the three structures represented different historical periods of the site (Hellenistic, Roman, Late Roman). Third, based on scale, they seemed to reflect different urban functions (the Hellenistic building and the Q13-1 structure are likely domestic; the L14 structure is likely public). Finally, both the Hellenistic building and the Q13-1 structure showed evidence of at least two building phases. Therefore, these buildings seemed good candidates for testing our method and exploring our goals.

The Hellenistic Building in N6/N7

The Hellenistic building is located in the northern spur of the tell, spanning grid sectors N6 and N7 (see figs. 1, 4). This structure measures approximately 16 x 12 m, with walls preserved only approximately five courses high, as the higher courses and later occupation were removed by *sebbakhin*, probably in the 19th

[25] Lorenzon and Zermani 2016.

[26] Ardel Harfoush, who conducted the XRD and XRF analyses, passed away soon after submitting the initial chemical report. We would like to acknowledge his contribution and his extensive knowledge of the geology of the tell.

[27] Pers. comm. with current inhabitants of nearby Timai el-Amdid, the local mudbrick manufacturer, and builders employed by the expedition during the preservation project. They discussed the modalities in which old mudbricks are often broken down and remolded for new construction as well as the need for mud plaster to be maintained through yearly repairs. See Lorenzon and Zermani 2016.

[28] Kemp 1977; 2000, 82; Bailey 1999, 211–12.

[29] In the current excavations, Tell Timai is divided into 50 x 50 m grid sectors (also referred to sometimes as areas), with each sector assigned an alphanumeric code (Littman and Silverstein 2007). Letters represent the X-axis and numbers represent the Y-axis (e.g., Q13). Excavation takes place in units, which are frequently but not always 5 x 5 m^2. These units are named sequentially using a number attached to the grid sector in which the southwest corner of the unit falls. So, for example, N7-8 (the unit number for sample B008) is an excavation unit designation; the 8 indicates that it is the eighth unit opened in grid sector N7. The Hellenistic building falls across two grid sectors, N6 and N7, and was excavated as several distinct units, hence N7-8, N7-9, and so forth. The Q13-1 structure was excavated within a single unit, Q13-1. No excavation has taken place within grid sector L14, so we designate the large building within it as simply the L14 structure. Each stratigraphic layer within a unit is called a feature and is assigned a feature number, starting sequentially from F001. F777 is the feature number assigned to any artifact or sample collected from outside an excavated unit.

FIG. 4. Aerial view of the Hellenistic building. F number = feature; S number = sample (courtesy University of Hawaii Tell Timai Archaeological Project [labels added]).

century CE. The structure was fully excavated during the 2010–2014 seasons and is firmly dated to the Hellenistic period on the basis of ceramic finds. A detailed analysis of the ceramic assemblages, accompanied by a preliminary discussion of the building's phasing and architecture, was published by Hudson in 2016.[30] Based on the building's layout and the finds recovered (including a large number of bread molds in a midden and a high concentration of drinking vessels), Hudson has suggested that the building functioned as a private household combined with a bakery or tavern.[31]

Enough architecture and small finds remain to reconstruct the building's early history. In his preliminary analysis of the stratigraphy, Hudson hypothesizes two building phases: the eastern half of the building is the earlier phase and the western half is a later addition.[32] Based on pottery from the foundation trenches and beneath floors, construction of the earlier phase (Hellenistic building Phase 1 or HB1) has been set in the later third century BCE. At the very end of the third century or in the early second century BCE, the structure appears to have been severely damaged by fire, as indicated by deposits of crushed ceramics showing evidence of burning found in four separate rooms. A cache of Ptolemaic coins (Ptolemy II–IV, 284–204 BCE) dug into one of the floors of HB1 provides a terminus post quem of 204 BCE for this destruction event. Hudson suggests that, after the destruction, the building was rebuilt on its original foundations together with a new addition: the western half of the building. This interpretation is based on the double wall (N7-7 F025) that straddles both halves, as well as differences in wall orientation and external wall thickness between the two halves (0.8 m in the east vs. 1.0–1.25 m in the west). The exact date of this rebuilt and expanded structure (Hellenistic building Phase 2 or HB2) is uncertain (the surviving remains appear to be below the floor level), but, based on the typological similarities between the ceramic evidence from the construction fills of the western addition and that of the destruction deposits of the original structure, Hudson has argued that HB2 was constructed in the second century BCE, soon after the earlier building's destruction. To see if closer analysis of the mudbricks themselves could contribute useful data about this structure and its stratigraphy, we took samples from the two parts of the building identified as separate building phases. From the eastern half, samples were taken from the external eastern and southern walls; from the western, later addition, samples were taken from the external western wall (see fig. 4, table 1).

[30] Hudson 2016b.
[31] Hudson 2016b, 228–31.
[32] Hudson 2016b, 202–5.

TABLE 1. Mudbrick and soil samples taken at Tell Timai.

Sample	Source (grid section and feature)	Description	Context	Source
S001	L14 F777	mudbrick	public	higher part of the wall structure, east exterior facade
S002	N7-9 F015	mudbrick	domestic	lower part of the wall, interior facade
S003	N7-9 F015	mudbrick	domestic	higher part of the wall, interior facade
S004	M6 F777	alluvium	N/A	soil sample
S005	M6 F777	alluvium	N/A	soil sample
S006	L14 F777	mudbrick	public	lower part of the wall, exterior facade near the staircase
S007	N6-10 F012	mudbrick	domestic	higher part of the wall, exterior facade
S008	N7-8 F027	mudbrick	domestic	lower part of the wall, interior facade
S009	N7-9 F018	mudbrick	domestic	higher part of the wall, exterior facade
S010	N7-9 F016	mudbrick	domestic	higher part of the wall, exterior facade
S011	Q13-1 F005	mudbrick	domestic	lower part of the wall, exterior facade
S012	Q13-1 F004	mudbrick	domestic	higher part of the wall, interior facade, northeast
S013	Q13-1 F004	mudbrick	domestic	lower part of the wall, exterior facade, northwest
S014	Q13-1 F005	mudbrick	domestic	central part of the wall, exterior facade
S226	Q13-1 F003	mudbrick	domestic	lower part of the wall, exterior facade
S232	Q13-1 F035	mudbrick	domestic	blocked doorway, lower part of the blocking wall
S242	Q13-1 F005	mudbrick	domestic	higher part of the wall, interior facade
S243	Q13-1 F002	mudbrick	domestic	higher part of the wall, interior facade
S244	Q13-1 F026	mudbrick	domestic	lower part of the wall, interior facade, southwest
S264	Q13-1 F019	mudbrick	domestic	higher part of the wall, interior facade
S272	Q13-1 F030	mudbrick	domestic	fill of the F030, collapsed mudbrick
S273	Q13-1 F003	mudbrick	domestic	central-lower part of the wall, interior facade
S286	Q13-1 F029	alluvium	N/A	soil sample
S287	Q13-1 F034	alluvium	N/A	soil sample

The Q13-1 Structure

In 2013, two blocks of buildings on either side of a main road oriented northwest–southeast in grid areas Q13 and Q14 were surveyed and evaluated for conservation, which was carried out in the 2013–2014 seasons. In addition, during the 2014 season, a single unit (Q13-1) measuring 7 x 16 m was opened at the juncture of the main northwest–southeast street and a crossroad to get a better sense of the date of the visible remains in this neighborhood (figs. 5, 6). This unit is approximately 350 m southeast of the Hellenistic building. Excavation of this unit revealed at least three rooms that we believe are part of the same structure; we refer to this group as the Q13-1 structure. The limits of the structure have yet to be conclusively determined, and its associated small finds have been

