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The preservation of exposed mudbrick architecture in Karanis (Kom Aushim), Egypt

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Excavations in the arid regions of Egypt provide insight into the many types and uses of mudbrick architecture. Upon exposure the inherently unstable building material decays rapidly, resulting in severe loss or complete destruction of once well-preserved buildings. The preservation of mudbrick structures is relatively complicated and expensive. Research has focused on the circumstances that enable preservation and the influence of climate and weather over time. Conservation treatments should address these two processes as soon as possible after exposure of the structures. Our assessment of a range of conservation methods leads to the conclusion that reburial is among the least objectionable method of preservation, despite its drawback of returning the excavated buildings to a situation where they are invisible to both researchers and the public.

Keywords: adobe, conservation, Egypt, mudbrick, preservation

Introduction

Mudbrick or adobe has been used as building material from the earliest Neolithic structures in the Levant (Twiss 2007) to the majestic buildings in Bam (Iran), Djenné (Mali), and Shibam (Yemen); as well as for ancient monuments in Egypt (Abydos and Hierakonpolis) and Peru (Huaca del Sol and Tambo Colorado) and modern shanty towns on all continents except Antarctica (Oliver 1983; Bourgeois 1987; Agnew *et al.* 1990; Bourdier 1993; Maldoner 2007; Rainer *et al.* 2011). The word “adobe” can likewise boast a long and complex history. It can be traced back to the Middle Egyptian word “dj-b-t,” which had the same meaning around 1500 B.C.E. This word eventually morphed into Coptic “tobe.” Shortly after 640 C.E. this was borrowed into Arabic as “al-tub,” and subsequently into medieval Spanish as “adobe,” from which it entered English in the 18th century (Kemp 2000: 79–90). Many archaeological projects encounter mudbrick architecture and have to deal with the problem of its preservation and presentation (e.g., McIntosh 1974; Agnew *et al.* 1990; Burch 1997; Buccellati 2006; Fuji *et al.* 2009; Daneels and Guerrero-Baca 2011; Rainer *et al.* 2011). In this article we provide a brief overview of methods that

are employed for this and, based on our own research in Karanis (Kom Aushim, Egypt), emphasize the importance of reburial as a method of preservation.

Mudbrick architecture is part of a larger set of building techniques collectively referred to as earthen architecture (Agnew *et al.* 1990; Rainer *et al.* 2011). Next to mudbrick this includes cobb (*tabya*), rammed earth (*tapial* or *pisé de terre*), wattle and daub, and similar methods and materials. It is estimated that 20–40% of the world’s population currently lives or works in buildings that are partly or wholly constructed of earth. The main reason behind the wide-spread and long-lived popularity of mudbrick is that its raw materials—mud as well as non-plastic fillers, such as dung, straw, sand or pebbles, which are necessary to prevent excessive shrinkage—are usually cheap and readily available; while their transformation into bricks, mortar and plaster does not require complex installations or expensive fuel. An additional advantage is that discarded (old) or (new) surplus bricks can readily be reused as raw material for new bricks, or even returned as soil onto the fields. Furthermore, mudbrick buildings are well isolated and thus comfortable during hot summers as well as cold winters (Kemp 2000; Amador 2013). They do, however, require more maintenance than buildings of fired brick, stone or concrete due to the properties of clay-based building materials.

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Mudbrick architecture is susceptible to tremors and earthquakes as well as, less dramatically but more importantly, to water and wind erosion (Friesem et al. 2011). Mudbrick structures are usually built away from sources of water and in Egypt thus usually outside the wet lands in the Nile Valley. The structures also need near-constant upkeep. While inhabited this will likely be done by their inhabitants or users (Fodde 2007; Amador 2013). They are able to monitor the state of the building continuously and any repairs are in their direct interest. After a building has been abandoned, however, it will quickly decay (Goodman-Elgar 2008). Where mudbrick architecture is encountered archaeologically, it has almost invariably been protected from the elements by being buried for most of the time since its last use. After excavation the process of deterioration will resume, unless action is taken to preserve the building.

The study of earthen architecture is informally chronicled by the Getty Conservation Institute, at times in cooperation with the International Centre of the Study and Preservation and Restoration of Cultural Property (ICCROM), the Centre international de la construction en terre and l'Ecole nationale supérieure d'architecture de Grenoble (CREATerre-EAG), or within the frameworks of the Gaia Project (since 1994) or Project Terra (1998–2005). Their overarching goal is to develop the conservation of earthen architectural heritage into a science, a professional practice, and a social endeavor including education, research, planning and advocacy. To date, eleven large conferences have been organized, the first in 1972 in Iran and the latest in Peru in 2012, the proceedings of several of which have been published between 1990 (Agnew et al. 1990) and 2011 (Rainer et al. 2011). The international conferences of *Preserving Archaeological Remains in Situ* (PARIS) provide another regular platform for developments concerning the in situ preservation of archaeological remains. Other sources include the journal *Conservation and Management of Archaeological Sites* and the bulletin of the Association for Preservation Technology International (*APT Bulletin*), which occasionally publish articles on earthen architecture and its preservation (e.g., Jerome et al. 1999; Miller and Bluemer 1999; Kavazanjian 2004; Matero and Moss 2004; Maldoner 2007; Chaudry and Sikka 2009; Daneels and Guerrero-Baca 2011). Other pertinent research, however, is published in journals not regularly perused by archaeologists and conservators—such as the *Annual Journal of Hydraulic Engineering*, *Engineering Geology* and the *Structural Survey Journal*—potentially making it difficult to find (e.g., Fodde 2008; Watanabe et al. 2008; Fujii et al. 2009).

