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Storage buildings in ancient Egypt and Nubia. Issues and perspectives

Adeline Bats, Nadia Licitra

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An aerial photograph of an archaeological site in a desert landscape. The site features a complex grid of rectangular structures, likely storage rooms, built with mud-brick. The structures are arranged in a regular pattern, with some larger, more prominent buildings. The surrounding terrain is flat and sandy, with a clear horizon line under a pale sky. The lighting suggests a late afternoon or early morning setting, with long shadows cast across the structures.

STORAGE IN ANCIENT EGYPT AND NUBIA

Earthen architecture and building techniques

ADELINE BATS & NADIA LICITRA (EDS)



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Storage buildings in ancient Egypt and Nubia

Issues and perspectives¹

Adeline Bats & Nadia Licitra

Storage buildings, ancient Egypt, ancient Nubia, archaeology, building materials, building techniques, food preservation, silo, granary, storeroom, Treasury, thēsauros, cellar, pantry, storage bin, niche

1. General remarks

During the Neolithic period, human populations (which had become sedentary and agrarian) adopted methods of acquiring food very different from those of the hunter-gatherers, based on an annual harvest providing most of the foodstuffs needed for the coming months. The appearance of large-scale storage facilities as a systematic practice is related to the beginnings of agriculture.² However, conservation of this sudden profusion of food entailed technical constraints. Storing large harvests over time required suitable structures to stabilise food while preserving its integrity, taste, and germinative properties. Alternation of periods of abundance and shortage was then regulated thanks to massive storage and smoothed out over long periods.

The study of the archaeology of storage, which combines principles of agronomy and ethnoarchaeology with technical and functional analysis of archaeological remains, is very well established historically in French research. However, its results are little known abroad as related publications are almost exclusively written in French. Food storage was the subject of a series of technical studies initiated by François Sigaut (SIGAUT 1978; SIGAUT 1979; SIGAUT 1981) and continued over the course of several symposiums published in the late 1970s and early 1980s (GAST, SIGAUT 1979; GAST *et al.* 1981; GAST *et al.* 1985). Sigaut's research on food storage in the field of archaeology as well as economic and social history focuses on two main themes: the conditions necessary for proper conservation of grain and cereal products and definition of types of storage facilities meeting environmental and economic constraints. These themes are still prevalent in studies of ancient and medieval Europe, and numerous research projects have been carried out (GARCIA 1997; GRANSAR 2000; FERDIÈRE 2015; GERACI, MARIN 2016; ZURBACH 2017; HUITOREL 2017; LAUWERS, SCHNEIDER 2022; DOMINGUEZ *et al.* 2022). Several

1 This research was supported by a public grant overseen by the French National Research Agency (ANR) as part of the Nile's Earth project (ANR-21-CE27-0019-01).

2 Hunter-gatherers who stored certain quantities of food also existed (TESTART 1982). Only small quantities were concerned and, above all, rare goods on which their overall economy was not based.

years after his initial research, F. Sigaut (2006) returned to the theme to which he had contributed so much:

“Le stockage n’est pas, en soi, un thème de recherche plus intéressant que d’autres. Mais c’est un thème qui a quelque chose d’exemplaire. Pourquoi ? Je ne suis pas sûr de pouvoir en donner toutes les raisons. Certaines sont loin d’être spécifiques. Il y a par exemple un effet de rattrapage assez simple : un point de vue longtemps négligé semble ouvrir des perspectives nouvelles du seul fait qu’on cesse de le négliger. Mais il me semble qu’il y a aussi des raisons qui tiennent véritablement au contenu du sujet. Plus peut-être que d’aucun autre fait social, on peut dire du stockage qu’il est inclassable : c’est un fait technique, mais aussi économique et institutionnel, dont on ne sait pas trop s’il relève de la production ou de la consommation, qui intéresse aussi bien l’organisation de la famille que la guerre ou que l’architecture... L’anthropologie a besoin de subdivisions, nous le savons tous. Mais nous savons aussi que si nous n’y prenons pas garde, ces subdivisions peuvent paralyser la pensée au lieu de la guider. L’étude du stockage nous rappelle qu’elles ne sont que des instruments, à utiliser en toute liberté. C’est là, me semble-t-il, un des principaux enseignements qu’on puisse en tirer.”

When it comes to the archaeology of storage and study of ancient civilisations’ practices, the complexity of this *fait social* inevitably has to confront the partialness of the evidence, which depends on chance finds and material remains’ state of conservation. Each of the categories listed by F. Sigaut can provide a valuable research approach, but it is only by combining them that we can hope to get an idea of the overall context.

Identification of storage facilities in an archaeological context is not always easy (e.g. MARGUERON 1996, BERNARDOS SANZ, VIRLOUVET 2016, pp. 59-60; B. REDON in this volume), but various markers enable detection of storage practices in a given place, including architectural layout, technical systems and facilities, containers, organic remains and administrative material (CASADEI 2019, pp. 140-141). The list may be extended to include remains of raw materials (i.e. wood, precious stones, gold, silver, etc.) and manufactured goods for royal or religious storehouses, as was the case with the so-called Treasury of Sanam dating back to the 8th-6th centuries BCE (VINCENTELLI 2011).

Research on technical aspects of storage cannot dissociate building (or facility) layouts and architectural features – including their hygrometric and thermal properties (§ 3.5.6) – from food processing and packaging strategies (§ 2), since the former must offer storage conditions suitable to the properties provided to foodstuffs

by the latter (MARGUERON 1996, p. 105). As far as architecture is concerned, the use of specific building layouts (§ 3) and building materials (§ 4) can reveal the precautions taken to keep the goods safe from humidity, pests, heat, etc. At the same time, a functional approach focusing on such features can help identify places devoted to storage as such. The study of building layouts can also provide valuable data on storage temporality (short- medium- or long-term) and management (MARGUERON 1996, pp. 104-105).

Given the subject’s complexity and the difficulty in interpreting surviving archaeological evidence correctly, A. Farnoux’s “simple questions” (FARNOUX 1996, p. 67) can be an efficient way of starting any investigation on ancient storage practices: what to store? Why store? How long to store? How to store?

