“Another Brick in the Wall” or How to Build an Ancient Egyptian House

JOANNA DĘBOWSKA-LUDWIN[A1] AND KAROLINA ROSIŃSKA-BALIK[B]

[A]JAGIELLONIAN UNIVERSITY

[B]JAGIELLONIAN UNIVERSITY AND POLISH ACADEMY OF SCIENCES

[1] Corresponding author J. Dębowska-Ludwin: joanna.debowska-ludwin@uj.edu.pl

ABSTRACT: In an attempt to answer many practical questions related to mudbrick production, this paper sets forth an experimental approach relevant to the technique used in Late Pre- and Early Dynastic Egypt. The paper surveys possible sources of information on the ancient technique and previous experimental approaches. Then, it presents the experiment methodology and the resulting observations and calculations, which were later used as a standard for simulations of time and workload needed to construct particular types of structures excavated in Tell el-Farkha. Our most important observations are the widely underestimated stage of seasoning, the problem of accessibility of space for brick drying, transportation of ready-to-use bricks to the construction site and calculations we made based on numbers obtained during the experimental brick production. Our simulations show that building monumental structures needed communal effort, while household structures could have been built by the people who intended to use them for their own needs.

INTRODUCTION

For millennia the most common Egyptian building material was mudbrick, sometimes called adobe in order to connect it with similar materials made in other parts of the world (Emery 2011: 1-2). Egypt is seen as a civilisation of stone, mainly because of the pyramids and temples of the Pharaonic Era. In actuality, mudbrick was far more common, and used for a variety of structures; from small houses and workshops to monumental residences and tombs (Arnold 2003; Kemp 2000; Spencer 1979). It should be kept in mind that stone architecture was merely a small part of the ancient Egyptian building repetoire meant only for the gods and a few chosen people; mostly the dead. Ordinary people had no use for stone architecture as a place to live, hold their livestock, protect their homestead, or store their food. Thus they used mudbrick, which served those purposes.

Although the process of making and building with mudbrick was simpler, it did not necessarily require less work. How exactly was this common material produced? What was the ratio of its basic components? How long did the process of brick-making take? Were there any particularly difficult moments in the *chaîne opératoire* of mudbrick building? In an attempt to answer all these and many other practical questions, we developed an experimental approach to mudbrick [illegible] of Tell el-Farkha, which is dated to the Pre- and Early Dynastic periods (c.3700-2600 BC).

The paper presents the experimental methodology as well as the resulting observations and calculations, which were later used as a standard for simulations of time and workload needed to construct particular types of structures excavated in Tell el-Farkha. As the structures were mostly preserved only to their foundations, results of the experiment served as supplementary material for archaeological data in order to better understand mudbrick architecture at the site.

THE BEGINNING OF EGYPTIAN MUDBRICK ARCHITECTURE

Our interest in mudbrick and its production process is focused on the Early State Formation period in Egypt (for chronological details see table 1). However, to provide a more detailed background, we start in the Middle Predynastic, which falls in the first half of the fourth millennium BC (i.e. Naqada IB to IIIA, and the Chalcolithic in the Near East), as the oldest known evidence of mudbrick production dates to this period (Hoffmann 1980).

Table 1: Egyptian chronology (after Mączyńska 2013: 54; Wilkinson 2010: 14-20).

Absolute dates in years BCE	*Culture-historical phase*		*Relative chronology*
343-664	Late Period	Dynasties 26-30	
664-1069	Third Intermediate Period	Dynasties 21-25	
1069-1539	New Kingdom	Dynasties 18-20	
1539-1630	Second Intermediate Period	Dynasties 14-17	
1630-2010	Middle Kingdom	Dynasties 11-13	
2010-2125	First Intermediate Period	Dynasties 9-11	
2125-2650	Old Kingdom	Dynasties 3-8	
2700-3100	Early Dynastic	Dynasties 1-2	Naqada IIIC-D
3300	Protodynastic	Late Predynastic	Naqada IIIA-B
3600	Middle Predynastic		Naqada IIC/D-IIIA
3900			Naqada IB/C-IIB
4500	Early Predynastic		Naqada IA/B Badarian
5100			El-Omari Merimde Beni-Salame Fayiumian

Mudbrick constructions, which belong to a wider category of earthen architecture (Niroumand et al. 2013), have a long history in Egypt. An early example of building with mud comes from the Neolithic, where lumps of mud mixed with organic material were recovered from phase III of Merimde Beni-Salame (Junker 1932: 46, fig. 1). Other early examples, roughly dated to the Early/Middle Predynastic period, were found both in Upper and Lower Egypt. One example comes from locality HK 29 (Hierakonpolis), where walls made of stone, roughly made mudbricks and some perishable, organic materials were recorded at the Naqada cultural context (Friedman 2009: 95).