More general goals and principles for the preservation, protection and management of archaeological sites can be derived from international charters like the Venice Charter for the Conservation and Restoration of Monuments and Sites (1964), the Charter for the Protection and Management of the Archaeological Heritage—formulated in 1990 by the International Committee on Archaeological Heritage Management (ICAHM)—and the Nara Document on Authenticity—formulated in 1994 by the International Council on Monuments and Sites (ICOMOS). According to international conservation guidelines, suitable protection and conservation methods, as well as compatible conservation materials, should be defined for each individual object. These should be appropriate to its composition, material properties, current condition, and authenticity. The prerequisites for the development of sustainable conservation concepts, maintenance and site management plans for exposed mudbrick architecture are detailed investigation and documentation, including a thorough condition assessment. Archaeometric research and close interdisciplinary cooperation between archaeologists, conservators, architects and structural engineers are indispensable to collect all relevant information and identifying parameters affecting the preservation condition of a site (Fodde 2008; Nodarou et al. 2008; Watanabe et al. 2008; Fujii et al. 2009; Friesem et al. 2011; Love 2012; Fodde and Cooke 2013).

The development and implementation of sustainable conservation and maintenance protocols for exposed archaeological mudbrick architecture remain a challenge. No single preservation method will be universally successful as the composition of the raw materials as well as the construction techniques of mudbrick buildings vary considerably through time and space. Soil, clay, mineral aggregates and organic fillers differ geographically, while mixing ratios and surface treatment depend not only on the availability of materials but also on local traditions. Mudbrick and clay mortars are furthermore inherently unstable building materials, mostly because their cohesion is accomplished by mechanical and reversible, rather than irreversible chemical, processes. When water is added to clay it causes the clay to swell and become plastic. Mineral aggregates and organic fillers can be added at this stage and the resulting paste can be shaped into bricks or applied as plaster. As the added water evaporates, the clay shrinks and hardens without chemical changes as clay minerals and intermixed components are held together by mechanical interlocking and adhesion. The latter is the result of electromagnetic forces within and between clay minerals, resulting in a relatively weak bond (Mora et al. 1984). If water, either in liquid form or as a vapor, enters into dried clay it will cause swelling and loss

of cohesion up to the point of disintegration. Furthermore, mudbricks and clay plasters are easily damaged by mechanical forces such as structural stress, impact or wind erosion.

The Graeco-Roman site of Karanis (modern Kom Aushim, 36R–296700 E–3267300 N; or: 29°N 31'07.60"–30°E 54'08.70") is located on the northern edge of the Fayum depression in Egypt (FIG. 1), about 80 km southwest of the modern capital Cairo and 450 km northwest of Luxor. The large town was occupied between approximately 300 B.C.E. and 600 C.E. Besides two stone temples and some structures of fired brick, which are typically associated with water, its many multi-storied buildings were mostly constructed out of mudbrick, clay plasters and wood. In 1890 the abandoned site was visited by W. M. Flinders Petrie (Petrie 1891). Bernard Grenfell, David Hogarth and Arthur Hunt performed the first excavations in 1895 and 1900 (Grenfell et al. 1900; Grenfell and Hunt 1901). From their finds they could identify the ancient remains at Kom Aushim as the Graeco-Roman town of Karanis. In their publication they mention the on-going removal of mudbrick and organic debris (*sebakh*) from the site to be used as fertile soil on nearby fields. At the suggestion of Francis Kelsey, the University of Michigan started large-scale stratigraphic excavations in the residential areas of Karanis in 1924. These were initially directed by James Starkey and from 1926 to 1934 led by Arthur Boak and Enoch Peterson (Boak and Peterson 1931; Boak 1933). When the team from Michigan started work in Karanis the removal of *sebakh* was organized at an industrial scale by a company with a permit to remove 200 cu m per day. The excavators eventually succeeded in halting this destruction of the ancient city, but on their maps they had to identify the central part of the site—between the two stone-built

temples—as “area totally destroyed.” As was customary at the time, large areas were excavated relatively quickly and left abandoned after excavations came to a halt, without any arrangements for their preservation (FIG. 2). From 1972 to 1975 a project of Cairo University in cooperation with the *Institut français d'archéologie orientale* excavated the northwestern part of the town, first under the direction of A. A. Ali, and subsequently led by S. A. A. El-Nassery (El-Nassery 1975; Wagner and El-Nassery 1975). Their publication of the architecture focuses mostly on a decorated bath-house (El-Nassery et al. 1976), leaving large parts of the city both exposed to the elements and unpublished.