These straightforward questions have rarely been asked directly in investigations of ancient Egyptian and Nubian remains (§ 2-3). In 2020, however, with them in mind, the *Research Group on Storage in Ancient Egypt and Sudan*³ was created with the intention of bringing together archaeologists, architects, archaeobotanists, ceramologists, historians, and, more broadly, any specialist interested in storage archaeology in the ancient Nile Valley. With a view to federating the Group’s members around this collaborative research project, meetings were organised in order to establish a shared technical vocabulary and discuss current research hypotheses and problematic case studies. During two workshops held online in 2020 and 2021⁴, Group members dealt with architectural analysis of storage facilities and related building techniques, focusing mainly on earthen buildings (in cob or mud-bricks) and using a comparative approach with West African vernacular traditions and contemporary foodstuff storehouse buildings. The main aim was to share thoughts on characterisation of storage buildings in the ancient Nile Valley. Some of the case studies discussed during the workshops are presented in this volume.

Drawing up a complete state-of-the-art of storage architecture in the ancient Nile Valley would have been beyond the aim and scope of this contribution. We have therefore chosen to highlight the main issues pertaining to storage architecture in ancient Egypt and Sudan and present a provisional typology of storage buildings in order to provide a frame of reference of possible use to the scientific community. Our aim is to identify economic and social rationales that provide information on given social groups’ stock management strategies. Therefore, before going on to economic analyses, the following chapters, along with this volume’s other contributions, will present the premises behind this ongoing research, first and foremost

3 <https://stockagenil.hypotheses.org>.

4 <https://stockagenil.hypotheses.org/les-journees-detudes-du-groupe-de-travail>.

by using architectural analysis to explore technical aspects of storage practices in the ancient Nile Valley.

2. Food preservation in ancient and traditional societies

As with all consumable and perishable products, time and environment cause degradation of foodstuffs over the short- or long-term, making them unfit for consumption. Cereals are the product most often mentioned in historical studies. They are more readily identifiable in archaeological contexts (botanical remains, storage buildings like silos or granaries, etc.) and are often mentioned in administrative/political texts. Their management by authorities, even if only partial, led to production of epigraphic documents with which historians are familiar. However, other foodstuffs, not mentioned in textual sources as often as cereals, also had to be stored and preserved. Two different strategies could be used to keep food qualities intact for medium- or long-term storage: food processing and/or packaging. These strategies were employed according to type of food and future uses. For example, meat could be dried or salted and then packed in an airtight container, often a jar. For shorter-term storage, the same meat could simply be cooked and consumed within a few hours or days. We also know of more radical processing methods, such as cooked meats that combined cooking and salting/drying for medium- or long-term storage. For liquids (such as oil or wine), packaging in jars or amphorae made from non-porous fabrics was essential, as was effective sealing of the container itself to ensure its contents' isolation. These examples suggest that not too great a distinction should be made between cooking and storage. Grain processing can be regarded as a second stage of food preservation, for example, the best-documented and best-known case being dried pasta, invented in Italy in medieval times (O. REDON, LAURIOUX 1997). It is therefore crucial to integrate the idea that some food processing provides the product with a new lifespan. This being so, storage as a *fait social* is not limited to studying buildings or containers but also includes analysis of cooking techniques and practices.

Cereals are the staple food in many societies because they are a rich source of starch. By storing cereals over the long term, people accumulate a vital stock that guarantees survival. However, grain storage requires special procedures to preserve the seeds' germination capacities and ensure the possibility of later consumption. To this end, the environment must be stabilised so as to avoid temperature and humidity variations leading to proliferation of insects and micro-organisms and heating of cereals. In addition to controlling the environment, ensuring that the stock is isolated from pests (insects, birds and rodents) is crucial. F. Sigaut initiated study of the various grain preservation environments (SIGAUT 1981). In this article, we will base ourselves on his results and on the various studies carried out subsequently (§ 1).

Several techniques can be used to stabilise the grain's environment during storage:

Airtight storage involves placing the grain in an impermeable structure in order to prevent exchange between internal and external environments. It is generally accepted that cereals and legumes (lentils, chickpeas, etc.), i.e. bulk foodstuffs, stored in this way will consume internal oxygen, release carbon dioxide and become dormant. Peter Reynolds' experiments (REYNOLDS 1979) show that, by absorbing the little air inside, the grain located against the structure's walls will germinate, causing partial loss of the crop. While Reynolds' work is widely known and used by archaeologists interested in storage, the "rotten grain crust" he describes has never been found in archaeological silos. Moreover, the gas exchange phenomenon – which would participate in deterioration of part of the grain – remains little understood (DOMINGUEZ *et al.* 2022). Research continues to improve understanding of how cereals come to be perfectly preserved in an airtight environment (see BATS *et al.* in this volume). In the absence of oxygen, any pests in the facility die. If anaerobic conditions are maintained, moisture content and internal temperature should remain more or less constant, regardless of the external environment. When the structure is opened, some air is reintroduced, making it necessary to repackage the grain elsewhere or process it. This is why it is impossible to open a hermetic device regularly if grain is to be preserved. This type of storage therefore provides effective protection against pests but conditions the cereals' entire processing and consumption chain. Consequently, airtight storage has been used for conservation, a good example being the silo, underground or built, which is effective for medium-term (a year, between two harvests) or long-term (several years) storage. However, the silo also presents certain risks (MULTON, SIGAUT 1982, p. 1167). Increasing internal temperatures can ignite the large amount of dust (micro-straw) present in the structure. The more fine particles the silo contains, the higher the risk of fire due to the various elements' proximity and the low energy required to burn them. Moisture-related fermentation and heating created by insects that have infiltrated a perforated silo can also lead to the structure exploding (even these days, grain silos explode or catch fire; for an example, see LECOMTE 2018).