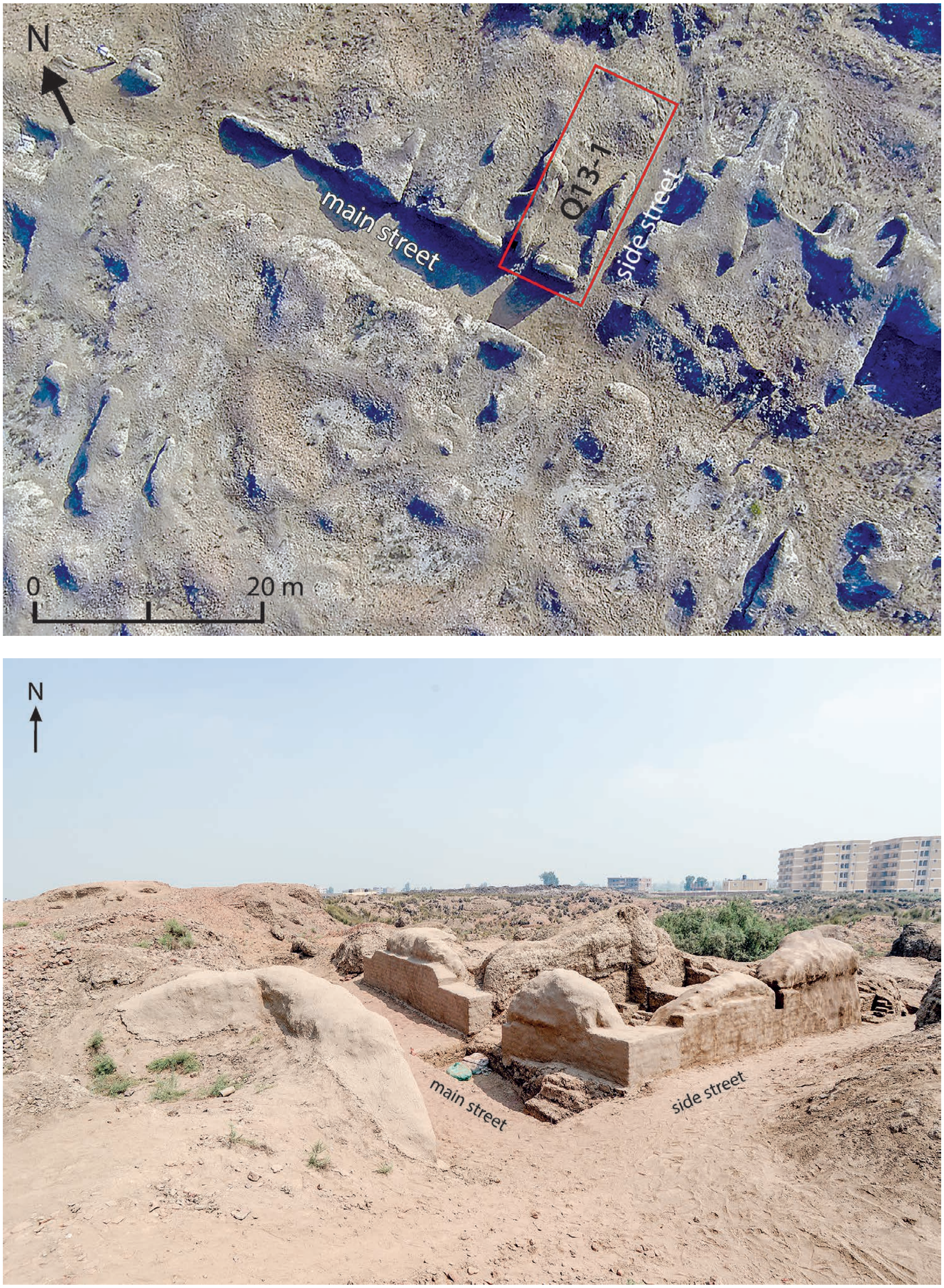

FIG. 5. The Q13 area: *top*, aerial view of the Q13 grid sector showing the Q13-1 structure; *bottom*, the Q13-1 area after excavation and restoration (*top*, courtesy University of Hawaii Tell Timai Archaeological Project; *bottom*, J. Nitschke).

only preliminarily studied. However, based on size, layout, and the nature of objects found, the structure is thought to be domestic and to date to the Roman period.

The eastern part of this structure was particularly heavily damaged, with few remains above ground level. Excavation revealed several collapsed and fragmentary walls, and it is difficult to discern the overall stratigraphy of the walls and the corresponding building phases. Even so, overlapping walls with different alignments suggest that the building went through extensive modification over the course of its history. The walls in the western part of the structure, on the other hand, are well preserved (between 2.3 and 4.3 m in height as revealed so far) and present a clear plan. However, no floor has been encountered in the western part of the structure, nor has the bottom of the structure yet been reached. Despite the lack of floors in the western part, we could still observe a clear change in the construction of the upper and the lower parts of walls in this section of the building, particularly in the size and composition of the bricks. This suggests that the structure had at least two major phases, which we designated as Phase A (upper) and Phase B (lower).

A lack of sealed contexts overall makes phasing and dating the structure difficult, but a few diagnostic artifacts have been found in useful contexts. A bronze coin of Hadrian (r. 117–138 CE) was found in one wall (Q13-1 F020). Diagnostic ceramics were found under the eastern part of Q13-1 F004 Phase A and in its associated construction fill (see fig. 6). Together, this material indicates that at least Phase A can be dated to the second century CE or later. A Late Hellenistic lamp found embedded within collapsed mudbrick at the bottom of the western half of the unit may indicate that there is at least one Hellenistic building phase below what has so far been revealed. To help clarify the stratigraphy and sequence of building, samples were taken from the mudbricks in several parts of the walls in both the western and eastern parts in order to carry out a more detailed comparison.

The L14 Structure

The third structure sampled is a monumental structure also in the center of the tell, in grid sector L14, located approximately 250 m from the Q13-1 structure (fig. 7). The L14 structure has not been excavated, but, based on survey evidence, it is hypothesized that the standing walls date to the Late Roman or Byzantine periods, although exactly when they were erected and how long the building was in use is purely speculative at this point. Neither the plan nor the building's full size is discernible from the surface, but it measures at minimum 41 x 32 m and is perhaps much larger. In the southern part of the structure, the walls (the tallest still standing at Timai) are preserved in places to a height of more than 12 m above the current surface and measure up to 6 m wide. A spiral staircase within a tower is still preserved in the southwest corner. This structure is unusual in the Delta region, especially in an urban setting and especially for its remarkable preservation and the sheer size of its mudbrick walls. Because of its ruined form, unconfirmed plan, and our lack of detailed knowledge about the structures, date, and urban plan of this area of the site, we can only speculate as to the function of this building. However, from its scale and central location at the site, we can assume that it served some public function, whether administrative, religious, or as an official residence. We decided to include the L14 structure in our case study so that we could compare a public building with the modestly sized Q13-1 structure and because preservation work was already being carried out on the structure. Samples were taken from the northeast wall and the south wall, near the spiral staircase (see fig. 7).

METHODOLOGICAL APPROACH

The methodology we developed determines ancient mudbrick recipes and construction practices through the combination of geoarchaeological analyses that are easy to implement with techniques taken from the field of building archaeology, especially mensiochronology—the dating of brickwork by analysis of brick dimensions and bricklaying techniques. The methodology includes macroscopic observations of structures and individual mudbricks in situ as well as microscopic analyses of samples from mudbricks in the field laboratory. All elements of the methodology as described below should be implemented together for a given structure to guarantee the reliability and usefulness of the results.

Geoarchaeological Methods

From the data of the 2011–2012 geoarchaeological pilot study described above, it was not possible to determine whether similarity between bricks was the result of similarities in manufacture or the result of the recycling of earthen materials. Therefore, we

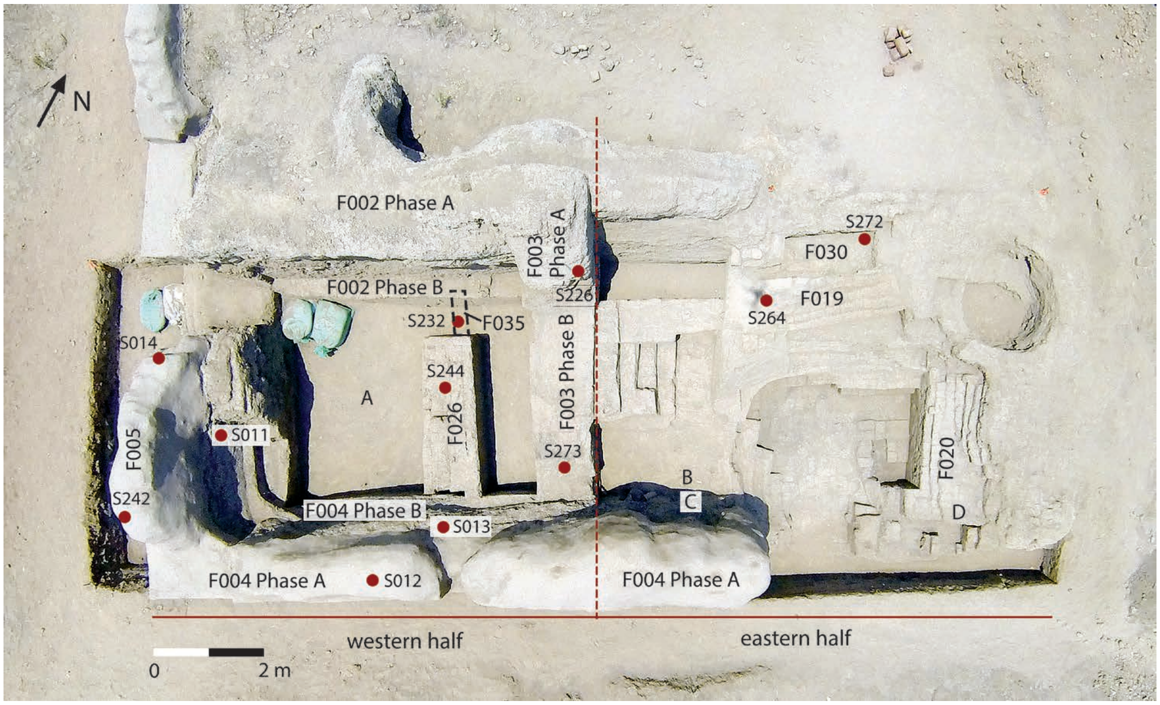

FIG. 6. Aerial view of the Q13-1 structure. In addition to feature numbers and sample numbers, locations of finds mentioned in the text are marked: *A*, Hellenistic lamp; *B* and *C*, diagnostic pottery under wall F004 in Phase A; *D*, coin of Hadrian in wall F020 (courtesy University of Hawaii Tell Timai Archaeological Project).