The Preservation of Exposed Archaeological Mudbrick Architecture

In 2005, an international multi-disciplinary project of the University of California, Los Angeles (USA), and the University of Groningen (the Netherlands), later joined by the University of Auckland (New Zealand), decided to reinvestigate the site. This included a detailed survey of visible archaeological remains, targeted excavations, the conservation of selected structures, and the partial restoration of the University of Michigan dig-house for use as a visitor's center (Beyt Sobek). Research activities in Karanis are combined with an archaeological field school for both Egyptian antiquities inspectors and foreign undergraduate students (Bos 2008; Wendrich 2010; Cappers et al. 2013; Wendrich et al. 2014). When the University of Michigan ended their project in 1934, they left over 400 mudbrick structures—industrial as well as domestic compounds—exposed. While some of these remains were already severely damaged and unstable, others were remarkably well-preserved, from their mudbrick and plaster walls to their wooden support beams. Some notable examples had walls that stood over ten meters high (Husselman 1979). The University of Michigan expedition, however, did not backfill their excavations, nor did the later Cairo University project, but instead left all uncovered architectural remains exposed to the elements. Aeolian sand, atmospheric moisture and intermittent rainfall, combined with human and animal activities, subsequently caused widespread damage to the mudbrick architecture, resulting in surface loss followed by large-scale collapse of the ancient structures. As much as 60% of the remains uncovered in the 1920s and 1930s are now no longer present, while the remainder survives only as fragmentary lengths of walls, or their stone foundation layers less than a meter high. Navigating the site using the maps prepared by the University of Michigan is extremely challenging as only a few structures are still recognizable (FIG. 3). Collapsed structures and an

Figure 1 Location of the UCLA–University of Groningen–University of Auckland project's dighouse and offices (1), on-site store rooms (2), and newly excavated ancient granary (3) at the northern edge of the Fayum depression in Egypt.

Figure 2 Photographs comparing the appearance of Karanis after excavation in the 1920s (top) with the situation today (bottom). A) A view of structure C123, south of the North Temple, looking west (photograph KM 7.2368 by George R. Swain); C) Approximately the same view as above in 2012 (photograph KM Z12.0001 by Sebastián Encina; B) A view of structure T1, north of the South Temple, looking south (photograph KM 7.2303 by George R. Swain); D) Approximately the same view as above in 2012 (photograph KM Z12.0002 by Sebastián Encina). Photographs used with permission of the Kelsey Museum of Archaeology, University of Michigan.

altered ground surface, either raised by collapsed architecture or deflated by erosion, provide the average visitor little opportunity of accurate orientation within the ancient town. Apart from concluding that the loss of mudbrick structures in the past 80 years has been enormous, it is important to record the ongoing rate of loss.

From 2006 to 2008 several grants of the Antiquities Endowment Fund, administered by the American Research Center in Egypt, enabled the systematic photographic recording of all extant walls in the area excavated by the University of Michigan. This information was further enhanced in 2010 when our architectural survey included the use of a laser scanner, made available by the Center for Advanced Spatial Technology (CAST) at the University of Arkansas, Fayetteville. The resulting three-dimensional point-cloud model records an area of over 180,000 sq m, with the surfaces of all architectural structures recorded at no more than two millimeters distance between any pair of points. The resolution of this dataset allows the model to be used as a benchmark

for establishing changes to the site, including the calculation of surface loss and small instances of erosion, as well as the larger collapse of mudbrick structures. This information should prove an aid to future conservation and site-management efforts. As the deterioration of the site is a relatively slow process, the effects of our conservation effort can only be evaluated years after their implementation and our initial recording of the condition of the ancient structures.

Our condition assessment of several mudbrick complexes in Karanis may provide a paradigm for the recording of deterioration phenomena that cause the decay of such buildings. The observed phenomena and their underlying causes are representative for other ancient mudbrick structures in Egypt and elsewhere. Although only partially excavated and preserved, the exposed complexes at Karanis present a large variety of mudbricks, clay mortars and plasters, as well as earthen architectural elements with ancient building materials manufactured from different types of clay and fillers. Preliminary petrographic and chemical analyses, combined with field surveys on site and in

Figure 3 Plan of the eastern part of the center of Karanis, with structures standing in 1935 shown in grey. The remains visible in 2010 are overlaid in black, revealing the dramatic loss of architecture in the intervening years (image prepared by Bethany Simpson, based on [Husselman 1979](#) and our topographic survey of the site).

quarries in the surroundings, were performed by the authors and other members of the research group. Local clays from older geological deposits like the Upper Eocene Birket Qarun Formation, which was formed under primary marine conditions, seem to have been preferred by the ancient brick makers. Such clays, consisting mainly of glauconitic clay enriched with fine silts and containing microfossils, are still being quarried today for the industrial production of tiles, toilets and washing basins. Colors range between Munsell hues 10YR and 2.5Y, between light yellowish-brown and dark greyish-brown. Alluvial Nile clay, which was collected from the floodplain for the production of ceramic vessels, was apparently not a major source of raw material

for mudbricks. Besides minor differences in the clay mineralogy, such as the abundance of iron-hydroxides, all mudbricks and most mortars contain gypsum, which appears native to the raw materials. Several types of mudbricks could be differentiated according to their size and chemical-mineralogical composition resulting from the used clay type or the recipe followed. Three main groups of mudbricks were identified: silty mudbricks, clay-rich mudbricks, and straw-rich mudbricks. Certain brick types seem to have been used more frequently in certain areas or time periods, but no strict pattern could be established and no type appeared restricted to a single period or building phase.