In contrast, **Ventilated storage** relies on air renewal via a ventilation system. In a ventilated environment, the grain's moisture content will depend on the humidity of the air circulating in the storage facility, which is usually provided with a raised floor and vents at the top of the walls. If the room's hygrometry is too high, the grain will absorb the water. Conversely, if the air is too dry, the cereals will emit moisture. A balance has therefore to be established between the internal environment and the stored grain. In such a system, the grain must be piled up, whether

Type of building	Advantages	Disadvantages	Summary
Barn	<ul style="list-style-type: none"> • High volume • Further processing of cereals • Variety of stored commodities + agricultural tools 	<ul style="list-style-type: none"> • No conservation environment • Significant risk of deterioration if treatment is too late or if there is an infestation 	<ul style="list-style-type: none"> • Storage of large quantities of crops during the harvest • Multi-purpose building, but for temporary storage
Underground silo	<ul style="list-style-type: none"> • Small or medium-sized quantities • Stabilisation of the stored bulk product • Constant temperature • Quick, adaptable construction • Potential hiding place 	<ul style="list-style-type: none"> • No regular access to stored products • Risk of water infiltration • Weak walls • Requires maintenance between each emptying 	<ul style="list-style-type: none"> • Storage for conservation of small or medium-sized volumes of crops • Medium- and long-term conservation
Built silo	<ul style="list-style-type: none"> • High volume • Stabilisation of the stored bulk product • Constant temperature? • Quick, adaptable construction • Takes up less space than the granary for the same volume of storage 	<ul style="list-style-type: none"> • No regular access to stored products • Explosion risk 	<ul style="list-style-type: none"> • Storage for conservation of large quantities of crops in a dry environment • Medium- and long-term conservation
Granary	<ul style="list-style-type: none"> • High volume • Regular access to stored product • Suitable for all types of environments (necessary pre-drying of the stock for wet environments) 	<ul style="list-style-type: none"> • Requires periodic shovelling of grain • Costly, time-consuming construction • High risk of fire 	<ul style="list-style-type: none"> • Storage for conservation of variable quantities of crops • Foodstuffs intended to be consumed or exchanged at any time • Possibility of long-term storage

Table 1. Summary of grain storage methods according to different storage facilities.

previously dried or otherwise, and regularly shovelled, turning it over thoroughly in order to dry it and disperse the gases emitted. As in an airtight environment, the risk of spontaneous combustion is high in the absence of good air circulation. Therefore, such structures should be equipped with sanitary voids to facilitate air circulation under the building and so enable long-term preservation. This storage method's main advantage is the accessibility of the stocks involved, enabling total or partial removal as required and so facilitating exchanges. However, insects can attack the grain easily because the structure is not airtight. Elevation of stocks using crawlspace ventilation and providing high openings limits the arrival of pests. Lastly, the only way to combat mildew is by regular shovelling.

In addition to these technical considerations, it is essential to distinguish storage facilities according to their role in grain processing: the “barn” appears upstream in association with the threshing floor, while the “silo” and “granary” are used for medium- and long-term storage. These terms (“silo” and “granary”) are used according to the type of environment chosen: airtight or ventilated. Hence, a building enabling storage of grain under anaerobic conditions should be called a “silo” while a building storing grain under ventilated conditions should be referred to as a “granary” (BROMBERGER 1979). A series of symposiums in 1979, 1981, and 1985 standardised the vocabulary (GAST, SIGAUT 1979; GAST *et al.* 1981; GAST *et al.* 1985) that is still used today. Therefore, one of the *Storage in Ancient Egypt and Sudan Research Group's* primary aims was to establish a common vocabulary based on current research on storage archaeology and adapt it to the remains present in the northern Nile Valley.

In general, choice of storage facility is partly conditioned by the environment, in order to control

stock degradation risks, as well as by accessibility of reserves. However, preferences put constraints on grain management and condition the economic system (table 1).

It is interesting to note that these conservation environments were not only theorised in modern Europe (for a review of agronomic research during modern times, see SIGAUT 1978; GERACI, MARIN 2016, pp. 87-115; LAUWERS, SCNHEIDER 2022). Similarly, Pliny speaks of airtight structures in the ground (*Natural History*, XVIII, 301), while Varro warns about the gases that escape when a sealed silo is opened, as they can asphyxiate anyone too close by (*De Re Rustica*, I, 63). Similarly, as regards ventilated buildings, various ancient authors recommended raising the floors, in some cases with openings, in order to improve air circulation (GERACI, MARIN 2016, pp. 99-108). Likewise, in his *Kitâb Al-Filâha (Book of Agriculture)*, Ibn Al-‘Awwâm, an author who lived in Seville in the second half of the 12th century CE, mentions both kinds of environments (Ibn Al-‘Awwâm, *Le livre de l'agriculture*, pp. 512-513):

“Conservation des grains alimentaires (céréales particulièrement). Le froment, dit Kastos, peut se conserver de deux manières, d’abord en le garantissant contre l’air et le vent de façon qu’il ne le ressente jamais, résultat que l’on obtient en le déposant dans des silos (Matmûr, plur. Matâmîr, litt. “cachette”) ou quelque chose d’analogue ; ou en second lieu, au contraire, en l’exposant au vent, en le portant d’un lieu dans un autre, dans un grenier ou autre emplacement analogue (en le jetant à la pelle). On étale au fond du silo une couche de paille de froment de deux coudées d’épaisseur qu’on a soin de bien écarter ; on dispose aussi sur les côtés, tout à l’entour, de la paille en la

forçant par la pression, afin que, bien isolé, le blé ne soit point en contact avec les parois du silo. Quant aux greniers, ils devront être pourvus de fenêtres à l'aspect du levant et à celui du couchant, et à l'opposé du midi pour que le grain reçoive les vents de ces aspects et enlève les causes d'altération ; mais il faut bien se garder de pratiquer des ouvertures à l'aspect du midi, à cause de la violence des vents qui viennent de ce côté. ”

Finally, grain could be kept in a **hybrid environment**, neither ventilated nor airtight. This category includes various containers in which the air is not deliberately renewed. These were facilities with solid walls, made of wood, wickerwork, leather, or textile, but which were not hermetic. Exchange between internal environment and external varied in quantity, however, depending on the material used and the thickness of the walls. Partial restriction of the amount of oxygen available in these containers inhibited insect activity. Such storage facilities were not suitable for long-term preservation of grain and were not an effective deterrent to rodents. There were numerous advantages, however, depending on the foodstuffs involved and the materials chosen for their packaging. Small containers enabled storage of small quantities that could be easily accessed in the house or domestic annexes.

Inner temperature, humidity and pests all affect preservation of grain stocks negatively. The purpose of buildings and containers is to create good isolation conditions for the grain and/or protect it through an airtight or, to a lesser extent, a hybrid, or ventilated environment. How long grain can be stored in a temporary storehouse will depend on the climate: it may be longer during the cold season, especially if the weather is dry.