concluded that analytical methods such as XRF and XRD in and of themselves would be of limited use in investigating construction phases and diachronic development of earthen architecture. We turned instead to different geoarchaeological analyses that are both efficient and easy to carry out in the field, namely: quantification of vegetal temper through microscopic observation conducted with a Dinolite digital polarized microscope, at magnification 20–200x;[33] and grain-size analysis, also known as particle-size analysis, using a hydrometer.

To understand the different components of our geoarchaeological method, it is important to consider the properties of mudbricks. Mudbricks are made up of three components: soil, water, and temper. Soil is by far the largest component and is typically characterized by a high percentage of sand (usually approximately 40%), which constitutes the coarse fraction, while the fine fraction is composed of silt and clay. The clay percentage can range from as little as 6% to as much as 70%; more than this causes the mixture to be hard and no longer workable.[34] Variations in the ratios of clay, silt, and sand reflect recipes that can be linked to different raw source materials, manufacturing processes, and traditional know-how shared within the community.[35] Tempers, sometimes referred to as degreasers or additives, include both vegetal (especially straw or chaff) and nonvegetal inclusions (e.g., potsherds, grog, ashes). They are added to the matrix to make the mixture more pliable, to increase tensile strength, and to improve thermal behavior (how well

[33] NEEWER Portable 20X–800X 8LED 2.0M Pixel CMOS USB Digital Microscope with Base Stand.

[34] The limits of the quantitative variables of clay, silt, and sand in mudbricks are known as the critical constraints. In some modern earthen architecture, the ratio has become optimized and standardized through technological advances so as to reduce the need for the addition of tempers; for statistical percentages recorded in modern contexts, see McHenry 1989, 48–54; 1996, 11; Minke 2006, 20–21. In ancient contexts, high variability in grain ratios (but still within the limits of the critical constraints) from archaeological contexts has been widely observed; see Fathy 1969, 42; Aurenche 1981, 46; French 1984; Jerome 1993, 384; Rosen 2004, 2584–85; Wright 2005, 77–78, 106; Oliver 2008, 97–99.

[35] Goldberg 1979, 64; Aurenche 1981, 46–54; Jerome et al. 1999; Goodman-Elgar 2008, 3062–69; Love 2012, 142.

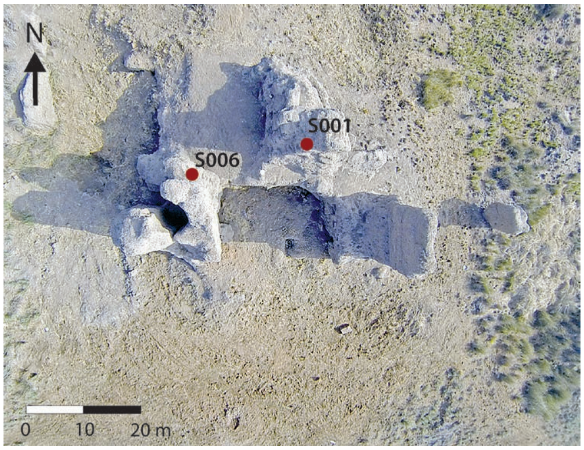

FIG. 7. The monumental structure in L14: *top*, aerial view showing sample locations; *bottom*, view of the structure, looking north (*top,* courtesy University of Hawaii Tell Timai Archaeological Project; *bottom*, J. Nitschke).

the bricks insulate indoor spaces).[36] Vegetal temper is the most common additive and is used to minimize shrinking during drying. In Egypt, straw or chaff may have already been present in the raw source material if the brickmakers were collecting soil from areas of cultivation.[37] Additional sand and straw can be employed to compensate for a matrix high in clay to reduce the risk of fracture. Often, vegetal temper is added through the use of dung, which typically contains a high amount of vegetal fiber.[38] Dung and other vegetal temper can be very useful in providing information about the local natural environment and agricultural cultivation; such analysis, unfortunately, was beyond the scope of this project at this time.[39]

Our geoarchaeological method consisted of the following operations: step 1, macroscopic observation of bricks in the field; step 2, microscopic observation of raw samples of mudbrick; and step 3, hydrometer analysis. For steps 2 and 3, we took 20 mudbrick samples from the walls of the three buildings described above (see table 1). The number of samples was limited by equipment, personnel, and time constraints. As the N6/N7 structure was already excavated and the Q13-1 structure was in the process of excavation, most of the samples were taken from these two buildings (6 and 14, respectively) because there would be stratigraphic data available to complement the geoarchaeological data. From these two structures, samples were taken from walls hypothesized to be from different constructions phases; in the case of Q13-1, this also meant, in some cases, samples from the bottom and top parts of the same wall. We took samples only from well-preserved walls so that our geoarchaeological analysis could be performed in conjunction with construction method analysis and mensiochronology, which are difficult to carry out on degraded mudbrick walls. Most of the samples were taken from exterior walls, as they usually have a longer life span; in the case of Q13-1, samples also came from the two interior walls to help determine the stratigraphy of the walls excavated in the structure.

In addition to the mudbrick samples taken from the three structures described above, four alluvium samples were collected from two different parts of the site to test the range of raw source material available and to compare the raw material with the mudbrick recipes in the buildings tested. Two samples were collected from grid sector M6, in the northern area of the site near the Hellenistic building. This area is believed to have been

[36] See Morgenstein and Redmount (1998, 129–30) and Kemp (2000, 82) for types and uses of temper in ancient Egyptian mudbricks. For the use of straw in both ancient and modern mudbricks in Egypt, see Littman et al. 2014. For the identification of additives in ethnoarchaeology, see Aurenche 1981, 50–52.

[37] Kemp 2000, 80.

[38] Morgenstein and Redmount 1998, 129, 143; Goodman-Elgar 2008, 3064; Friesem et al. 2011, 1144.

[39] See Lorenzon and Sadozaï (2018) on the different use of vegetal temper in Tajikistan and its relationship to craft specialization, and Lorenzon (2017) on the use of vegetal temper in Bronze Age Crete. On the origin and typology of chaff, see Bellue and Hendry (1936), Ayyad et al. (1991), and Marinova et al. (2011). Dung can be identified in micromorphological thin section or geochemical analysis by the increased level of phosphate, but these methods require that the samples be exported to a laboratory environment. Dung cannot be easily recognized with the field methodology we discuss here.

in close proximity to the Hellenistic harbor and thus to the riverbank at that time.[40] Two samples were also taken from grid sector Q13 in the central part of the tell. This area is close to the Q13-1 structure and, in contrast to the alluvial samples from M6, was far from the riverbank in antiquity.

For step 1, we characterized the bricks on the basis of their macrofabric. By macrofabric, we refer to the macromorphological characteristics of the mudbrick fabric that are visible to the naked eye. We carried out visual assessments of the bricks in situ in order to determine the quantity and consistency of visible inclusions such as pottery sherds. We defined coarse macrofabric as mudbrick in which the visible inclusions are present in a high quantity (>40–50% of the matrix) and which contained inclusions larger than 2 cm or a prevalence of inclusions approximately 1–2 cm in size. We defined fine macrofabric as mudbrick in which the visible inclusions were less numerous and smaller. The designation of the fabric as coarse or fine, along with a detailed description, is important for obtaining as much information as possible regarding steps in the *chaîne opératoire*, such as the initial screening of the sediment, eventual sieving, and the incorporation of additives.