Newly excavated buildings show comparatively well-preserved wall and plaster surfaces, whereas

exposed sections of walls display extensive damage, including the complete loss of bricks and setting mortar. The original organic fillers—comprising mostly the threshing remains of wheat (*Triticum turgidum* ssp. *durum*)—have often decayed, leaving small cavities that provide starting points for erosion. In places structural and static stress has resulted in large cracks that cut through masonry and overlying plaster. The loss of wooden elements, such as lintels and stabilizing beams, further destabilizes the structures. Repeated swelling and shrinking of the clay-based materials associated with rainfall and subsequent drying created a network of superficial shrinking cracks, both in plastered and unplastered masonry. Deeper fine cracks separate layers and cause the delamination of setting mortar from adjoining bricks, or of plaster from its supporting wall or underlying plaster layers (FIG. 4: top). This damage often progresses into the detachment of plaster. Hollow areas behind detached plaster can then fill with masonry fragments, dust and sand, leading to the bulging of plaster fragments. White washes and wall paintings that are in places preserved on plaster and clay stucco show cracks, flaking and structurally destabilized paint layers with slightly powdering pigments. Powdering or sanding is also noticeable on weathered plaster and mudbrick surfaces, making these increasingly friable. In many places scaling occurs within the masonry. The delamination and detachment of scales, combined with the crumbling of brick and mortar, leads to further loss of material, ultimately resulting in gaps in the structures. These phenomena are often associated with salt contamination. The presence of salts in masonry and plasters can also be recognized by salt efflorescences or damp patches associated with hygroscopic salts. Such damp areas stimulate the growth of bacteria and mold.

The deterioration of the excavated mudbrick buildings in Karanis is caused by a suite of interdependent processes of damage and deterioration. Important are the exposure to wind, rain and sun. Strong winds, which in the region are almost invariably from the north, move sand and debris around. This erodes exposed mudbrick walls and causes reduction of their surfaces. Vertical construction joints, areas where architectural elements are connected, and cracks are often weak points where erosion occurs more readily (FIG. 4: bottom). Especially where walls are exposed along hilltops, the preferential erosion of lower courses eventually undercuts the wall leading to its collapse. Such fracturing and loss of support in turn exposes other walls to the same destructive mechanism causing the general destabilization of the masonry and the loss of structural integrity of the building. Undercut walls furthermore attract feral dogs looking for shelter whose burrows accelerate

the destructive process. Clay-based building materials react directly to the relatively large daily and seasonal variations in temperature and humidity (FIG. 5). They expand with an increase in relative humidity and temperature, and contract again when drying or cooling down.

Heavy rainfall is scarce in Egypt south of Cairo, but happens occasionally. The rainwater dissolves and washes out fine and soluble materials that function as binders within the mudbricks, mortars and plasters. The resulting voids and defects in the microstructure change the building material texture and leads to structural destabilization. Characteristic damage phenomena after rains are flows of washed-out material and a net of shrinking cracks fracturing the dried surfaces. The edges of the fragments between the cracks often start to lift and scaling occurs. Such processes associated with volume expansion and contraction can also cause interfacial surface tension between the building materials and in the long term result in delamination and detachment of mudbrick and setting mortar or plasters from their supporting wall. With moisture penetration by rainfall or the capillary rise of groundwater, additional salts are transported into the masonry and plasters. Upon evaporation of the water these salts crystallize causing internal pressure. The cyclic repetition of dissolving and recrystallization of salts creates significant stress that reduces the cohesion of building materials. This eventually results in the sanding or crumbling of mudbricks, especially inhomogeneous bricks with coarser aggregates. The gypsum, partly present in the primary materials and partly a secondary precipitate, makes the building materials even more susceptible to such damage as it functions as a source for newly formed and recrystallizing damaging salts.

The heterogeneity of the building materials, a common feature in Karanis where different clays were used both singly and mixed, promotes the deterioration process. In addition, a wide variety of mineral aggregates is used in bricks and mortars, including (fine to coarse grained) desert sand, (course) pebbles, lumps of different geological materials (white clay, ochre and iron-rich sediments), as well as potsherds and fragments of stones or burnt bricks (FIG. 6: top). Tiny fossil inclusions such as bivalves and gastropods are common in many mudbricks and attest to the marine origin of the used clay. Although greatly variable within and between architectural complexes, the different mortar and plaster types are mainly manufactured out of a single clay type combined with fine to middle grained mineral aggregates that are mostly smaller in size than those used in the mudbricks. Whereas the heterogeneous mudbricks clearly show strong susceptibility to weathering, the more homogeneous mortar and plaster materials appear more resistant to

Figure 4 A) Detail of the left engaged column of a vaulted, plastered niche showing characteristic shrinking cracks in plaster and mudbrick surfaces and areas of delaminating white-washed stucco; B) Remains of a mudbrick wall showing loss of plaster, crumbling mudbricks, large cracks, displacement and collapse (photographs by Alexandra Winkels / URU Fayum Project).

degradation (FIG. 6: bottom). The organic fillers also vary in material, quantity and size between various mudbricks, mortars and plasters. While the clay- or silt-rich mudbricks, often including coarse aggregates, were predominantly set in a silty clay setting mortar with fine mineral aggregates and little or no organic fillers, the setting mortar for the straw-rich mudbricks usually received a higher straw content. The plasters, on the other hand, mainly contain smaller sized organic fillers, although large amounts of coarse plant fragments next to finely chopped culm fragments also occur. As each of these materials react differently to changing environmental conditions, distinct degradation stages can often be observed within a single wall or building.