Evidence of the early use of mudbricks in Egypt also comes from the site of Sais in association with phase Sais III, where some structural features were discovered (Wilson 2006: 86-89). The structures are interpreted as a grey mud floor with post holes around it and pottery concentrated at the edges of the floor. The artefact labelled 3002.16, described as a fired mud 'brick' (Wilson 2006: 88) with its regular size and rounded shape, shows that at this early date bricks were purposely manufactured and also played some specific, not only structural, roles in buildings, such as elements like fireplaces.

Particular kinds of mudbrick dating to the Middle Predynastic again come from Hierakonpolis, context HK 29A, where they were flat and more tile-shaped (Friedman 2009: 95 footnote 54), and Tell el-Fara'in/Buto (Von der Way 1986: 119-122), where they formed D-shaped blocks of burnt mud. Interestingly, the use of early bricks illustrated by the examples above is not restricted to any particular cultural context, since the discoveries were registered at sites of both the Naqada and Lower Egyptian cultures. Also in Naqada IIC, at the Central Kom of Tell el-Farkha, a double fence constructed in the wattle and daub technique, which separated the Lower Egyptian residence from other structures, was replaced with a solid mudbrick wall. The bricks had a regular cuboid shape and were very carefully arranged in rows, which together composed a wall slightly more than 1m wide (Chłodnicki and Geming 2012).

CONTEXTUAL SETTING: THE SITE OF TELL EL-FARKHA

The background of our experimental activity is Tell el-Farkha, located in the eastern Nile Delta, Daqahliya province. The rather small site covers c.4 ha and is composed of three mounds called the Western, Central and Eastern Koms. Excavations started in 1998, led by a Polish team from the Poznan Archaeological Museum and Jagiellonian University in Krakow directed by M. Chłodnicki and K.M. Ciałowicz (Chłodnicki et al. 2012).

The settlement was founded on a Pleistocene natural sand hill called a 'turtle-back' or 'gezira', which over centuries of fluvial activity was covered with silty sediments creating the present shape of the Nile Delta (Pennington et al. 2017). The first village was located about 10km from the seashore (Pawlikowski and Wasilewski 2012). Its elevated location in the surrounding floodplain usually protected houses from damage caused by the annual Nile floods. It also gave the settlement's inhabitants easy access to fertile fields downslope which were used for agriculture and as a mud source. However, this specific location meant that during periods of high water, lasting about four months every year (Butzer 1984), there was severely limited space available for human activity, resulting in a high building density within the settlement.

The earliest human presence at Tell el-Farkha is attested at c.3700 BC, during the Naqada IIB period, and lasted uninterrupted until the turn of Dynasty 3 and 4 during the Old Kingdom (c.2600 BC). The long sequence was divided into seven occupational phases (table 2), which correspond to the development, prosperity and decline of the settlement. During a millennium, a small Lower Egyptian village evolved into an exchange centre linking Egypt and the Levant. Subsequently it turned into an early Deltaic proto-capital, to be finally dominated by the power of the pharaohs and subsequently depopulated (for more details see Ciałowicz et al. 2018).

Mudbrick structures are most prevalent at the site almost from its very beginning. Only in the first phase related to the Lower Egyptian culture are various pit features and larger furrow structures, made probably in the wattle and daub technique, more common. From its introduction in the second occupational phase onwards, mudbrick predominates over other building materials. The popularity of mud-brick is so evident that in these early layers until the settlement's abandonment other building materials were rarely registered. Where present they were limited to roofing features, fences and animal pens. Mudbricks were used all over the site for construction of separation walls (sometimes of near-monumental size), official residences, shrines and monumental tombs, as well as regular and very simple household structures, workshops and graves, thus proving to be the most universal building material across the site. Interestingly, the material was very consistent throughout its long history.

Table 2: Chronology of Tell el-Farkha (after Ciałowicz 2019: 118).

Phase	*Relative chronology*	*Absolute chronology*
1	Naqada IIB-IIC	ca. 3700-3500 BC
2	Naqada IID1	ca. 3500-3450 BC
3	Naqada IID2/IIIA1	ca. 3450-3350 BC
4	Naqada IIIA1-IIIB	ca. 3350-3200 BC
5	Naqada IIIB-IIIC1 / 0/1st dynasty	ca. 3200-3000 BC
6	Naqada IIIC2-IIID / 1st-2nd dynasty	ca. 3000-2700 BC
7	3rd/4th dynasty	ca. 2700-2600 BC

The shape of mudbricks was always the same, with only slight variations of size between particular structures, but not types of structures. Two main types of bricks were registered at the site (one darker, and another lighter as it included more sand in its makeup). The only observation of chronological importance is the change in relative popularity of these two types. The oldest bricks of the second Tell el-Farkha phase were only dark, while light-coloured bricks were introduced in the third phase, and almost immediately gained equal popularity, and were often used side by side within the same structures. The reason for this was probably clearly practical, resulting from their different physical properties (see below).