In step 2, we collected samples from individual bricks for microscopic assessment. For these samples, we cut out a chunk weighing approximately 100 g (about 3 x 3 cm, depending on density). Ideally, this was done with a scalpel, but a small, sharp trowel worked as well. These samples were taken to a space set aside in the dig house workroom that served as our laboratory. Through microscopic observation (magnification 20x) of the freshly cut samples, we confirmed the coarseness or fineness of the fabric, made a rough quantification of inclusions, and measured the planar pseudomorphic voids and impressions that indicate the presence of vegetal temper.[41] The quantity of vegetal temper and other inclusions was determined following an abundance estimation chart adapted from the guides to sediment characterization developed by Bullock and by Terry and Chilingar, and the quantity was recorded as a percentage, rounded to the nearest 10%, of the visible matrix.[42]

We then created smear slides to observe the main qualitative characteristics of the sediment (i.e., grain sphericity and sorting) as well as any inclusions we might have missed in the initial microscopic observation.[43] By sorting, we refer to the distribution of grain size in sediments. A well-sorted sample will show grains of similar sizes, whereas a poorly sorted sample will have a mix of small and large grains. Sorting can indicate intervention by the brickmaker; for example, a well-sorted sample suggests that the soil was sieved prior to brick manufacture. Grain sphericity (sometimes referred to as particle or grain shape) for each sample was characterized according to the standard six categories of roundness, which range from very angular to well rounded.[44] The smear-slide technique is fast, efficient, and simple to perform in the field, and it is commonly used in geoscience and sediment analysis to assess grain size and compositional patterns of sediment samples.[45] In addition, smear testing requires only a very small amount of sediment (1–3 g) and thus is particularly appropriate to archaeological contexts where sampling is restricted either by regulation or by poor survival of materials. To make the smear slide, we placed 2 g of each sample on a glass slide, added a drop of distilled water, and then smeared the mixture using a toothpick. The slide was put under a lamp to evaporate the water and then analyzed under the Dinolite stereoscopic microscope (magnification 200x).

In step 3, we used hydrometer analysis to determine particle distribution (i.e., the ratio of clay, silt, and sand in the brick matrix) following the methodology set up by French at Tell el-Amarna and Love at Çatalhöyük.[46] We dry sieved the samples using 2 mm mesh to remove especially coarse inclusions (e.g., pottery sherds). Then we measured 50 g of the sample, lightly crushed it, and then pretreated it with sodium hexametaphosphate (a water softener available commercially under the brand name Calgon) to break up (deflocculate) the sediment particles. To do this, we mixed the 50 g of crushed sample with one liter of distilled water plus 40 g of sodium hexametaphosphate in a closed container, then shook for 20 seconds to mix

[40] Littman and Silverstein 2007, 6; Morriss 2012, 13–15.

[41] Goldberg 1979; Rosen 1986; Friesem et al. 2014b, 561–64.

[42] Terry and Chilingar 1955, 230–33; Bullock et al. 1985, 112.

[43] This approach to the description of sediment fabric has been adapted from Bullock et al. (1985, 112), Courty et al. (1989, 73–74), and Matthews (1995, 53–55).

[44] Powers 1953.

[45] Rothwell 1989; Shillito 2011, 633.

[46] French 1984, 192; Blair and McPherson 1999; Love 2012, 147.

thoroughly. This mixture was left to sit for 24 hours so that the hexametaphosphate had sufficient time to deflocculate the sample. Subsequently, we shook the container again for 20 seconds to remix thoroughly, then transferred the entire mixture into a calibrated cylinder and left it to sit for a further five hours to allow the particles to separate and settle. According to Stokes' Law, the heaviest particles (in this case, sand) settle first, followed by silt, and then clay. Once the particles settled, we measured the sand, silt, and clay fractions of the sediment using the calibrated cylinder.

Finally, after taking the measurements, we shook the cylinder containing the sediment and the liquid and wet sieved each sample through three overlapping sieves of decreasing mesh sizes (2 mm, 0.02 mm, and 250 μm) to separate the sand, silt, and clay.[47] Samples were dried for several days, then the three components of each sample were weighed and examined under the microscope again (magnification 200x) to further inspect inclusions and to confirm (or adjust, if necessary) our characterization of the microfabric that was made during step 2 (the smear slide).

Because of limitations of equipment, space, and the excavation schedule, we did not undertake hydrometer analysis of all the samples simultaneously but rather over a series of days, reusing the calibrated cylinders once the wet sieving was complete and the sediments left to dry. For this reason, the hydrometer analysis was done in a room kept at a constant temperature, which is essential for this part of the process, as fluctuations in the ambient temperature can affect how the particles settle.[48]

Building Archaeology Methods

Building archaeology relies on nondestructive methods, such as the observation of exposed surfaces, to provide a comprehensive history of the built environment over time, focusing on materials, construction phases, techniques, and craft specialization.[49] Since the 1980s, building archaeology has opened a new horizon in the study of earthen architecture as an expression of craft and social values that supplements the archaeological record.[50] Mensiochronology, a branch of building archaeology, consists of the analysis of brick composition, measurements, binders, and bricklaying techniques to provide a relative chronological assessment of building phases.[51] This tool was first developed and popularized in the study of fired-brick architecture in Roman and medieval contexts around the Mediterranean, where it is a widely accepted method for distinguishing multiple construction events within the same architectural structure.[52] We believe this approach can be useful for earthen architecture as well, especially since, at the moment, there is no standardized methodology for the clear identification of distinct construction events within earthen structures. Rather, most case studies in earthen construction identify different phases based on plan analysis, such as the movement, removal, or addition of internal walls or extensions to the building. This is problematic, as new construction can happen without changes in the plan of the structure.

Spencer's foundational 1979 monograph on brick architecture in Egypt drew attention to mudbrick measurement as a method of comparative analysis, as he established how mudbrick sizes and bricklaying tend to be regionalized or even site-specific. Mold size can be site-based, period-based, or even vary within the same structure in the same period. Mensiochronology has been performed on Pharaonic-period materials at, for example, Amarna, Karanis, Medinet Maadi, and Edfu.[53] As Kemp has pointed out, in applying this technique for determining construction phases, one must be mindful of the reuse of older bricks.[54] Brick

[47] French 1984, 192; Love 2017, 356. At this point, there was some surviving vegetal temper (charred seeds), which we handed over to the dig archaeobotanist. These were not useful for the purposes of her research; however, such material may be relevant for the study of brickmaking. In 2014, we were not in a position to study and analyze such material, but we hope to include such analysis in our future development of this method.

[48] Love 2017, 356. A room with temperature control (air-conditioner or heater, as the case may be) makes this easier, but a room with a stable ambient temperature will suffice if the final calculations are corrected following the ASTM Standard D7928–17 (2017, ASTM International, www.astm.org/Standards/D7928.htm).

[49] Mannoni and Milanese 1988; Morriss 2000; Cristini 2012; Jiménez Hernández 2015.

[50] Spencer 1979; Oates 1990; Love 2013b; Pittaluga and Pagella 2014.

[51] Hesse 1971; Sanjurjo-Sánchez 2016.

[52] Mannoni and Milanese 1988, 383–86. For mensiochronology generally, see Pittaluga and Ghislanzoni 1991; Brogiolo 2002; Giuliani 2006; Boato 2008; Brogiolo and Cagnana 2012, 60–64.

[53] Boak and Peterson 1931; Bresciani 1968; Hesse 1970; Spencer 1979, 147–48; French 1984.

[54] Kemp 2000, 85.

reuse should be easily detected by the careful application of mensiochronology integrated with the geoarchaeological analysis outlined above.[55] Until now, the application of geoarchaeology and mensiochronology has been rare in studies of ancient, pre-medieval architecture. However, through the combined use of these methods, it is possible to present a more complete record of earthen architecture and construction practices and, eventually, to reduce the need for excavation and to provide the groundwork for preservation plans.[56]

In applying building archaeology, we first observed and recorded the bricklaying techniques, joint measurements (i.e., the gaps between bricks that are filled with mortar), and wall construction. This included an examination of how the bricks were laid into courses, the type of bonding, the brickwork at corners, the inclusion of different materials (such as wood, stone, or ceramics), as well as a comparison of adjoining walls with respect to these characteristics.