Despite the mentioned interdependency of the deterioration processes, the preservation of mudbrick architecture is mostly influenced by specific phenomena. Wind erosion quantitatively causes the most damage, by abrasion of the exposed structures with destabilized building materials. Even if scarce, rainfall also results in heavy damage as it triggers different deterioration phenomena, the result of which is clearly visible in the many washed-out features on site. In connection with water impact, salts create a

continuous potential thread of weakening the cohesion of materials by salt efflorescence cycles. Tentatively it can be stated that degradation increases with the heterogeneity of the composition of the building materials. Subsequently, the mudbricks in Karanis are especially vulnerable and without plaster covering are likely to deteriorate and collapse. Given the importance of the weather on the deterioration processes, the orientation of the architectural elements influences their state of preservation. It is evident that in Karanis the erosion of the standing architecture is worse on the north and west sides of walls and buildings, while the preservation of architectural surfaces facing east and south is comparatively better. Other natural phenomena, such as sizable earthquakes, growing plants and burrowing animals—including insects, birds, rodents, foxes and dogs—are responsible for the partial destruction of mudbrick structures, although they seem to play only a minor role in Karanis. A final source of damage is human activity, ranging from damaging friable ancient surfaces by touching them to the removal of architectural elements. This can happen accidentally or out of ignorance, but also in order to reclaim ancient materials or as an element of looting or vandalism.

Figure 5 Daily minimum and maximum temperatures (°C) and average relative humidity (RH%) in 2010 measured at the Cairo and Luxor Airports (weather stations 623660–HECA and 624050–HELX). Karanis is located about 80 km southwest of Cairo Airport and 450 km northwest of Luxor airport; these locations are the closest for which such high-resolution data is reliably and publicly available (data obtained through www.tutiempo.net and visualized by Hans Barnard).

The processes that have contributed to the current condition of the archaeological earthen architecture should be taken into account when suitable protection and consolidation methods are developed. When the original brickwork should remain visible and accessible after treatment there is often tension between the state of preservation of unearthed mudbrick structures and their presentation. After more or less basic conservation treatment of the architectural surfaces, the following methods are commonly used to protect architectural features against weathering and further decay (TABLE 1). A method often employed is capping, in which one or more layers of new bricks are placed on top of ancient wall fragments. A more extensive version of this method is the complete encasing of architectural fragments with a protective layer of new bricks. Such layers or encasings protect the

original walls from most eroding forces and provide tourists and other visitors a clear outline of the structure. While the first version leaves some or most of the original bricks visible and accessible, for study or additional treatment, the latter covers the ancient wall completely and adds to its thickness. Adding new bricks to repair or stabilize an area, or applying a plaster layer to one or both wall faces provides structural and surface protection (Caperton 1990; Chiari 1990; Jaeschke and Friedman 2011), but at the same time limits visibility and accessibility of the ancient materials. When the repair or covering of authentic architectural fragments appears to be the appropriate measure, the added materials should be matched to the original in composition, material and mechanical properties, but remain visually distinguishable. To achieve this new bricks can, for instance, be marked

Figure 6 A) The heterogeneous mudbrick composition of a wall in Karanis; B) Fragment of the wall of a house along a street in which the inhomogeneous bricks have eroded faster than the more homogeneous and now alienated setting mortars (photographs by Alexandra Winkels / URU Fayum Project).

with an identifying stamp. Mortars and plasters should be made distinguishable by choosing raw materials with a subtly different color compared to the ancient materials.

Capping and replastering are commonly used on archaeological sites in Egypt. These methods do not prevent erosion, but protect the original structure and shift the relentless decay from the ancient materials to the added modern architectural elements. When one of these protective methods is chosen, regular maintenance again becomes necessary resulting in a chain of logistical and financial consequences (Jerome *et al.* 1999; Chaudhry and Sikka 2009). In

either case, it must be assured that the ancient remains are structurally stable enough to receive the protective covering layers, not only the static structure but also the microstructure of the ancient clay materials. The condition of the ancient mudbrick architecture thus needs to be assessed and, when necessary, to receive immediate conservation treatment prior to capping, replastering or encasing. For instance, large destabilizing cracks within walls and hollow areas behind delaminated plasters need to be grouted and secured with mortar fillings.

Structurally destabilized, powdering or sanding mudbrick, mortar or plaster surfaces and flaking

Table 1 Overview of the effects of different approaches to preserve mudbrick on the original brickwork.