Despite these broad conservation principles, several questions still need to be asked. As regards ancient storage practices, the chemical process of grain preservation, farmers' know-how, the preserved grain's quality, maximum storage time, and silo lifespans are still unknown. It should be borne in mind that preservation of cereals today requires energy for refrigeration and ventilation, along with pesticides in many cases, and that, despite this, silos still occasionally explode in industrialised countries. Ancient and traditional knowledge must be rediscovered and fully understood. Likewise, conservation of other foods (meat, fish, vegetables, fruits, liquids, etc.) remains a less well-explored field, and is a complex subject as their processing was linked to culinary practices.


3. Provisional typology of storage buildings in the ancient Nile Valley


The question of crop storage in the northern Nile Valley has rarely been addressed directly and has been dealt with

in *ad hoc* fashion, based on iconographic, prosopographic and archaeological data. However, most previous studies have neglected an essential aspect of storage: the technique. They also make indiscriminate use of the terms “granary” and “silo”, often considering them as synonymous and ignoring the specific characteristics of the storage methods associated with them (§ 2), and proposing economic and social interpretations that are sometimes debatable as a result. Studies undertaken in the past focus on the quantities of cereals stored in a facility or on the distinction between domestic and collective/institutional storage. All of them converge in producing summaries on supply of cereals to urban centres, redistribution of grain in the form of food rations, and demography (for example, see KEMP 1986). Initial definition of a typology is essential, however, as it enables classification of archaeological remains and involves initial analysis of food stabilisation techniques. Such preliminary work provides a solid basis for developing analytical discussion of food stock management.

Food storage and packaging of non-perishable products can take many forms. Archaeology mainly records buildings and ceramics, but other containers are known to have existed.

Ancient Egyptian texts mention various types of storage buildings (BATS 2017, with previous bibliography). The most common term is  *šnw.t* (*Wb* IV, 510.1-16), which refers to a building for bulk foodstuffs, especially grain. Translating the term as “granary” is therefore erroneous. In addition to the fact that no “granaries”, up to now, are archaeologically known for the Pharaonic period, in the scenes depicted in private tombs this word always accompanies representations of silos. Other means of storage are sometimes associated with *šnw.t*, such as bags and baskets stored in rooms. The term should therefore be translated as “food reserve”, knowing that the most common commodities stored were bulk cereals.

The word  *mḥr* is often translated as “silo” (*Wb* II, 134.6-8). However, a lexicographical study has led to correction of this interpretation (BATS 2017, pp. 163-165). Unlike the *šnw.t*, the *mḥr* is a building associated with rural areas. It was used to store various commodities, including cereals, seeds (packaged in ceramics) and fodder. The texts indicate that it was a place people came in and out of and that goods kept in it could be transferred. Hence, this type of building could have been a kind of barn – perhaps also acting as a tool shed – as it is associated with harvest processing and fodder storage, which suggests a hybrid and/or ventilated environment.

The  *wd3* “storehouse” is sometimes regarded as a place for storing grain (*Wb* I, 402.10-15). However, in pReisner, the *wd3* is a place for storing wood and stones or where men are assigned to work on these materials stored

in the facility (pReisner II, fragment 1, vs. p. 3, l.2: SIMPSON 1965, p. 34, pl. 20; 1969, p. 37. See also the evidence from Licht: ARNOLD 1990, pp. 76-77, W27-8). As a facility used for craft production, this type of building was also used to store straw, possibly in the context of brick production (pReisner III, section F⁵, l. 25-29: SIMPSON 1969, p. 25, pl. 12). In Rekhmire's tomb, several vaulted storehouses are depicted, with their names indicated above the doors: *pr.yw-hd, wd3 n(y).w hw.t-ntr, pr.w-nb.w (ny.w) hw.t-ntr* and a fourth lost (TT110, mid-XVIIIth Dynasty, No. DAVIES 1943, pls. XLVIII-XLIX). Only the latter storehouse contains food products. In Rekhmire's *wd3*, various commodities are stored on several levels, including feathers, animal hides and elephant tusks.

𓂏𓂏𓂏 *'t* is a generic term used to refer to spaces composing a building, such as part of a temple (*Wb* I, 160.1-13), a room in a *wd3* storehouse or as an area in the *šn'* in which food was prepared and stored (pReisner III, section E, l. 30: SIMPSON 1969, p. 32, pl. 10). Where the room is clearly associated with food, we will translate the term *'t* as “pantry”, as these areas appear to have been used for packaging or processing of foodstuffs (*'t mw* “water pantry”, *ÄgWört* II, 470 {50430}, or *'t jrt.t* “milk pantry”, *ÄgWört* II, 470 {4618}). The cereal by-products concerned are bread (*'t t*) and beer (*'t hnq. t*), terms occurring in the various subordinate administrative titles: *jhms n(y) 't hnq.t, jhms n(y) 't t, wdpw n(y) 't hnq.t, wdpw n(y) 't* and *wb3 n(y) 't hnq.t* (BATS 2019, pp. 664-667).

Several archaeological buildings and objects can be interpreted as containers for foodstuff storage or long-term conservation. Some of them were specialised and exclusively dedicated to bulk grain, while others were more versatile and used to store non-food items and long-life foodstuffs. However, despite the different types known to have existed and their various characteristics, it can often be challenging to define their roles clearly. In order to do so, before interpreting storage patterns, it is essential to identify the storage environment on the basis of presence or absence of openings (to allow air to pass through), internal and external features, and how foodstuffs were packaged.

On the basis of the archaeological evidence available, a provisional typology of storage buildings including the main archaeologically known categories is proposed in the following paragraphs. As far as possible, functions and related storage methods have been characterised and several examples are given for each category. The “granaries” with interconnecting rooms studied by Barry Kemp (1986) in his well-known contribution in ZÄS 113 have been omitted deliberately. Without rejecting their interpretation as facilities devoted to grain conservation (often associated with seal impressions mentioning the institution of *Šnw.t*), reassessment of the storage methods associated with them would seem

necessary in the light of the conservation principles referred to in § 2. On the basis of their layout and the presence of interconnecting chambers, we deem it impossible to consider these spaces as silos (airtight). If they were used as granaries (ventilated environment) their operation needs to be clarified, especially as regards air circulation and access to the bulk cereals stored in the innermost rooms. A reassessment of these buildings is currently underway and will be presented in a future contribution on the subject (LICITRA, BATS, in preparation).

The following typology should be regarded as a research tool set to evolve as the study progresses, with the addition of new categories and subdivisions. As an initial result of our categorisation, we can get some idea of the variety of storage methods used throughout Pharaonic and Nubian history and up until the Greco-Roman and Meroitic periods, most probably linked to different products and storage temporalities, in dwellings as well as in public and institutional storehouses.