We then applied mensiochronology, examining each brick individually, measuring it and documenting the surface work and finish, to investigate the possibility of standardization, continuity, and changes in mudbrick production over time. This included assessing the state of preservation and looking for signs of plastering and whether any stamps were present. We measured more than 1,000 mudbricks from the three structures—the Hellenistic building, the L14 structure, and the Q13-1 structure. These measurements were rounded to the nearest 0.5 cm.[57] The results were imported into the statistical software R (3.2.2) and analyzed to obtain a statistical mean and its standard deviation.[58]

RESULTS

We begin by summarizing our results across all the buildings and proceed with a more detailed discussion of each building. Hydrometer analysis of the 24 samples shows that the coarse fraction of mudbricks at Timai consists of gravel and sand mixed with visible macro-inclusions such as pottery sherds and small stones (>2 cm). The macroscopic mudbrick fabric is superficially very similar to the natural alluvium in Timai, with a matrix of alluvial silt and sand particles, in which plagioclase feldspar, calcite, limestone chips, and quartz are easily detectable. Color varies from yellowish (10YR 7/6 in the Munsell color system) to dull reddish brown (5R 5/4) to brownish gray (10YR 4/1). Geologically, the readily available floodplain alluvium in Timai has characteristics such as a high clay-silt component due to regular Nile overbank flooding.[59] With geological layers enriched by yearly overbank deposits, Timai's alluvium presented a natural and opportune choice of raw source material for mudbrick production. The sediment possesses the required ratio of the three key elements, clay, silt, and sand. However, analysis of the sediment samples (especially those from sector M6) also indicates a high percentage of clay, which would require a degreasing process during manufacturing (i.e., the addition of sand or other tempers, as described above) to obtain a mixture appropriate for durable earthen architecture construction.

Grain-size analyses of both the sediment and the mudbrick samples reveal differences based on the variable ratio of coarse and fine fraction (figs. 8, 9), described in more detail below (table 2). A high fine fraction (>50%) characterized the geology of the north area of the tell, exemplified in the sediment samples (S004 and S005 from area M6) and reflected also in the mudbricks manufactured and employed in the same area (S002, S003, S007, S008, S010, and S011). These mudbrick samples present a higher fine fraction percentage than the samples from other areas. The similarities between alluvium and mudbrick samples are likely explained by procurement from a raw source in the same area. A high percentage of fine fraction (a combination of clay and silt) and variability in the proportion of fine fraction to coarse fraction in ancient bricks (in contrast to modern bricks) has been attested all over the Mediterranean in numerous past studies.[60]

In our building analysis, we observed that mud mortar was used as a binder throughout all the structures in the case study. Although we would have expected the

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[55] Lorenzon and Iacovou 2019.

[56] Homsher 2012; Love 2013a; Lorenzon 2017.

[57] As pointed out by Kemp (2000, 84), the faces of ancient bricks are not true planes, and either weathering or the application of mortar on the walls can obscure the original edges; therefore, measurements more precise than 0.5 cm are difficult to achieve with accuracy.

[58] Hesse 1970.

[59] Barrell 1912, 382, 418; Morgenstein and Redmount 1998. Morgenstein and Redmount (1998, 134) note the lack of in-depth knowledge regarding the geology of the northeastern Delta, particularly regarding the Mendesian Nile branch where Timai is located.

[60] Rosen 1986, 76; Rosen 2004, 2590–91; Wright 2005, 106–7; Emery and Morgenstein 2007, 113; Friesem et al. 2011; Love 2012, 146.

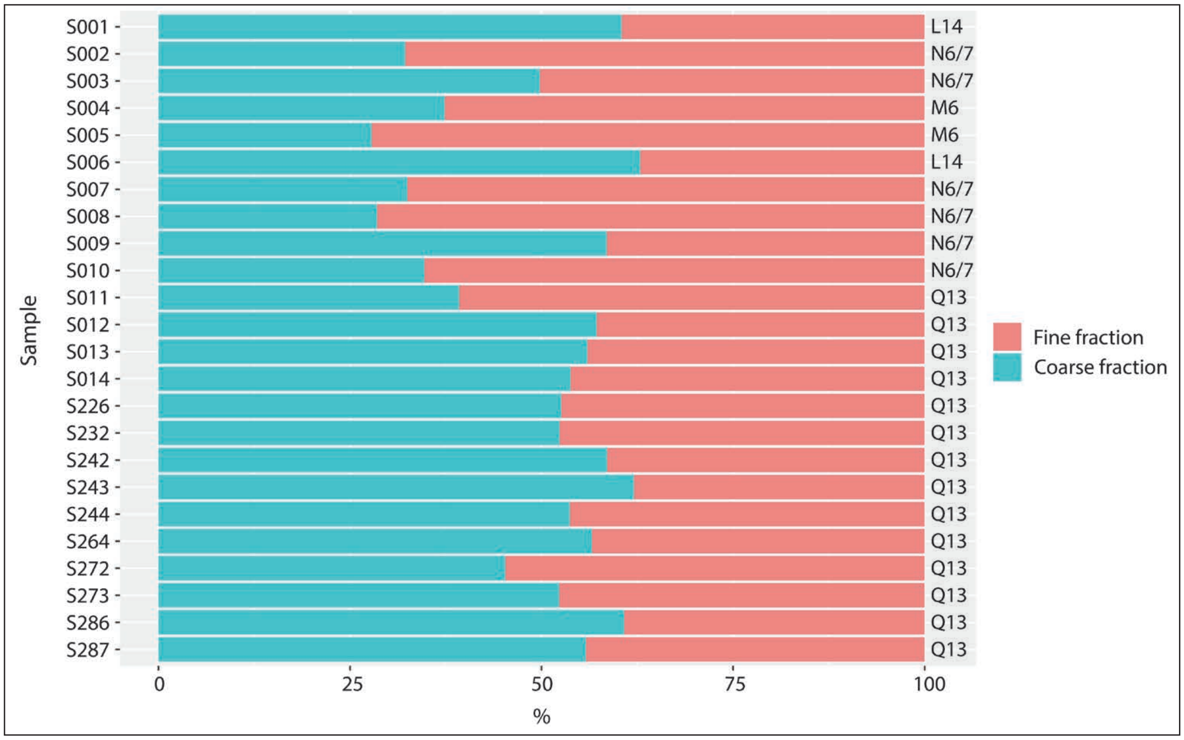

FIG. 8. Grain-size analysis bar plot, illustrating the ratio of fine and coarse fraction in the samples.

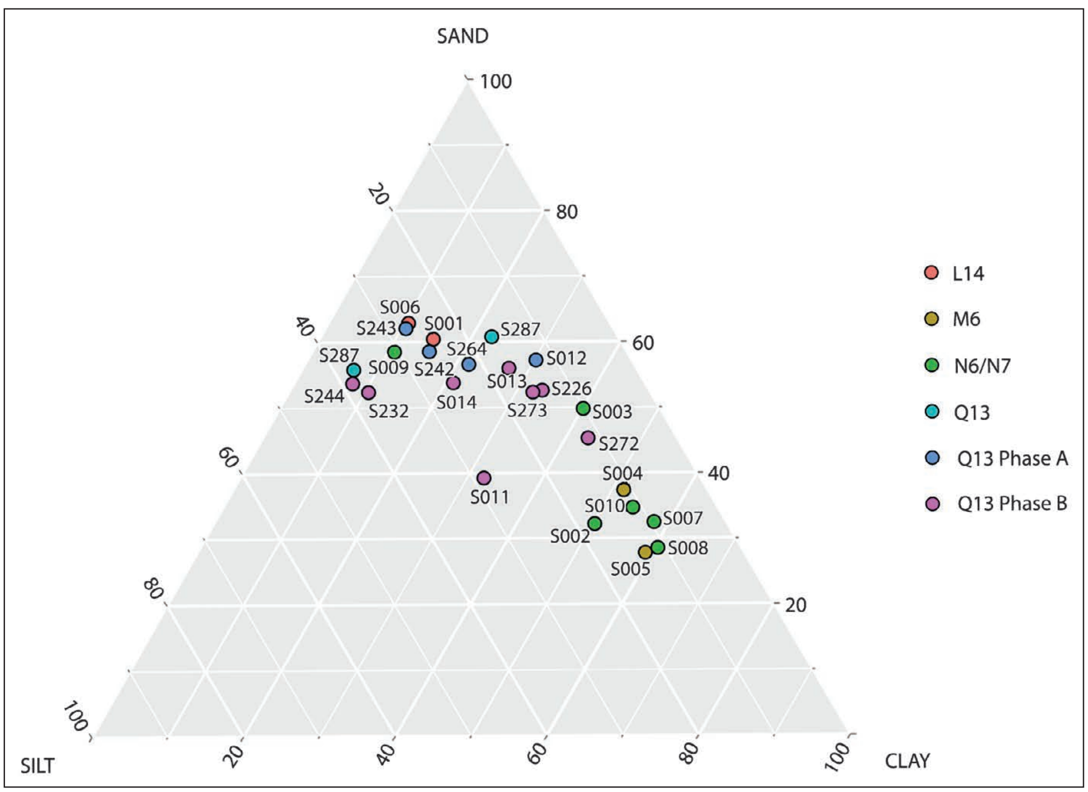

FIG. 9. Grain-size analysis triangular scatterplot, visualizing grain-size variation according to study areas.