	...leaves the original brickwork...			
	...visible.	...accessible.	...unaltered.	...protected.
Capping...	yes	yes	no	yes
Encasing...	no	yes	no	yes
Reassembling...	yes	yes	no	no
Rebuilding...	no	no	no	no
Reburying...	no	yes	yes	yes
Repairing...	yes	yes	no	yes
Replastering...	no	yes	no	yes
Sheltering...	yes	yes	yes	yes

paint layers need to be conserved with suitable consolidants and adhesives. Without such primary conservation measures the ancient clay materials will be too friable and may be damaged and superficially reduced during the application of the modern covering materials, be mixed with newly applied modern materials, or even be crushed under the superimposed weight of brick encasing. The application of a reversible protective interface or separation layer between the pre-consolidated original structure and its capping, replastering or encasing should always be considered, especially if the original surfaces were plastered or have preserved fragile washes, paint layers or wall paintings. Such can, for instance, be achieved by applying a layer of Japanese tissue paper—made from *Broussonetia papyrifera* (koko) or *Wikstroemia sikokiana* (gampi) fibers—with a temporary volatile binder such as cyclododecane ($C_{12}H_{24}$), which will slowly evaporate without leaving a residue (Rowe and Rozeik 2008); or by covering original brickwork with geotextile (Kavazanjian 2004). Geotextile is a non-woven fabric with excellent conservation properties, especially when compared to the plastic membranes that are sometimes used for covering ancient structures. Permeable to both air and water vapor, geotextile provides a protective layer against erosive elements. It allows humidity within the covered architecture to evaporate and even promotes the drying process when water penetrates after rainfall or by the capillary rise of groundwater, thus preventing persistent moisture and the related growth of bacteria and mold. By including preconservation treatment and adhering to the principle of using traditional materials and techniques combined with suitable conservation materials, capping, replastering and encasing can provide effective protection with the benefit of reversibility. The latter permits the periodic replacement of the sacrificial layers, as well as their complete removal when the need for such arises or further conservation treatment can be implemented.

A different approach to the preservation of ancient mudbrick structures is to build a shelter over the ancient remains (Schmidt 1988; Buccellati 2006; Bendakir et al. 2011; Gamarra 2011), meant to protect the antiquities and at the same time leave them unaltered, visible and accessible. This method is regularly employed in Syria and Peru. Like capping and replastering, it should not be expected to be entirely effective or easy to implement. Shelters that remain partly open to the elements will not completely stop the eroding forces and often allow sand, dirt and refuse to be trapped inside. Rain water can be collected and channeled by the shelter, because of its design or a leaky roof, and greatly damage sections of the ancient structure. Shelters that are entirely closed will quickly develop a micro-climate inside,

unless the internal conditions can be carefully controlled. This new environment is likely to be very different from that in which the original structure has survived and subsequently give rise to new erosional processes. A shelter can also structurally or optically be obtrusive and has to be designed and constructed carefully to prevent damage when placed on or near ancient walls. With a shelter again occurs the responsibility of its maintenance. Sometimes a defective shelter will catalyze rather than prevent the erosion of the structure that it was intended to protect.

A Case for Reburial

A third approach for the protection of mudbrick structures is their reburial after excavation, documentation and analysis in order to prevent deterioration because of exposure (Miller and Bleumel 1999; Agnew et al. 2004; Matero and Moss 2004). Reburial can be used as emergency treatment or as a long-term conservation technique. The method aims to replicate as close as possible the conditions and micro-climate in which the mudbrick architecture was preserved before its excavation. Although this will likely be the most effective approach, it leaves the original architecture invisible and relatively difficult to access (TABLE 1). This is sometimes mitigated by the construction of a (partial) replica of the ancient building on top of or nearby the original remains, much like the replicas of the Paleolithic drawings and wall paintings in the halls of Lascaux II. This has, for instance, been done on a relatively small scale in Giza and Amarna (both in Egypt).

As part of our objective to limit further damage to the ancient mudbrick structures in Karanis, an effort is made to backfill all newly excavated areas with clean sand as soon as possible. In addition, several of the particularly fragile structures excavated in the 1920s by the University of Michigan were covered with sand (FIG. 7: top), or geotextile and sand (FIG. 7: bottom). Sand was brought in from the surrounding desert and transported across the site on donkey back, which appeared the least destructive method of transportation. Covering ancient structures with sand will obviously protect them from wind erosion and damage by humans and animals. If available, protective reburial can be further optimized by adding a lightweight, pH-neutral filler (Matero and Moss 2004), such as perlite (an amorphous volcanic glass) or vermiculite (a phyllosilicate). Immediate consolidation measures might be necessary before reburial, such as grouting cavities, stabilizing delaminated plaster fragments, applying mortar bridges along plaster edges, or consolidating paint layers and protecting them with Japanese tissue paper. Beyond this, reburial is non-invasive and reversible.

Figure 7 A) The reburial of an ancient mudbrick structure in Karanis (Kom Aushim, Egypt) using clean desert sand carried across the site on donkey-back (photograph by Sigrid van Roode / URU Fayum Project); B) The remains of one of the ancient bathhouses in Karanis, partly built of fired brick, being covered with geotextile after excavation (photograph by Tony Cagle / URU Fayum Project).