3.1 Underground silos

Main features:

- **Environment:** Airtight
- **Storage life:** Long-term
- **Contents:** Bulk foodstuffs
- **Other:** Potential hiding place

An underground silo is a facility for long-term storage of cereals, pulses, and certain fruits and tubers (SIGAUT 1978; 1979), as well as cured meats and fodder for livestock (VILLES 1981). In the absence of oxygen renewal, moist products such as fresh fruit and green hay ferment, like sauerkraut. An underground silo is an airtight facility, sealed with an earthen plug. The pit can have several designs, although the “bell” shape is the most common. The structure is divided into two parts: the storage chamber itself and the closure system. The stopper is composed of an underground neck and a plug, which corresponds to the cover visible on the surface (MATTERNE 2001, p. 150, fig. 69). Various arrangements ensure the pit's airtightness. The bottom of the structure is mulched in order to limit rising dampness, as is the neck in order to fill the space. Obstruction of the neck with non-food material decreases the air inside and provides a layer of protection against possible pests capable of digging in the ground in search of food. Finally, an internal lining may be applied, made of clay, plaster or plants (straw, wickerwork). In most cases, the upper part of the pit has not been preserved. Only the shape and the inner lining, necessary to protect the foodstuffs against water infiltration and pest intrusion, suggest an underground silo.

Underground silos appeared in Egypt during the Neolithic period, as evidenced by the discovery of

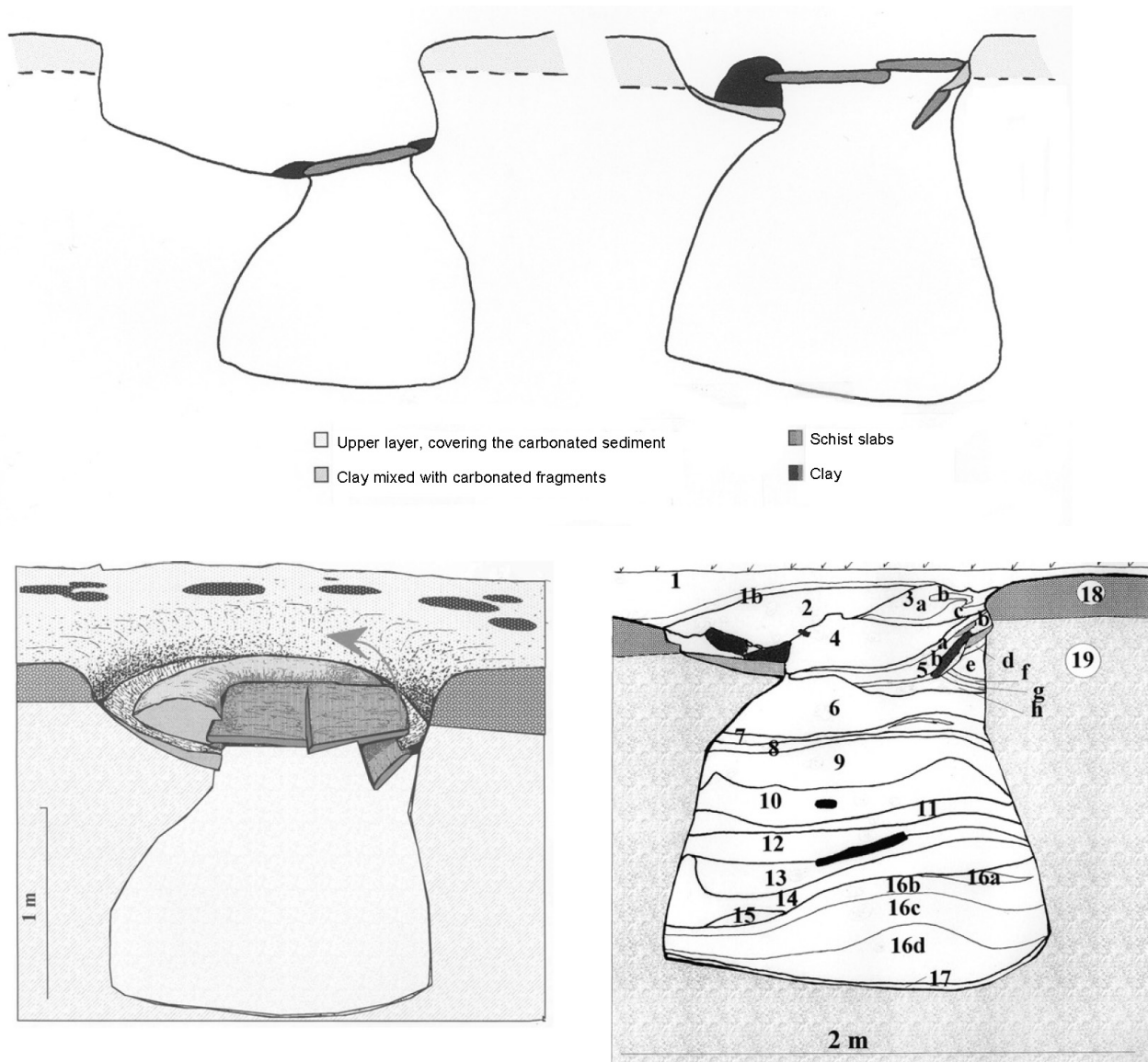


Figure 1. Pre-Kerma underground silos 26-27 (top left) and 22 (top right and bottom) from Sai Island. © Sai Island Archaeological Mission.

over a hundred circular or hemispherical pits on the Kom K site in Fayum (“Upper and Lower K pits”: CATON-THOMPSON, GARDNER 1934, pp. 41-54, pls. XXVI-XXVII; WENDRICH, CAPPERS 2005). Several pits that may have been used for the storage of foodstuffs were also discovered at Elkab (see the contribution by W. Claes *et al.* in this volume). Although built silos became the preferred choice from the Naqada III period onwards (TRISTANT 2004, pp. 102-108; DACHY 2014), underground silos still existed during the Pharaonic period. On Elephantine, the excavation of Haus 51c/d dating from the XIIIth Dynasty revealed the presence of an underground structure (096) interpreted as a silo. The 1.40-metre-deep pit had an unconstructed base but rested on a layer of potsherds. The walls were lined

with bricks coated with clay plaster. A plaster plug sealed the structure (VON PILGRIM 1996, pp. 146-147, fig. 58).