Each of the site's periods of prosperity and decline were marked with hundreds of mudbrick structures. One of them was a large building, found in the Central Kom associated with phase 1. It contained many highly valuable artefacts, such as objects imported from the Levant and Upper Egypt and very early pieces of golden jewellery. The structure, called the Lower Egyptian residence, was quite unsurprisingly separated from ordinary houses in the neighbourhood. The separation fence was probably executed in the wattle and daub technique, since the only remains preserved were narrow furrows and what appear to be mud shields with impressions of plants on one side and of human fingers on the other. Shortly after, the structure was replaced with a solid wall (fig. 1), which is the above mentioned first regular bricked structure known from Tell el-Farkha (Chłodnicki and Geming 2012).

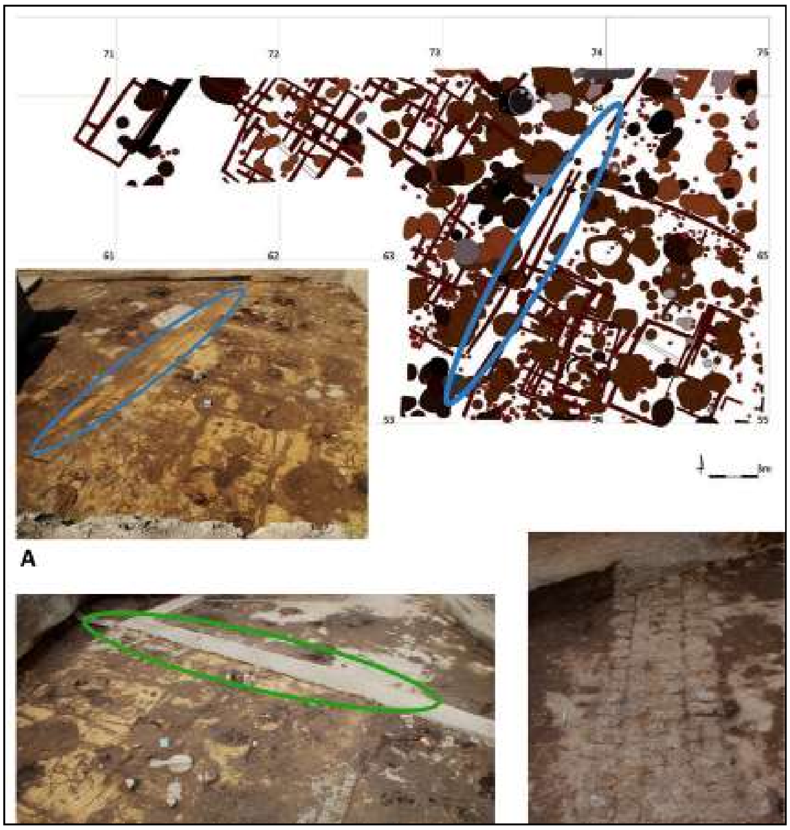

Figure 1: (a) Negative of wooden/organic material fence and (b) its mudbrick replacement at Central Kom at Tell El-Farkha (photographs by R. Słaboński, drawing by M. Chłodnicki and M. Geming).

A similar situation, where older fences were replaced by mudbrick walls, was found at the Western Kom, where likely the earliest brewery in the Nile Delta was discovered (Adamski and Rosińska-Balik 2014: 23-26). This brewing facility is the largest of a long series of breweries unearthed at Tell el-Farkha, and with its 13 vats it could have produced 200L of beer simultaneously. As it was an important building, it required a degree of control and/or protection. Therefore, it was at first surrounded by a fence (preserved archaeologically as a furrow) which, at the same period as at the Central Kom (Naqada IIC), was replaced with a solid mudbrick wall (fig. 2) (Ciałowicz 2012a).

Figure 2: Brewery center at Western Kom at Tell el-Farkha surrounded by an organic fence (a) and later by a mudbrick wall (b) (photographs by R. Słaboński).