The effects of reburial on temperature and relative humidity were tested using HOBO U10-003 data loggers (Onset Computer Corporation). These are small ($45 \times 60 \times 18$ mm; or: $1.8 \times 2.4 \times 0.7$ in) plastic boxes, which contain temperature and relative humidity sensors, a memory chip, and the necessary electronics and power source. They can be connected to a computer allowing instrument settings to be entered and data downloaded. Between January 2010 and October 2012 four of these devices were deployed at Karanis: two in modern concrete structures, the project's offices and on-site store rooms (FIG. 7); and two buried in the backfill of excavation units 11 and 20 (FIG. 8), at depths of 50 and 100 cm (20 in and 40 in), respectively. The loggers were set to record the temperature and relative humidity every hour, starting 12–24 hours after the sensor was put in place. After a period of 9–21 months the devices were retrieved and the logging of data terminated. The data files, comprising 6864–16,079 data points per device, were downloaded onto a laptop computer, converted into a Microsoft Excel spreadsheet and analyzed. This included sorting the numbers, to establish minimum and maximum

readings (TABLE 2), and visualizing the data as point clouds and line graphs. In order to reduce the influence of outliers, erroneous measurements and the limitations of the sensor, averages were calculated and plotted for periods of six hours (FIG. 9). A first finding was that the lower limit of the sensor for relative humidity in these devices is around 15 RH%. As expected, a weak negative correlation ($\rho = 0.681$) appeared to exist between temperature and relative humidity, meaning that as the ambient temperatures rises the relative humidity is likely to decrease. The trend-line was found to be $RH(\%) = -0.883 \times T$ (in $^{\circ}\text{C}$) + 60.245, with $R^2 = 0.463$.

In the modern concrete buildings close to Karanis, the temperatures varied approximately 28°C throughout the year, between a minimum of 12°C and a maximum of 40°C (TABLE 2). Over the same period the relative humidity varied between a minimum of less than 15% and a maximum of 75%. This appears similar to the fluctuations in the environment (FIG. 5). As the lower limit of the HOBO detector is around 15% it is not possible to provide an accurate measurement of the variability, but this exceeds 60%. Buried approximately 50 cm below the surface

Figure 8 Plan of the excavation units in a *thesauros* (storage facility), street and house in Karanis (Kom Aushim, Egypt). Stars indicate the approximate locations in which HOBO U10-003 data loggers (Onset Computer Corporation) were buried, approximately 50 cm (trench 11) and 100 cm (trench 20) below the surface (surveyed and drawn by Hans Barnard).

of the clean sand with which excavation unit 11 was filled at the end of the excavation season, the temperature range dropped from 28°C to 20°C and the relative humidity range from >60% to 8% (FIG. 9, bottom-left). The environment appeared slightly more stable at a depth of approximately 100 cm as shown by the measurements in excavation unit 20. Here the temperature varied only 15°C throughout the year and the relative humidity 8%. At this depth the temperature also shows less short-term fluctuations (FIG. 9: bottom-right). Only half a meter (two feet) of sand thus creates a dramatically different environment compared to the open air (FIG. 5) or inside a concrete

building (FIG. 9: top). These data show that reburial greatly reduces the fluctuations of temperature and relative humidity in the environment surrounding the buried architecture. Besides effectively shielding the ancient structures from erosive forces, such as abrasive wind, sun exposure, and most rain erosion, the hygric and thermic stress on the original materials is thus significantly diminished.

Discussion and Conclusions

Most archaeologists are well aware of the continuous degradation of ancient remains, whether in situ (buried) or excavated, and the notion that preservation

Table 2 Minimum and maximum temperature and relative humidity recorded in 2010–2012 by four HOBO data loggers in Karanis (Figure 9 shows the data in more detail).

	HOBO inside modern building		HOBO buried in excavation unit	
	Office	Store room	Excavation Unit 11 (HOBO at ±50 cm)	Excavation Unit 20 (HOBO at ±100 cm)
T min (°C)	12.6	11.1	16.3	18.6
T max (°C)	40.1	39.9	36.3	33.7
ΔT (°C)	27.5	28.8	20.0	15.1
RH% min	<15*	<15*	37	40
RH% max	75	76	45	48
ΔRH%	>60	>61	8	8

* 15 RH% is the lower limit of the HOBO data loggers

Figure 9 Average temperature and relative humidity recorded in 2010–2012 by four HOBO data loggers in Karanis. Each data point represents the average during the previous 6 hours. The circle indicates the period in which excavation of Trench 20 was resumed and the surface came increasingly closer to the sensor (data collected and visualized by Hans Barnard). The same dataset is summarized in Table 2.

and conservation should be integral parts of all archaeological projects. In the words of one of the founding fathers of the discipline, Sir Flinders Petrie (1904: 178):

With the responsibilities before us of saving and caring for [the] past life of mankind, what must be our ethical view of the rights and duties of an archaeologist? Conservation must be his first duty, and where needful even destruction of the less important in order to conserve the more important. To uncover a monument, and leave it to perish by exposure or by plundering, to destroy thus what has lasted for thousands of years and might last for thousands to come, is a crime.