TABLE 2. Grain-size distribution and vegetal temper measurement for each sample.

Sample	Source (grid section and feature)	Description	Clay (%)	Silt (%)	Sand (%)	Fine Fraction (%)	Coarse Fraction (%)	Vegetal Temper (%)
S001	L14 F777	mudbrick	24.48	15.07	60.46	39.54	60.46	50
S002	N7-9 F015	mudbrick	50.31	17.45	32.23	67.77	32.23	20
S003	N7-9 F015	mudbrick	40.1	10.11	49.78	50.22	49.78	20–30
S004	M6 F777	alluvium	51.6	11.04	37.37	62.63	37.37	5–10
S005	M6 F777	alluvium	59.17	13	27.83	72.17	27.83	5–10
S006	L14 F777	mudbrick	10.59	26.51	62.9	37.1	62.9	50
S007	N6-10 F012	mudbrick	58	9.51	32.49	67.51	32.49	20
S008	N7-8 F012	mudbrick	60.45	10.99	28.55	71.45	28.55	20–30
S009	N7-9 F018	mudbrick	10.91	30.58	58.51	41.49	58.51	15
S010	N7-9 F016	mudbrick	54.11	11.18	34.71	65.29	34.71	20
S011	Q13-1 (Phase B) F005	mudbrick	32.23	28.51	39.26	60.74	39.26	30
S012	Q13-1 (Phase A) F004	mudbrick	30.2	12.59	57.2	42.8	57.2	50
S013	Q13-1 (Phase B) F004	mudbrick	27.25	16.78	55.97	44.03	55.97	30
S014	Q13-1 (Phase B) F005	mudbrick	21.01	25.2	53.79	46.21	53.79	30
S226	Q13-1 (Phase B) F003	mudbrick	33.31	14.09	52.6	47.4	52.6	30
S232	Q13-1 (Phase B) F035	mudbrick	10.53	37.1	52.37	47.63	52.37	40
S242	Q13-1 (Phase A) F005	mudbrick	15.48	25.96	58.56	41.44	58.56	50
S243	Q13-1 (Phase A) F002	mudbrick	10.65	27.27	62.07	37.93	62.07	50
S244	Q13-1 (Phase B) F026	mudbrick	7.78	38.52	53.7	46.3	53.7	30
S264	Q13-1 (Phase A) F019	mudbrick	21.66	21.76	56.59	43.41	56.59	50
S272	Q13-1 (Phase B) F030	mudbrick	42.96	11.73	45.3	54.7	45.3	30
S273	Q13-1 (Phase B) F003	mudbrick	32.22	15.47	52.32	47.68	52.32	30
S286	Q13-1 F029	alluvium	22.6	16.62	60.78	39.22	60.78	5–10
S287	Q13-1 F034	alluvium	6.88	37.33	55.8	44.2	55.8	5–10

builders to have used a mud or lime plaster to face the walls, no plaster was visible on the wall surfaces at the time of our observations. No brick stamps, which have been found in New Kingdom buildings, usually featuring the name of the king or more rarely names of private individuals,[61] were observed. Three different types of bonds were observed in the wall construction: English bond, Flemish bond, and running bond (fig. 10). Finally, we observed three clear sets of dimensions used by brickmakers at Timai. Significantly, the same brick size was observed in two buildings of different scale (L14 and Q13-1), while two different sizes were found in two separate phases within a single structure (Q13-1). Additionally, a clear change in brick size was observed between the Hellenistic period (the Hellenistic building) and the Roman period (L14 and Q13-1 structures).

The Hellenistic Building in N6/N7: Results

Regarding construction methods, we found the bricklaying in the Hellenistic building to be consistent: builders used the running bond pattern (i.e., stretchers) throughout the building, with bricks measuring 40 x 20 x 10 cm (fig. 11). The vertical and horizontal joints are consistently regular throughout, measuring

[61] Spencer 1979, 144–46.

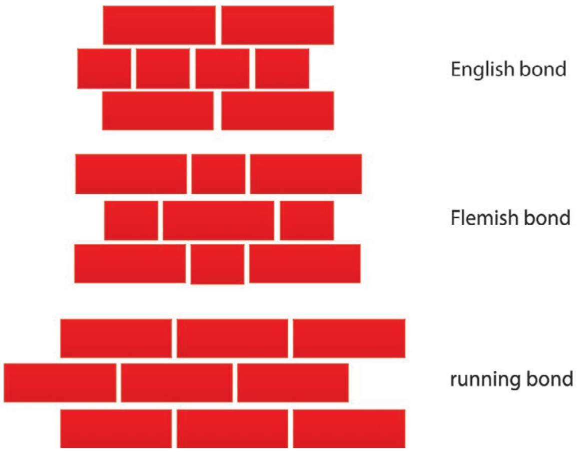

FIG. 10. Types of bricklaying patterns found at Timai.

0.5 cm wide. With respect to grain-size analysis, the results show a relatively high percentage of fine fraction (>50%), composed of clay and silt, with a lower percentage of coarse fraction, specifically sand (about 30–40%). In addition, a medium-low percentage of vegetal temper in the fabric, approximately 20–30% of the matrix, was recorded through a stereoscopic microscope in what can be defined as a medium-fine macrofabric, as we observed a small quantity of larger inclusions such as pottery sherds. Microscopic examination of both the smear-slide and the wet-sieved samples showed that the soil was well sorted and the grain shape subrounded. The ratios, brick sizes, and grain size are consistent in the walls from both phases (HB1 and HB2) of the building.

The outliers in the cluster are the mudbricks from the narrow wall N7-9 F018, which juts out from the main southern external wall of the house at an angle off-axis with the rest of the house (see fig. 4). Although the bricks in this wall are consistent with those of the other walls in terms of size and bricklaying, sample S009 taken from this wall shows a slightly different recipe and grain-size ratio from the other samples, characterized by a slightly lower fine fraction. The differences may be attributed to changes made in the original manufacturing process and sediment source when this later wall was added and may thus reflect production at a later time.

The Q13-1 Structure: Results

Through macroscopic observation of the bricklaying, mudbrick composition, and brick dimensions of the walls of the Q13-1 structure, we observed at least two distinct chronological phases of construction. This was clearest in the western half of the building (see fig. 6), where the wall preservation is excellent. The mudbrick dimensions vary between the upper parts of the walls, where bricks measure on average 25 x 15 x 10 cm (with ranges of 22–25, 12–15, and 9–10 cm, respectively), and the lower parts of the walls, where bricks consistently measured 30 x 15 x 10 cm (fig. 12).

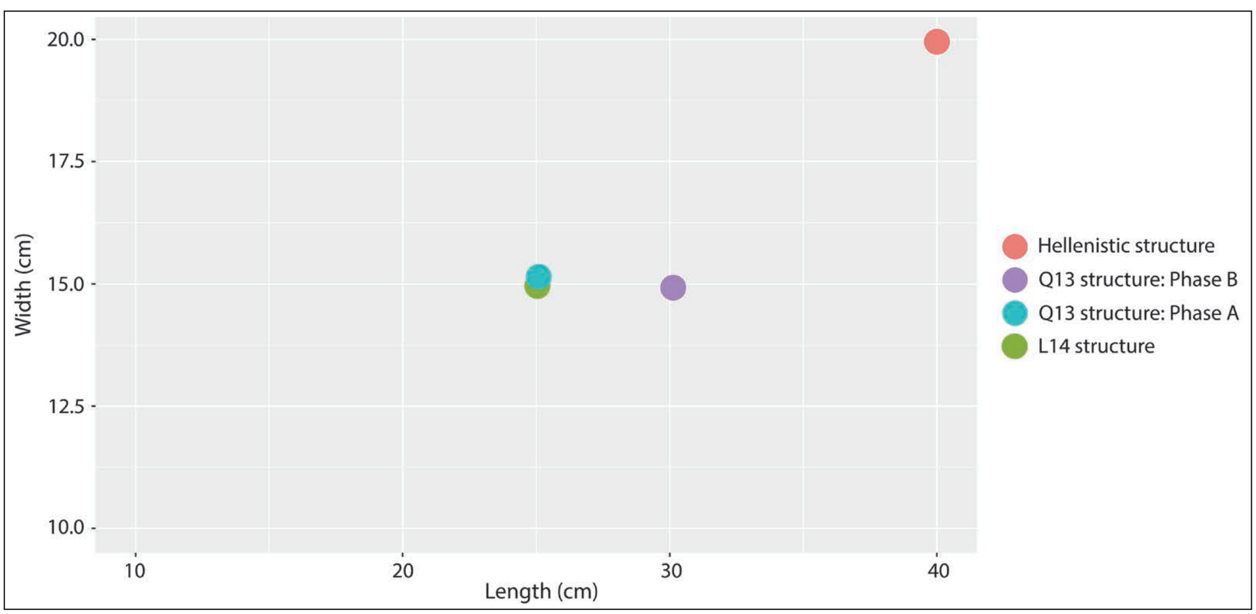

FIG. 11. Mensiochronology of bricks at Tell Timai using brick dimensions with standard deviation of the mean graphically represented to indicate the differences and similarities among sizes.