Another remarkable mudbrick structure is the Naqadian residence from the Western Kom dated to phases 3-4 (Naqada IID2-IIIB). It measures 500m^2, making it the largest edifice of the time (Ciałowicz 2012b). A final magnificent example of early Egyptian architecture comes from the Eastern Kom, where a monumental mastaba tomb dated to Naqada IIIA2/IIIB1 was excavated (fig. 3) (Ciałowicz and Dębowska-Ludwin 2013; Dębowska-Ludwin 2018). The other mudbrick buildings were much smaller, roughly rectangular or oval constructions of irregular, thin walls; most often between 0.3 and 0.5m. They were arranged along narrow streets and modified so often that in many cases it is difficult to reconstruct how many of them were actually contemporaneous (Karmowski 2014). Due to analyses of bulk artefacts recovered from the structures, they are interpreted as household structures, such as a bread baking facility recorded at the Eastern Kom in the Old Kingdom layers (Adamski and Kołodziejczyk 2014).

THE STATE OF RESEARCH ON ANCIENT MUDBRICK PRODUCTION

As mentioned above, structures found and excavated at Tell el-Farkha were built using two types of bricks: dark-coloured mudbricks with high organic material content ('muddy') and light-coloured bricks ('sandy') with a high amount of sand mixed in with the mud. Differences in composition of the raw material used to produce bricks influenced the physical properties of the final product. Thus, sandy bricks were stronger but vulnerable to erosion from rain, while muddy bricks were weaker but more resistant to moisture.

Exact reconstruction of the ancient production process may not be possible. However, ancient Egyptian scale models, real brick moulds and scenes depicted in contem-

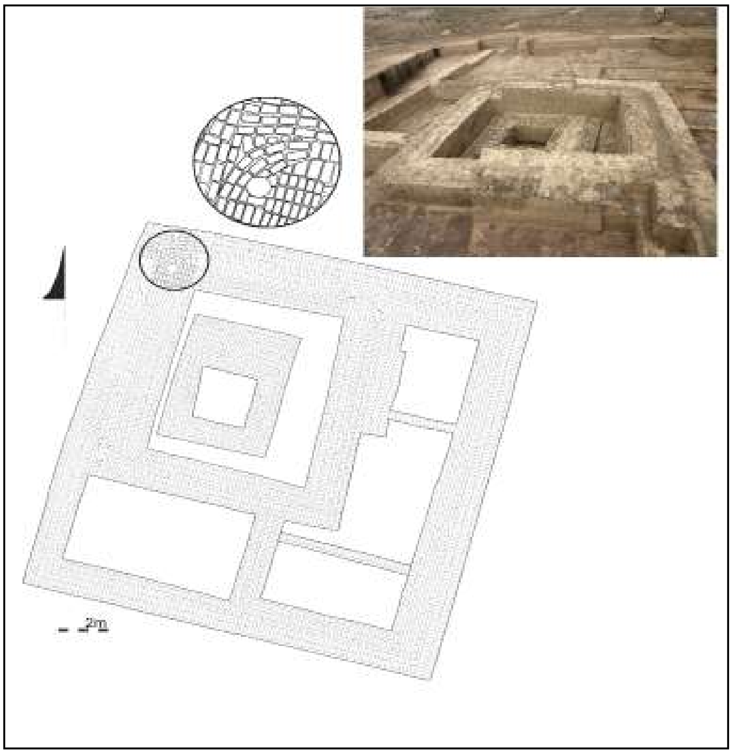

Figure 3: The earliest mastaba type grave in layout and its view. Eastern Kom at Tell el-Farkha (photograph by R. Słaboński, drawing by M. Czarnowicz).

porary artistic representations provide useful information. This can be supplemented with scientific analyses of ancient bricks, the practical know-how of modern Egyptian craftsmen and experimental works on earthen architecture conducted in many places around the world. Thus, the combination of various sources offers a promising insight into this ancient technique.

Ancient Egyptian wooden frames used for brick making and their smaller, model counterparts used for temple foundation deposits are well known in museum collections worldwide. They include, amongst others, a brick mould from the excavations at Kahun, dated to the Middle Kingdom (Manchester Museum, acc.no. 51); a brick mould from a foundation deposit for Hatshepsut's Temple dated to Dynasty 18 during the New Kingdom (Metropolitan Museum, acc.no. 22.3.252; fig. 4); and, finally, a model brick mould with the cartouche of Tuthmosis III from Gebelein also dated to Dynasty 18 (Museo Egizio in Turin, s.12448). A similar mould is presented on the relief on the wall of Red Chapel at Karnak, in the scene of brick making for a new temple performed by Queen Hatshepsut (Burgos and Larché 2006). All of the examples present the same shape—a

Figure 4: Brick mould from a foundation deposit for Hatshepsut's Temple, 18th dynasty, New Kingdom, at the display in the Metropolitan Museum (acc. no. 22.3.252) (photograph by K. Rosińska-Balik).