What exactly influences the preservation or decay of ancient remains in the soil, however, is often only very generally understood (Smith et al. 2006; Nodarou et al. 2008; Friesem et al. 2011; Love 2012; Fodde and Cooke 2013). For a better understanding of the preservation capacity of the burial environment in Karanis and to identify possible degradation factors, a baseline survey of some of the parameters affecting the preservation potential was conducted. Several physical, chemical and biological processes influencing preservation conditions, such as abrasive winds, rainwater impact, reoccurring salt efflorescence cycles, were identified by a

condition assessment of mudbrick remains, both exposed and buried. Based on this information, mitigating and consolidating actions were taken, limited only by the available time and funding. The quality of the burial environment can now be checked at regular intervals against the outcome of our survey, upon which additional measures can be taken if necessary (Huisman 2009). Monitoring and degradation research are essential parts of the site management program at Karanis (Bos 2008). The effects of other parameters—such as soil acidity, reduction potential and micromorphology—on the condition of the mudbrick will be studied in the near future. As the deterioration of the site is a relatively slow process, however, the result of any conservation effort can only be established after sufficient time has passed.

Although mudbrick has been used worldwide since early Neolithic times and is therefore encountered in many archaeological contexts, there is no consensus on the best practice for its documentation, analysis and preservation. Because of the significant efforts necessary to preserve inherently unstable earthen structures, as well as the significant costs of the development and implementation of sustainable conservation and maintenance methods, the preservation of ancient mudbrick architecture remains a

challenge and is still not standard practice alongside its excavation. Conforming to the internationally agreed principles for the protection and management of archaeological heritage (Petzet and Zieseme 2004), foreshadowed by Flinders Petrie in 1904, earthen structures should not be left exposed after excavation if provision for their conservation, maintenance and management is not guaranteed. Among the possible approaches to preserve excavated mudbrick architecture are repairs, like replacing missing

bricks in places where their absence substantially weakens the structure, protective capping or encasing to minimize erosion, and plastering wall faces to protect both old and new elements. Advantages of these methods include the effective protection of the architecture and its visibility to the public and scholars if original features are only partly covered. Disadvantages include the need for continuous maintenance. Moreover, conservation treatment to secure fragile areas and prevent further loss is

Figure 10 The remains of structure C50/51 as seen in the 1920s (top, drawing by I. Terentieff, adapted from Boak and Peterson 1931: Plan 32) and in 2010 (bottom, photograph and annotations by Suzanne Morris). The grey line across the architectural drawing indicates the outline of preserved part of the structure.

nearly always necessary before protective measures can be implemented. Another approach is to shelter excavated structures from eroding forces and interference by humans, animals and plants. This method leaves the original architecture unaltered and visible, but is very difficult to employ effectively while at the same time also introducing the need for periodic maintenance.

If a detailed conservation and maintenance program proves difficult to finance and implement, one method for immediate site protection is reburial of the ancient structures. This can be done with sand or soil, either from the excavation or brought in from the outside, preferably in combination with geotextile covers and emergency conservation to selected areas. This approach is in accordance with the principles of preventive conservation as it significantly slows down the decay of the ancient structures. Covering the architecture protects it from abrasive wind action, rain water, sun exposure and the activities of animals and humans. If implemented correctly it will more or less recreate the environment in which the structures survived until excavation and lead to much more stable environmental conditions. This dramatically impedes much of the deterioration processes. Reburial can be used as temporary emergency treatment or provide long-term protection. Although it hides the original elements from view, the procedure is reversible allowing future study or additional conservation treatment. Besides any necessary treatment before reburial the method is non-invasive and greatly reduces the immediate need for detailed conservation as well as long-term maintenance.

In Karanis large parts of the original architecture are still standing, after being excavated in the 1920s and 1970s, rendering arguments of the visibility and accessibility of newly excavated structures less relevant. These can and should thus be reburied, which according to our research is an effective and efficient method. A different and more difficult issue is the preservation of the exposed ancient structures. When left abandoned, these will slowly erode away until little above ground level will be left (FIG. 10). Some of the most vulnerable sections have now been covered with geotextile and sand, while emergency repairs and architectural conservation treatment were administered to others. This program will be expanded in the near future.

Another project entails the reconstruction of an ancient building, based on the excellent plans drawn in 1924–1934 by the team of the University of Michigan (FIG. 10: top). Located in an area without underlying ancient structures, this building will allow visitors to experience what an ancient structure would have looked like and at the same time enable archaeologists and conservators to further investigate building technology and maintenance methodology.

Meanwhile, further analysis of the ancient building materials, including their mineral and organic components, as well as their immediate environment continues. This research will in due course provide additional insights that can be used to formulate improved preservation methods. Finally, digital technology is another avenue recently taken to virtually preserve the antiquities of Karanis (Wendrich et al. 2014). Site recording via terrestrial-based laser scanning may be resumed in 2020, in order for the results to be compared with the 2010 model and further quantify the rate of erosion and damage to the site. These models can furthermore serve as permanent benchmarks of the site and be developed for analytical as well as educational purposes. Three-dimensional, virtual renderings of Karanis may also be used to introduce the site to wider audiences, either online or incorporated into the on-site visitors' center in the Beit Sobek. The currently on-going effort to create digital models of objects from Karanis, kept in various museums, and virtually return them to their original location within a digitally reconstructed structure of the ancient town will be an important part of this endeavor.

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