The walls are two brick lengths in width; therefore, the upper parts are slightly narrower (roughly 50 cm) than the lower parts (about 60 cm). In addition, the bricklaying technique in the upper parts of the walls is clearly different from that in the lower parts of the walls. The quality of bricklaying is consistently better in the lower parts and the bricks are disposed in the Flemish bond pattern (i.e., headers and stretchers combined in the same row). This contrasts with the higher parts of the walls, where the bricklaying seems to follow a more casual and irregular pattern of English bond, with an occasional header or stretcher out of place. The casual execution of the English bond seems to have been common in the Roman and Byzantine periods in Egypt.[62] The horizontal joints are generally consistent in their thickness in both the upper and lower parts of the walls, measuring approximately 1.0–1.5 cm. Vertical joints are thinner and differ between the upper wall (1 cm or wider) and the lower wall (0.5 cm).

The macroscopic fabric differs between the upper and lower parts of the walls. The bricks in the lower parts have a fine macrofabric with small inclusions such as grog, whereas the bricks in the upper parts have a coarse macrofabric, characterized by larger inclusions (>2cm) such as pottery sherds and gravel. Smear-slide analysis shows that the soil for the bricks from the lower parts of the walls is well sorted and the grain shape subrounded, whereas the samples from the upper parts of the walls are poorly sorted with grains subangular in shape. The latter observation suggests that, for bricks in the upper parts of the walls, additional temper, specifically sand, was added to the local sediment and functioned as a degreaser to the clay and to prevent the mudbrick from cracking when dried. Finally, grain-size analysis on the samples reveals distinct differences between the bricks in the upper portion of the walls and those of the lower portion. Samples from the upper parts contain a higher percentage of vegetal temper and lower fine fraction (<45%), whereas the samples from the lower parts contain a lower vegetal temper percentage and higher fine fraction (>45%). There is one outlier from the lower portion of one of the walls (S013), which shows a fine fraction just below 45%. However, its vegetal temper measurement is consistent with the other samples from the lower parts of the walls, as are the sorting and grain shape.

[62] Spencer 1979, pl. 17; Wright 2009, 247–48.

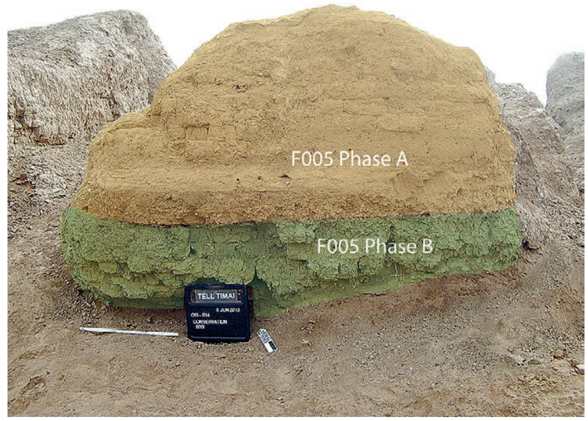

FIG. 12. Exterior of the western wall of the Q13-1 structure (Q13-1 F005). English bond is used in the upper level (Phase A) and Flemish bond in the lower level (Phase B).

The L14 Structure: Results

Bricklaying in L14 is extremely consistent throughout the main body of the building, with multiple courses of English bond characterizing the brickwork of the structure (fig. 13). Mudbrick dimensions are also consistent with average measurements of 25 x 15 x 10 cm. The dimensions vary slightly because of deterioration and different degrees of shrinkage among mudbricks; the ranges of measurements, respectively, are 22–26, 14–16, and 10–12 cm. The vertical and horizontal mortar joints consistently measured 1 cm wide throughout.

The mudbrick samples from the L14 structure, which were collected from two different sides of the building, are consistent with each other in terms of the percentage of vegetal temper (approximately 50%) and the grain-size ratio of the recipe. Grain-size analysis shows that L14 mudbricks have a higher percentage of coarse fraction (60% on average) in comparison to the mudbricks from the Hellenistic building (30–40%). The fine fraction in L14 is lower than 45% and the macroscopic fabric is coarse. Notably, the two samples from L14 show strong similarities with those from the upper parts of the walls of Q13-1 in several respects. The samples from both L14 and the upper walls of Q13-1 are generally characterized by a small fine fraction (<45%) and the intensive use of additives such as straw and sand. In the macroscopic fabric, there is a large amount of medium-sized inclusions, such as pottery sherds and stones, indicating a lack of intensive sediment preparation (i.e., sieving) during manufacturing. Microscopic analysis of the smear-slide and

FIG. 13. Exterior wall of the L14 structure with bricks laid in the English bond pattern, looking west.

wet-sieved samples of L14 likewise revealed poorly sorted soil and grains subangular in shape similar to the samples of the upper walls of Q13-1.

Sediment Samples

As mentioned above, four sediment samples were taken, two from grid sector M6 (S004 and S005) and two from unit Q13-1 (S286, S287), for comparison with the mudbrick recipes found in the buildings. The comparison between sediment samples from M6 and Q13 show a general chemical and mineralogical similarity, with montmorillonite being the main clay present and small percentages of illite and kaolinite. Other minerals that are consistent in all the samples are quartz, pyroxene, and plagioclase feldspar. The samples show a difference, though, in grain-size ratio. The M6 sediment samples show a high fine fraction (62% and 70%), which is similar to that found in the bricks of the Hellenistic building in N6/N7. The Q13-1 samples have a significantly lower fine fraction (39–44%), which correlates to the samples from both the Q13-1 and L14 structures.

DISCUSSION

Based on grain-size ratio and brick size, the collected data show the presence of at least three distinct recipes implemented at Tell Timai during the Graeco-Roman period, each of which is associated with a different type of bricklaying (table 3). Recipe 1 we refer to as a Hellenistic recipe; it was used in the Hellenistic building in N6/N7 and is characterized by a medium-fine macrofabric and high fine fraction. Bricks with this recipe were laid following the running bond pattern. Recipe 2, a Roman recipe, is used in the lower walls of the house in Q13-1 (Q13-1 Phase B) and is characterized by a fine macrofabric and medium fine fraction. Bricks with this recipe were laid following the Flemish bond pattern. Recipe 3, a later Roman recipe, is used in the upper walls of Q13-1 (Q13-1 Phase A) and in L14 and is characterized by a coarse macrofabric and low fine fraction. Bricks with this recipe were laid following the English bond pattern.

Recipe 1 was used consistently across both building phases (HB1 and HB2) of the Hellenistic building in sectors N6/N7. This agrees with Hudson's chronological reconstruction in which HB1 was rebuilt soon after its destruction. The similarities in the recipes and morphology of the bricks suggest a continuity in the mudbrick *chaîne opératoire* or the reuse in HB2 of bricks in good condition from the earlier phase. As for the difference in wall thickness and orientation of HB2, this might be attributed to a different architect or construction team, to spatial limits imposed by the existence of surrounding structures, to owner requirements, or some combination of the three. It is significant for understanding production processes that, in this case, the mudbrick size was not modified to accommodate the changes in wall size.

Recipes 2 and 3 were used in the lower and upper phases of the Q13-1 structure, respectively. The use of these two distinct recipes, along with the building analysis, confirms two different construction phases: what we call Phase A (upper) and Phase B (lower). The older walls of Phase B thus functioned as a foundation for the walls of the later Phase A. Based on comparative analyses, we were then able to tentatively assign a number of other walls in the eastern part of the Q13-1 structure—where the building is more decayed and the stratigraphy was uncertain—to either the earlier or the later phase. As mentioned above, the diagnostic ceramics found beneath the eastern part of F004 Phase A and in its associated construction fill

TABLE 3. Characteristics of the three mudbrick recipes and their associated bricklaying techniques identified in Tell Timai.

	Macro-fabric	Fine Fraction (%)	Vegetal Temper (%)	Brick Size (cm)	Bricklaying	Location Where Used	Approx. Date of Use
Recipe 1	medium-fine	50–70	20–30	40 x 20 x 9–10	running bond	Hellenistic building	Hellenistic (late 3rd/ early 2nd c. BCE)
Recipe 2	fine	>45	30–40	30 x 15 x 10	Flemish bond	Q13-1 Phase B [lower]	Late Hellenistic/Early Roman
Recipe 3	coarse	<45	40–50	25 x 15 x 9–10	English bond	Q13-1 Phase A [upper]; L14 structure	Roman (2nd c. CE or later)

point to a second-century CE terminus post quem for the construction date of Phase A in Q13-1.