wooden frame for single (only in a few cases double) brick with a simple handle attached to/modelled out of one of the mould's longer sides. The most famous ancient Egyptian representation of the brick making process comes from the tomb painting of Rekhmire of Dynasty 18 during the New Kingdom (Davies 1943: 54-55, pls. LVIII, LIX, LX). The scene depicts workers or captives at all stages of the mudbrick production process from preparation of raw materials to brick laying. Details of the process are also known from various wooden scale models, which were a typical element of nobles' funerary equipment during the Middle Kingdom. A model, which shows three male figures making bricks, was found in Beni Hassan tomb 275 (Dynasty 12), now in the British Museum collection (no. EA63837, Garstang 1907: 131, fig. 129).

There are a number of other ancient iconographic sources (Lorenzon 2016), which show the same scheme of work. First, the soil is dug out to prepare a mixture together with water carried in containers. The mixture is then transported to the place where bricks are formed with a wooden mould and left in rows for drying. A final source of information directly related to ancient brick production comes from a few ancient Egyptian texts (Kitchen 1976). However, due to their fragmentary condition, they do not provide significant detailed information.

The composition of ancient bricks was a subject of interest as early as the first half of the twentieth century (Nims 1950). More recent laboratory analyses (Abdel Rahim 2016; Goldberg 1979; Love 2012; Morgenstein and Redmount 1998; Nodarou et al. 2008; Pawlikowski and Słowioczek 2012) show that mudbricks found in various geographic locations have similar composition of clay, sand, silt and organic material. The specific ratio of the ingredients varies significantly between particular sites, but compositional differences are also observable between particular structures of the same or similar context.

The first observation may be quite obviously explained as resulting from different properties of local sources of mud used for brick production. For the second, it is suggested that the variability could reflect the existence of specific household-based recipes (Love 2012: 152), where the general production technique remains the same but the exact list of ingredients is unique for each brick making family/workshop. Similar conclusions can be drawn from analyses of bricks and natural sediments in Tell el-Farkha (Słowioczek 2016: 74), where the source of raw material for brick production was generally identified north from the site in the surrounding fields. Inconsistency in brick texture and composition may therefore suggest various individual recipes and/or that sources of mud used for production were dominated by the variable nature of the alluvium itself which is greatly dependent on season of collection and particular location (see French 1984).

The process of brick making was also studied through experimental archaeology. There is a body of research which focuses on brick making know-how for a number of reasons. Some attempts were made in order to revive the ancient technique for use in contemporary society (Avrami et al. 2016; Fathy 1973). Others to facilitate conservation of such important Egyptian sites as the Dynasty 2 royal enclosure in Shunet el-Zebib (Adams and O'Connor 2010; Crosby 2016) or the immense and beautifully preserved Ptolemaic city in Tell Timai (Littman et al. 2014). In one case, the aim of experimental brick production was to completely rebuild ancient fortifications of the Hittite capital in Hattusa (Seeher 2007). Some more detail-oriented studies examined engineering properties of bricks (Trzciński et al. 2016) and aimed to reconstruct the possible height of complete structures based on geomorphological analyses of building material (Trzciński et al. 2017).

Other research used an ethnoarchaeological approach to mudbrick (Correas Amador 2013; Lehmann 2013) or tried to apply the concept of 'architectural energetics' (Abrams and Bolland 1999) to discuss ancient mudbrick production and the complete process of building (Homsher 2012). Furthermore, the potential of the *chaîne opératoire* (Dietler and Herbich 1998; Sellet 1993: 106-107) as an interpretative perspective for mudbrick architecture has already been discussed (Miller 2017: 15-19).

THE EXPERIMENT: METHODS AND RESULTS

Although a lot of work has already been done on the subject of mudbrick production, none of the previous studies covered all issues related to the material at the earliest stage of its use; just after its introduction to the repertoire of Egyptian architecture. Thus, deeply rooted in the Late Pre- and Protodynastic periods, we decided to experimentally produce mudbricks to answer three basic questions:

1. What is needed for mudbrick production in terms of materials, their amounts and space?
2. How much time and workload does the process require?
3. Are there any local deltaic conditions that facilitate/endanger successful production?