As in Egypt, underground silos certainly existed in Sudan during the Pre-Kerma Period for storing cereals (GEUS 2004). The pits identified on Sai Island were of different shapes and sizes, while the closing system was composed of a large slab of schist, surrounded and partially covered by a thick clay binding (fig. 1).

Underground jars

Main features:

- **Environment:** Airtight or hybrid
- **Storage life:** Short- medium- or long-term
- **Contents:** (Bulk) foodstuffs and liquids
- **Other:** Potential hiding place

Large ceramics buried up to the neck have been identified on several urban sites, either in one of a house's rooms or in its courtyard, notably at Elkab in an Early Dynastic context (see CLAES *et al.* in this volume) as well as in the late Middle Kingdom settlement of Balat/Ayn Asil (MARCHAND, SOUKIASSIAN 2010, pp. 127-131). This practice is attested throughout the Pharaonic and Islamic periods (MARCHAND 2013, pp. 328-330). For some additional examples, see also MAZOU in this volume; LICITRA, DAVID 2016, pp. 78-79, 91-92). In Balat/Ayn Asil jars are of various sizes and were found embedded in the ground up to their mouths. Lids confirm these ceramics' role as storage receptacles. The bowls also found inside must have been used to extract their contents. The few incised marks made before firing and a decoration on the Nr. 2047 jar have led archaeologists to assume that such ceramics were produced for other purposes and then reused as fixed containers. The archaeologists at the site assumed that they would have been used for grain storage during the various treatment and processing phases. However, the presence of a non-removable sealed clay stopper is not compatible with a role as by-product packaging, but rather with long-term storage. Storage of cereals and pulses in underground jars corresponds to medium- or long-term conservation in an airtight environment.

In conclusion, such receptacles could function like underground silos, as they were hermetically sealed and provided an efficient means of storage over the medium and long term. Under such conditions, it is reasonable to assume that they may have been used to store cereals, legumes, fruits and tubers in the same way as underground silos. However, unlike in grain pits, the products stored were very well protected against pests due to the ceramic walls' solidity. If the ceramic was not sealed, it may have been used to store liquids or other foodstuffs requiring robust protection and a stable temperature, due to the receptacle's location underground.

3.2 Mud-brick silos

Main features:

- **Environment:** Airtight
- **Storage life:** Long-term
- **Contents:** Bulk foodstuffs

The mud-brick silo was the most common storage facility in ancient Egypt both on archaeological sites (see CLAES *et al.*

and MILLET in this volume), and in "daily life" scenes (VANDIER 1978, pp. 198-203, 229-233, 273-283; SIEBELS 2001; MASQUELIER-LOORIUS 2017; BATS 2017; BARDOŇOVÁ 2018). They were often cylindrical but had a variety of shapes and sizes (fig. 2). In the current literature, quadrangular silos are known to have existed due to archaeological remains dating from between the First Intermediate Period and the early Middle Kingdom (M. ADAMS 2007; MOELLER 2016, pp. 228, 230, figs. 7.10, 12a; BATS 2017, pp. 168-169). Egyptian mud-brick silos are characterised by two openings: one at the top for pouring the grain in and one at the side for taking the cereals out.

This type of facility enabled preservation of raw foodstuffs, especially cereals, in an airtight environment. However, little is known about the mud-brick silo's elevation, which is absent from the archaeological remains, and its operation. In order to study them further, an experimental archaeology project was initiated in 2021 with a team of archaeologists, architects, and agronomists. The preparatory study and first results are presented in this volume (see BATS *et al.*).

3.3 Granaries

Main features:

- **Environment:** Ventilated
- **Storage life:** Long-term
- **Contents:** Bulk foodstuffs

Granaries are ventilated buildings whose layout makes for easier shovelling in order to evacuate the gases emitted by the bulk grain and prevent spontaneous combustion. For the Bronze Age, granaries have so far only been archaeologically attested in Sudan. The Middle and Classic Kerma granaries in Gism el-Arba have been studied in depth by Séverine Marchi (2017, pp. 208-213, figs. 9-12), who has demonstrated that they were located in Kerma's hinterland in order to supply the city. Their purpose was to store cereals before centralisation of part of the harvest in the capital's silos. These granaries, of various sizes and with a square (2-2.5 m) or rectangular plan (up to 6 m long), were provided with a raised wooden floor (about 40 cm: GRATIEN *et al.* 2003, p. 37), laid on rows of one or two sandstone blocks set one on top of the other, and cob walls (fig. 3). They were accessed up stone or mud-brick steps. Only faint traces of their wooden architectural components were identified during the excavation, while better preserved fragments of the cob walls made it possible to estimate the structure's original floor to ceiling height at 2.5 metres. Low walls were built around the granaries, possibly to protect their bases from wind erosion.

Similar buildings, also dating from the Kerma period, have been discovered on the Nile's eastern bank in the Northern Dongola Reach. The only one to be excavated,

Figure 2. XVIIIth Dynasty mud-brick silo discovered during the excavations in the Xth pylon courtyard of Karnak precinct. © CNRS-CFEETK/ Michel Azim (no. 13943).



Figure 3. Granary Str 140 from Gism el-Arba. © MAFGA/ Séverine Marchi.



Building P4 (10.8-11.06 x 11 m), has external walls built of sandstone blocks forming the plinth of a lost superstructure, possibly made of mud-brick, cob, wattle-and-daub, or timber. The blocks raised the building's floor about 30 cm, while the wall height did not exceed 3 m (WELSBY 2001, pp. 121-122, 203-205, 577, 581, fig. 3.76, pls. 4.3-4.4; WELSBY 2019, pp. 146-147, figs. 4-5). This kind of granary seems to have been used up until the Meroitic Period, as it is attested by building XLVIII of Meinarti, where remains of the charred beams laid on the stone blocks were found in situ (W. ADAMS 2000, pp. 35-36, fig. 8, pl. 3). Interestingly, the steps leading up to the granary reached a level above the building's internal floor (WELSBY 2019, p. 144).

No similar granaries are known in Egypt, perhaps because they have yet to be identified or because the ancient Egyptians did not favour the use of ventilated environments for long-term conservation. However, the association of raised floors and storage of cereals, for the reasons already referred to (§ 2), is also documented outside the Nile Valley, with numerous examples from Central Asia to the Roman world (RICKMAN 1971, pp. 293-297; BUKOWIECKI *et al.* 2018) as well as in West Africa (see the contribution by A. Mayor and T. Pelmoine in this volume).