Recipe 3 is also found in the samples from the L14 structure, which similarly makes use of the English bond bricklaying pattern. That the same recipe and bricklaying technique were used in both Q13-1 Phase A and the L14 structure could mean that their construction was contemporaneous (broadly speaking). While the Q13-1 structure is probably a house, the L14 structure is the largest building standing on the site and is thus presumed to have had major civic importance, whether cultic or administrative. This result was somewhat surprising to us; since Recipe 3 is the coarsest of the three recipes, we would not have expected to find it in what might have been the most prestigious building on the tell. The homogeneity of the mudbrick recipe in buildings of different types and vastly different scales could be an indication that mudbrick production was centralized. At some Pharaonic-period sites (Abydos, Amarna, and Karnak), mudbricks were manufactured by a centralized producer and used in all buildings regardless of function.[63] However, whereas the quality of the bricklaying in Phase A of Q13-1 is inconsistent, with irregular patterns in places, the bricklaying appears more consistent in the L14 structure. This suggests that if brickmaking at this time was centralized, resulting in the homogeneity of bricks irrespective of the status of the building and its patron, the same uniformity did not extend to the building teams. Presumably, for the larger, more publicly significant structure, more highly skilled and no doubt more expensive laborers were employed than for the domestic structure of Q13-1. This is a very preliminary hypothesis, and more data are needed to develop and substantiate it. But it highlights the need for more regular study on the differences and similarities in mudbrick morphology across different genres of building, something that has received only limited attention in Egyptian archaeology so far.

Finally, comparison between the recipes and the sediment samples allows us to make some preliminary observations about differences in the *chaîne opératoire* and in the quality of construction materials among our three case studies. First, there is a clear difference in the raw source material used for the bricks in the Hellenistic building in the north of the tell versus the raw material used in the Roman period for the structures in L14 and Q13. During the mudbrick production process, the mudbrick makers generally adjusted the local sediment to compensate for deficiencies. The strong similarities between the grain-size distribution of Recipe 1 and the local alluvium sampled in M6 indicates that few adjustments were made to the silty-clay sediment found in this part of the site. The adjustments were primarily restricted to the inclusion of straw to balance the high fine fraction (especially the clay fraction). No degreasers such as sand were added.

On the other hand, the sandy-loam and medium-loam sediments in the central part of the tell, as represented by the sediment samples from Q13-1, seem to have required more modification. Both Recipes 2 and 3 show that mudbrick makers added degreaser, namely straw and sand, to a higher degree. However, in comparing Recipes 2 and 3, what is especially notable are the differences in temper and fine fractions in these bricks. In Recipe 2, the higher percentage of fine fraction, the exclusive use of straw as vegetal temper, and the removal of coarse inclusions such as

[63] As indicated by brick stamps (Kemp 2000, 83). See also French (1984, 195) and Spencer (1979, 46).

stones and pottery sherds bigger than 5 cm indicate a more specialized production, specifically careful sieving of the sediment. Sieving allows the brickmaker to control the proportions of fine and coarse fractions in the raw material, reducing the need for extensive tempering; it also leads to better sorted grains. Fewer coarse inclusions and better grain sorting result in a more durable brick.

This is in contrast to Recipe 3, which produced a coarse macro- and microfabric characterized by a heterogeneous macrofabric and mixed types of tempering agents. This coarser fabric is more prone to erosion by evaporation and humidity as the water may travel faster through the cracks created around the coarse inclusions, which progressively produces a loss of material. The presence of coarser inclusions such as pottery sherds indicates a less careful *chaîne opératoire*, namely, a lack of sieving of the sediment after collection, which also suggests a faster mudbrick production (fewer manufacturing steps). Lack of preparatory sieving can lead to an imbalance with respect to the fine fraction; this could account for the intensive use of mixed tempers in Recipe 3, which would have helped to reduce shrinkage during the drying process by balancing the clay fraction's tendency to shrink. It should be noted, however, that the higher proportion of tempers may also indicate the reuse of older, decaying building materials, in which old mudbricks were broken down, combined with additional degreasers and water to prevent shrinking and to increase the plasticity of the dough, and finally remolded. Such remixing can result in a coarse fabric. Reuse would not be surprising given the later date of these structures; by this time in Timai's history (second century CE or later), there would have been plenty of older building material available. The presence of Recipe 3 in both the L14 monumental structure and the Q13-1 domestic structure suggests that its use in Q13-1 was not a case of a home renovation done on the cheap but rather a community-wide production choice, whereby, for whatever reason, the mudbrick manufacturers became less discriminating in the preparation of the raw source material for production.

CONCLUSION

This study demonstrates that building archaeology in conjunction with geoarchaeology has the potential to be a useful tool for the study of earthen architecture in Egypt. The data obtained from this case study have provided valuable information about the stratigraphy, phasing, and construction methods of the buildings at Timai and provide a path forward in the continued study and excavation of the mudbrick structures on the site. The three recipes and measurements registered in Timai structures so far seem to indicate three distinct periods of production and usage of mudbricks at the site, each following different vernacular traditions. These conclusions have allowed us to start forming hypotheses about social and cultural practices related to building. We believe this methodology can be especially useful in light of the rising interest in urban studies of the Graeco-Roman period in Egypt. Several recent papers have outlined such challenges faced by these studies, including the deterioration of mudbrick structures already damaged long ago by papyri hunters and now in a critical state of preservation.[64]

Regarding the limitations of the present study, an obvious one is the small sample size, representing only a very small portion of the mudbricks at the site and ranging across a wide chronological period. Further investigations need to be carried out to determine if the recipes identified reflect site-wide practices of mudbrick manufacture in specific chronological periods. In addition, more samples for hydrometer analysis would have been helpful for strengthening the results and confirming outliers, such as S009 from wall N7-9 F018. This can be achieved in the future by better preseason planning, namely by making the collection of mudbrick samples part of the normal fieldwork data collection, acquiring sufficient graduated cylinders, and organizing excavators to assist in preparing and analyzing the samples.

The results here are generally consistent with what is known about mudbrick morphology (size and shape) at other sites in Graeco-Roman Egypt.[65] However, we should recall that every site is a unicum and should be investigated as such. It is important to avoid generalizations about brick sizes and recipes used in one period across different regions of Egypt, since mudbrick manufacturing processes can depend on the local workforce and on local raw source material. In this respect, it is important to remember that the robustness

[64] Ali and Massoud 2016; Barnard et al. 2016; Rossi and Magli 2019.

[65] For example, from houses at Karanis, Dime, Hermopolis, Medinet Habu, and Armant (Spencer 1979, 98–103).

of the methodology laid out here relies on the joint application of both the geoarchaeological and the mensiochronological components.

Notwithstanding the small sample size, this field method has achieved what we set out to discover—a quick and easy way of getting real-time feedback in the field that can complement excavation and survey efforts. This approach allowed us to identify variations in the vernacular architecture as well as multiple operational steps of construction: screening of sediment, addition of tempers and degreasers, molding, bricklaying, and mortar usage. Thus, we believe the techniques employed in this case study should become a regular part of the survey and excavation efforts of Timai and other sites in Egypt. At a time when funding, permits, and time are in short supply, new methods are needed to glean useful information about the architecture of these large and often complex sites as quickly as possible. Development of this methodology (e.g., to include microscopic analysis of vegetal temper) and its broader application to more buildings and sites could open up further opportunities for analysis to address questions regarding skills transfer, cultural evolution, local economy, social organization, and craft specialization.

Finally, we should mention that a parallel ethnoarchaeological and community project conducted by the excavation team furnished information about modern earthen architecture practices in the Egyptian Delta. This is useful, as mudbrick manufacturing has remained largely the same in Egypt for millennia.[66] Discussions and collaboration with builders in the community provided us with insights on how builders reuse older mudbricks in construction and how walls should be maintained by the fresh application of mud mortar and mud plaster each year. Their information on the latter point is especially important because it indicates that the regular maintenance of mud plaster is a necessary part of any conservation plan. Thanks to the community outreach project, conservation of the block in which Q13-1 is located was conducted with the expertise of the local community. New mudbricks were manufactured and added to shore up eroded portions of external walls, and these were subsequently plastered (see fig. 5, bottom). Thus, greater focus on mudbrick analysis in the field can serve as a catalyst for engaging local communities in understanding and maintaining Egypt's cultural heritage.

[66] Morgenstein and Redmount 1998, 130. See Lorenzon and Zermani (2016) for the results of the ethnoarchaeological and community project.

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