STAGE 1: PREPARATION OF PASTE

We started the experiment with the preparation of the paste which is a mixture of mud with chaff/straw/other plant material, sand and water. The basic component is mud which in the Nile Delta always derives from local alluvium. It consists of variable amounts of clay, silt, sand and organic remains, the ratio of which depends on the place and time of mud acquisition. As this greatly influences the final product, admixtures such as chaff and sand were added when the composition of the mud was unsuitable for brick production. The organic material added to mud is responsible for the cohesion and plasticity of the paste, while sand prevents shrinkage and cracking at the drying stage and increases the strength of a brick (e.g. Love 2017: 353-354). Small fractures filled with sand help stabilise larger elements within the paste, which enhances the durability of the final product.

To produce the paste we added about 6kg of chaff and about 50L of water to each one cubic metre of local alluvium. The chaff was a typical harvest left-over of common wheat (*Triticum aestivum*), which was the closest available material to emmer wheat (*Triticum dicoccon*) cultivated at the site in antiquity (see Kubiak-Martens 2012). There was also a small admixture of pure sand. However, our leading craftsmen added sand in various amounts according to his assessment. A similar situation was observed in Tell Timai, where the main brickmaker adjusted the final formula 'by feel' during the paste preparation process (Littman et al. 2014: 16). As shown in Table 3, particular numbers obtained in other experiments vary depending on the region (Egypt: Clarke and Engelbach 1930; Littman et al. 2014; Mesopotamia: Oates 1990). Although no data about water amounts was provided, it is obvious that the raw materials remain the same in each case. Our specialists worked in a team of two–a master and an apprentice. The time they needed to prepare the paste was about 30 minutes. Subsequently, the mixture was aged for a day before it was ready for forming bricks.

STAGE 2 AND 3: BRICK MOULDING AND DRYING

For this stage of the process we had to move to an empty, flat, dry and sunny space, where the newly formed bricks, arranged in long but separated rows, could be left drying (fig. 5). The mould we initially designed was meant to make a brick of the most typical size used at the site (24x12x6cm). It was a simple rectangular wooden frame devoid of a handle. However, very soon our local brickmaker added one in the same place as it was on the actual ancient moulds.

The forming of 100 bricks took our two workers about 90 minutes. The master was working with the mould, which he kept wet to avoid it sticking to the fresh bricks. He filled the mould with a portion of paste and, each time when he was certain that there was no more empty space in the mould, he removed it and started forming another brick. In the meantime, the apprentice was busy bringing larger portions of the paste from the preparation site to the moulding area and supplying clean water. The importance of water for smooth brick production was described also by Nims (1950: 27).

The freshly made bricks were then left for drying, which took a week. As we thought temperature might be important for the drying process, we measured air temperature four times a day. We obtained the following readings: at 6:40 10-11˚C, at 15:00 23-35˚C, at 18:30 12-18˚C and at 00:00 12-15˚C (the experiment was performed during the second half of March). During the drying time, the wet bricks were regularly turned manually to let them dry evenly and prevent them from cracking or twisting.

The area needed to finalise this part of the process was our first great surprise, because to dry each 100 bricks we used 4.2m^2 totalling 13.65m^2 for the complete production. In our experiment the drying bricks covered a parcel of land suitable for a house, which in the modern Deltaic landscape, full of cultivated land and crowded settlements, was quite challenging to find. Tell el-Farkha is considered among the first urban, densely overbuilt sites in Egypt (Chłodnicki 2014; Moeller 2016: 59-112). Furthermore, the potentially available space was also limited by annual Nile floods. The problem of space management must have been of crucial importance to the ancient inhabitants and was surely an important part of planning the complex brick making process.

STAGE 4 AND 5: TRANSPORT AND SEASONING

Transportation proved to be a major problem, as the bricks were too heavy to be carried from the manufacturing site to the construction area and too fragile to

Table 3: The amount of materials used for brick production in various experiments (after Clarke and Engelbach 1930; Littman et al. 2014; Oates 1990).

	Tell el-Farkha	*Tell Timai*	*Gourna*	*Mesopotamia*
Mud and sand mixture	1m³	1m³	1m³	*no data*
Chaff	6kg	7.5kg	15.4kg	60kg
Water	50l	*no data*	*no data*	*no data*
Number of bricks	84	*no data*	*no data*	100

transport with a modern car. Thus, we followed the advice of our local specialist and used a donkey cart wadded with bunches of straw. In other studies on bricks, the transportation issue was also discussed as a challenging part of their production process (Homsher 2012: 18; Seeher 2007). However, the numbers quoted there were calculated for much bigger bricks of an average weight of 22kg, while at Tell el-Farkha a typical brick weighs about 3kg. So, our bricks were smaller and thus easier to relocate, however the total volume of bricks always naturally depends on the size of a structure.

The finished bricks were transported to the construction site. However, before the bricks were used for building, they were stacked in a loose pile and seasoned for two more weeks. This stage revealed itself to be a very important part of the whole procedure, although it is hardly mentioned in other studies (Homsher 2012: 12; Nims 1950: 27).