3.4 Grain storehouses for short-term storage

Main features:

- **Environment:** Hybrid
- **Storage life:** Short- or medium-term
- **Contents:** Packaged grain

Recent archaeological investigations carried out in Uronarti fortress' Unit FA have enabled elucidation of the area's function by convincingly linking Room 5 to short-term storage and distribution of grain, largely due to the discovery of unprocessed grain along with textile threads (BESTOCK, KNOBLAUCH 2020, pp. 33-37). In this area, internal dividing walls, a half-brick thick and about 1 m high, were built in the eastern and western halves of the room, between 1.4 and 1.75 m away from each other. This layout only left a narrow passageway, equivalent to the width of the door. It is tempting to regard the low walls as supports for raised wooden floors on which sacks of grain were arranged in stacks (GERACI, MARIN 2016, pp. 88-89, fig. 1). The presence of multiple layers of plaster preserved on the low walls is consistent with the room's probable function as a storage area for cereals (§ 4.3).

Therefore, short-term grain storage buildings do not fall within the categories of silos (airtight) or granaries (ventilated). They are storehouses in which cereals were packaged in a hybrid environment, in bags, baskets or jars. Such buildings were used for storing grain prior to its processing, distribution or shipment.

3.5 Rectangular storerooms

Main features:

- **Environment:** Hybrid
- **Storage life:** Short-, medium-, or long-term (depending on context and type of stored products)
- **Contents:** Packaged, long-life foodstuffs, raw materials and/or manufactured items

In Nile Valley archaeological sites, rectangular vaulted rooms have been identified in a variety of contexts – royal palaces, temples, fortresses and private houses – as storehouses for long-life foodstuff (such as honey, vegetable oils, animal fats and wine), raw materials (gold, silver, precious stones, ivory, etc.) and craft goods (clothes, amulets, ritual materials, etc.).

With regard to foodstuff, such storerooms were intended for the storage of different types of products, as shown by the iconography (for some examples, see: No. DAVIES 1903, pp. 37-38, pl. XXXI; ASSMANN 1991, pp. 35-36, pl. XXIIIb and 18-19-scene 15; HOFMANN 1995, pp. 77-79, pl. XL; ABD EL-RAZIQ 1981, pp. 411-413) and epigraphic material sometimes discovered during excavations (for example, see BOUVIER 2003 and 2004; PANTALACCI, SOUKIASSIAN 2019, p. 197; PANTALACCI 2022, p. 431). This implies that, due to their nature, processing or type of packaging, these commodities had common needs in terms of insulation and thermal and hygrometric conditions in order to ensure their preservation over the medium and long term.

These storerooms' general architectural features include (fig. 4):

1. A modular layout composed of one or more rectangular rooms in one or more rows. In Egyptian architecture, their length can vary from a few metres (e.g. 6.8 m at Balat/Ayn Asil: PANTALACCI, SOUKIASSIAN 2019, p. 189) to over 50 m (Ramesseum's STI annexes: CEDAE 1976, p. 29), while their width mostly ranges between 3.5 and 4 m (for examples, see storerooms M2-M7 in SAF5 on Sai Island: ADENSTEDT 2016, pp. 72-76; Ramesseum's STI and STA annexes: CEDAE 1976, p. 29; LECUYOT 2017, p. 138, n. 9; Ramesside magazines in Tell el-Retaba: RZEPKA *et al.* 2011, p. 148). Regardless of the length, this simple layout minimises circulation space – in the middle of the room – to the benefit of the surface devoted to storage – along the two long walls. On the basis of this principle, the storeroom's width could be narrowed further depending on needs: good examples are the storerooms in Balat/Ayn Asil's southern palace, which are only 1.45-1.65 m wide. In this case, the rooms' dimensions seem to have depended on the arrangement of the commodities stored in it not requiring a greater width – i.e., large jars with



Figure 4. Rectangular storerooms in Ramesseum's annexes STI. © Thierry Joffroy.

rounded bottoms placed in a single row along each of the long walls (PANTALACCI, SOUKIASSIAN 2019, p. 189) – leaving about 80 cm for circulation. In Nubian architecture, the rooms seem to be less narrow than their Egyptian counterparts and/or have different width/length ratios: in the city of Kerma, the storerooms in buildings M42 and M281 measure 6 x 4 m (BONNET 2014, pp. 64-65) and 5.4 x 2.5 m (BONNET 2014, pp. 125-126) while in the so-called Treasury of Sanam the storerooms are 21 m long and 14 m wide (VINCENTELLI 2015, p. 320). Similar proportions have also been documented in the Ramesside magazines of Amara West (P. SPENCER 1997, pp. 56-59).

2. A single door in one of the short walls, enabling limited, controlled access to the room.
3. A vaulted roof, although a few flat roofs have been attested (see § 3.5.4).
4. Mud-brick as main building material. It should be emphasised that storerooms built of stone existed in Egypt (especially in religious, funerary and expeditionary contexts), but as they are outside the scope of this contribution, the following discussion only concerns mud-brick buildings.

The abovementioned features cannot be used as the sole markers for identification of medium- and long-term storage practices, as similar areas may have been devoted to other activities. It is therefore worth considering the topographical location of the rooms under study as well, with associated findings and appropriate comparisons.

Despite their apparent uniformity, variations in storerooms' architectural features can be easily identified and mainly concern: 1) their location (i.e. partly underground buildings); 2) floors; 3) internal divisions; and 4) roofs. The reasons for these variations – possibly linked, among other things, to the kind of stored products or different building cultures – cannot always be explained and additional research will be needed in order to ascertain the factors that may have determined them.

3.5.1 Partly underground storerooms

In some cases, rectangular storerooms were built partly underground. In Nubia, such is the case in the Pharaonic town of Sai Island (sector SAF5) where the magazines' floors are between 50 and 60 cm lower than their thresholds (ADENSTEDT 2016, pp. 38-42, pl. 32.2). Similarly, in the so-called Treasury of Sanam, the storeroom's floors

are about 35 cm lower than the external courtyard, with three steps giving access to the rooms (F. GRIFFITH 1922, p. 116, pls. L, LIb).⁵

In Egypt, during the Greco-Roman Period, partly underground, rectangular magazines were one of the main components of the *thēsauroi* (see § 3.9 and Loïc Mazou's contribution in this volume).