STAGE 6 AND 7: BRICK BUILDING AND EXCAVATIONS

Our total experimental production of 325 bricks was arranged in a small wall c.0.8m high, 1m thick and 0.75m long, which we constructed as an addition to an original ancient building, namely the monumental mastaba, in a place cleared in the course of excavations. Construction works took two hours, when the bricks were bounded and coated with mortar made of a mixture of local mud and water (fig. 6). The task was completed by two workers, with a master who carried out the bricklaying and his apprentice.

Our initial idea was to monitor and analyse the wall's degradation over time. However, our new bricks turned out to be useful for the local commity in the modern Ghazala village, who took and reused most of them, so only a small amount remained. We waited three years until we decided to terminate the experiment and excavate the wall's remains.

EXPERIMENTAL RESULTS AND ARCHAEOLOGICAL REALITY

The experiment resulted in various observations, some of which were practical and helped us understand the procedure's complexity. Others gave us numbers useful for further calculations. We found answers to our research questions: we learnt what components and their ratio were important for brick production, and how much space was needed for drying bricks. Furthermore, we found out how much time was involved at each stage of production and building.

It became apparent that the local Deltaic environment helped ancient brick makers by securing almost unlimited sources of mud, but on the other hand greatly limited the space available for brick drying. We also learned that the shrinkage of bricks

Figure 5: Experimental brick forming and drying (photographs by authors).

Figure 6: Construction of mudbrick wall as an addition to mastaba (photographs by authors).

during production was much higher than we initially thought at the drying stage (from 24x12x6cm at the beginning to 22x10.5x5cm). The shrinkage continues later during seasoning. In general, mudbricks lose as much as one third of their volume when compared to the initial paste.

Such a situation was observed in the superstructure of burial enclosure 55, where joints between bricks at the moment of discovery seemed empty, only partially filled with loose earth (fig. 7a). The feature was then interpreted as built using a special building technique, but when compared with the experimental wall excavated a few years after its construction, the same empty spaces were visible. As we were sure that mortar had been used to bind the bricks, it became clear that in the time between building and uncovering, the bricks had shrunk a little bit more giving the impression that the mortar had 'disappeared' (fig. 7b).

One of the most vital results of the experiment is the possibility of reliable assessment of the effort invested in constructing various types of structures. Information collected during our brick production attempt provided us with some basic numbers we then used for theoretical calculations. We chose three constructions as our case studies: two monumental structures (the Naqadian residence and mastaba) and one household building (the bakery of the Eastern Kom). In the case of the residence and mastaba we calculated the numbers for their preserved height, while for the bakery its height was estimated at 2m. According to our experiment two workers were able to make about 67 bricks per hour, and build at the pace of 163 bricks per hour. There are no ancient records which clearly state the length of a typical workday, especially in the Late Pre- and Early Dynastic periods. In order to calculate the number of days it took to produce bricks and construct a building we used two extreme values established in other experiments with ancient buildings, that is five (Erasmus 1965) and 10 hours of work per day (Seeher 2007: 211-224).

With these two numbers the brick production rate was between 335 and 670 a day and 815 to 1630 for bricklaying. This is an interesting observation when juxtaposed with results of other experiments, such as 2000-3000 bricks produced by four people during a day (Fathy 1969: 252), or almost 2000 in two workdays by an unspecified group of workers (Littman et al. 2014: 62). Implying that, although our numbers are smaller, they remain in a similar range, and a better organisation of work, more oriented on mass production, would probably boost the result. On the other hand, the efficiency of brick building at the level obtained in our experiment is higher than in other calculations (Homsher 2012: 20, table 3). Thus, the time lost at the moulding stage was recovered through higher building efficiency.

All the calculated numbers present theoretical estimations and relate solely to the labour involved (table 4) without downtime moments such as drying or seasoning. Nevertheless, they clearly show that using mudbricks was quite efficient for household structures. Their construction was possible for all inhabitants of Tell el-Farkha, because materials were local, space for brick drying was relatively small, and the manpower needed for such a project was within reach of a single family. On the other hand, the process seems to be inefficient for monumental structures. The huge amount of mud and chaff needed for production of bricks and most importantly the large space for drying suggest the application of special practical strategies. We suggest that one of them might have been scheduling brick production for the period just after harvesting crops but before the annual flood. It

Table 4: Number of bricks, amount of rough materials and workload needed for completion of various types of buildings calculated on the basis of the experiment results.

Materials and workload		***Nagadian Residence***	***Mastaba***	***Bakery***
Number of bricks per layer		6000	3000	750
Structure height in m		2	3	2
Total estimated number of bricks		180 000	135 000	22 500
Mud used in m^3		2160	1620	270
Chaff used in kg		12 600	9300	1575
Area for drying in m^2		7800	5850	945
Workload – brick preparation calculated for a two-people team	Hours	2687	2015	336
	5-hour work day	537	403	67
	10-hour work day	269	202	34
Workload – building calculated for a two-people team	Hours	1104	828	138
	5-hour work day	221	166	28
	10-hour work day	110	83	14

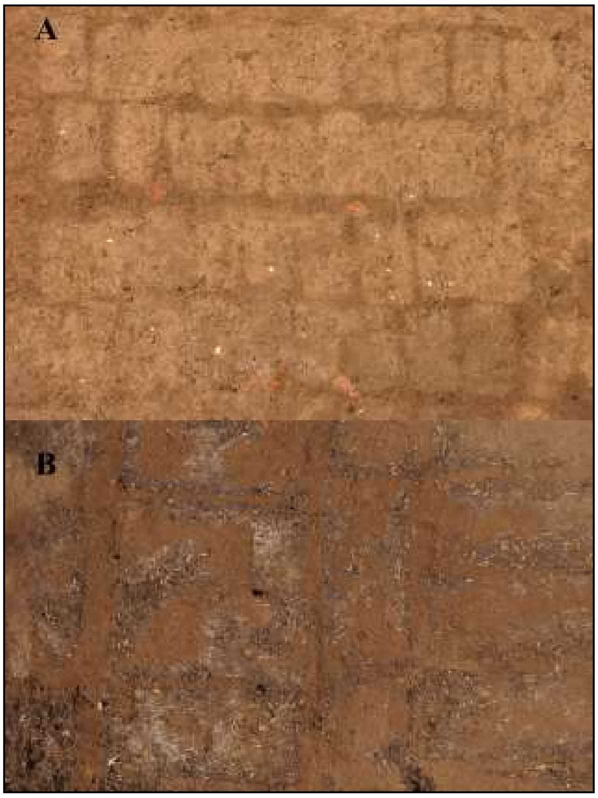
Figure 7: Brick arrangement in (a) the Grave 55 from Tell el-Farkha and (b) reconstruction wall after some years (photographs by R. Słaboński).

secured the abundance of chaff (harvest left-overs), mud (fields normally covered with alluvium and waiting for new flood) and space (empty fields, again).
Another possible strategy was assigning more work teams for the larger building projects. Our calculations show that engaging 10 such teams would reduce brick preparation time to 27 days in the case of the Naqadian residence, and construction time to as little as 11 workdays. Moreover, construction could have been performed during the annual flood, when people were not engaged in agricultural tasks.

An observation made at excavations is that larger buildings were multiphase constructions, where thick walls were made of a series of thin ones (see fig. 3) of very similar date (Ciałowicz 2012b; Ciałowicz and Dębowska-Ludwin 2013). It is possible that instead of building one thick wall, it was easier to construct it in segments, minimising possible problems with brick production fluency. Thus, building monumental structures was possible through the common effort of the whole community and the efficient organisation of mass labour which were the main factors in helping to accomplish the completion of such ambitious projects.

CONCLUSION

The mudbrick-making experiment proved very important for our understanding of the site of Tell el-Farkha, and early Egyptian architecture in general. It allowed us to answer our initial research questions and now we can say we know the *chaîne opératoire* for making and building with mudbrick. We are now aware of how much work the complex process required, what is more, how tricky and time consuming the single stage of forming bricks can be. We have also learned that local conditions influenced the whole process. The Delta seems to be a perfect place for mudbrick building, because of abundant sources of mud and plant materials. On the other hand, it is and was crowded and available land was at times limited by floods–factors which were most probably balanced with the organisation of work.

Our most important observations are related to the widely underestimated stage of seasoning, the problem of accessibility of space for brick drying and transportation of ready-to-use bricks from the manufacturing place to the construction site—which might have been one of the most difficult technical parts of the complex undertaking. Another important outcome was our ability to calculate numbers of material needed and time investment based on numbers obtained during the experimental brick production. Our simulations help to estimate the workload invested in construction of various types of buildings, and clearly show that building monumental structures needed communal effort, while household structures could have been built by the people who intended to use them for their own needs.

The brick-making project showed that simple solutions–regular form of a brick, local abundance of mud as the main rough material–are the best, but in most cases they were applied in combination with many other simple procedures to result in complex processes. To sum up, we are now much more informed as we better understand ancient building strategies, techniques and the manpower and organisation effort hidden behind every ancient brick structure.

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