The reasons for this particular building practice are not fully understood or proven, but in Sai Island and in the *thēsauroi* they might have to do with a desire to limit rises in internal temperature and keep the rooms cool.

3.5.2 Floors

Rectangular magazines usually have mud, mud-brick, or stone floors, with these different types of pavement sometimes coexisting in the same row of storerooms, as the examples below show.

Mud floors have been found in the abovementioned magazines of Balat/Ayn Asil (PANTALACCI, SOUKIASSIAN 2019, p. 189) and Sai Island (ADENSTEDT 2016, pp. 38, 71; AZIM 1975, p. 113). A layer between 5 and 10 cm thick, made of rammed earth mixed with straw, covered the natural ground in storeroom 34 in Ramesseum's STH annexes (BOUVIER 2003, p. 60) while at Tell Hebua I, a similar floor covers a layer of sand between 5 and 6 cm thick (ABD EL-MAKSOUH 1998, p. 51).

Square (40 x 40 or 39 x 39 x 10-12 cm) and rectangular (38 x 18 x 12 cm) mud-bricks laid on a layer of sand were used to pave the floors of Ramesseum's STI annexes (CEDAE 1976, pp. 35, 45). In both cases, the bricks were covered with a layer of mud mortar and a coat of white plaster. In the Temple of Seti I annexes in Abydos, the floor is made of square bricks measuring about 44 x 44 x 16 cm (GHAZOULI 1964, p. 158). It should be emphasized that, as in this latter case, mud-bricks paving a room were never left visible, but were always covered with a protective layer of mud sometimes coated with white plaster, not always preserved.

Stone floors appear to be less numerous than the two previous categories and usually go together with a stone lining covering the bases of the walls. A good example can be found in the so-called Treasury of Sanam where

5 The hypothetical reconstruction of this building provided by Derek Welsby (2019), aiming to explain the large number of small supports in addition to the columns in each storeroom, is questionable. Counter-arguments include the fact that absence of supports along the walls would have left the ends of the beams supporting the raised wooden floor unsupported, which is inconsistent from an architectural point of view. Furthermore, the stone slabs and orthostats covering the floor and the base of the walls have been carefully laid and plastered: it is difficult to understand the care taken with this part of the rooms if it was not intended to be seen. Finally, the steps leading down to the magazines would have been useless with a raised floor covering them.

the magazines floors and wall bases are covered with sandstone slabs (F. GRIFFITH 1922, p. 116, pls. LIb, LIIf; VINCENTELLI 2018, p. 127). Similarly, in Ramesseum's STF annexes, orthostats 1 metre high lined the mud-brick walls of rooms paved with irregular stone slabs. Although it has been posited that these vaulted rooms were weaving workshops (LECUYOT 2019), in the absence of sufficient evidence supporting this hypothesis, we would not rule out the possibility that these rooms were used for storage. On Sai Island, the stone floors in SAF5's M12 and M14 storerooms are made of irregular slabs of schist and white mortar, which also cover the bases of the walls (AZIM 1975, p. 113; ADENSTEDT 2016, pp. 24, 41-42, 82, pls. 29.2, 32). It is difficult to assess the exact reason(s) for such choice of building material and, as things stand at present, one can do no more than assume that these rooms probably had specific requirements to do with the kinds of commodities stored or duration of storage.

3.5.3 Two-storey storerooms

In some cases, magazines were provided with two storeys. As an example, in the Raneferef Pyramid complex in Abusir, several vaulted storerooms in the Early Temple Northern Sector and the House of the Knife had two compartments separated by a wooden floor, with the upper compartment accessible via a mud-brick staircase about 1.5 m high (VERNER 2006, pp. 59-66, 93-98, 130-132, 155-, figs. 1.2.45-47, 1.6.16-17). These rooms were not devoted to storage of foodstuffs but rather of ritual instruments and materials. Two-storey storerooms for storage of liquids (in jars) are known in Balat/Ayn Asil, however, where the lower storey is between 1.05 and 1.20 m high (SOUKIASSIAN 2022, p. 53, fig. 7).

3.5.4 Roofs

Rectangular magazines were usually covered by so-called Nubian vaults, i.e. barrel vaults whose brick courses leaned against an upright end wall (MONNIER 2015; KEMP 2000, pp. 93, 95-96, figs. 3.9a-c, 3.10; J. SPENCER 1979, p. 125; BESEVAL 1984, pp. 42, 44-46, figs. 31-32, pls. 12-16; GOYON *et al.* 2004, pp. 123-130; also called "edged-placed vaults": MONNIER 2013, pp. 132, 266). They were used in Egyptian architecture throughout the Pharaonic period (EL-NAGGAR 1999, pp. 141, 349-351, 358-365) and up to modern times (ZABRANA 2018).

Vaults are rarely preserved and their presence is often revealed by fragments found in buildings' destruction levels during excavations and/or by the surviving vault springs (as in the Treasury of Shabaqo in Karnak: LICITRA 2018, pp. 50, 52, fig. 10; the SAF5 magazines of Sai Island: AZIM 1975, p. 113, pl. IX, fig. 2; ADENSTEDT 2016, pp. 24, 151, pl. 15.4; and the storerooms in complex E13.3 at Amara West: N. SPENCER 2009, p. 48).

In Pharaonic architecture, the vault is well attested in private tombs and funerary complexes, while it was rarely used in domestic contexts before the Middle Kingdom. In fact, houses were generally equipped with flat roofs made of wooden beams and plant materials covered with mud, while vaulting was mainly used to cover specific areas such as stairwells, cellars, passages, niches and *malqafs* (§ 3.5.5). From the New Kingdom onwards, vaults become more frequent in settlements, as well as in royal palaces, and are systematically associated with storehouses (EL-NAGGAR 1999, pp. 339-341, 349-351). From the late New Kingdom onwards, their use is increasingly attested in all kinds of buildings (J. SPENCER 1979, p. 124), to support a flat roof or the floor of an upper storey.

The very few examples that have come down to us of Nubian vaults in storage buildings show that they supported flat terraces. Such is the case with the 4-course-thick vaults of Ramesseum's STI and STA annexes. Their flanks are filled with a heterogeneous layer mostly composed of sandstone chips mixed with earth, mud-brick fragments, and potsherds (STA storerooms: CEDAE 1976, p. 42; LECUYOT 2017, p. 138), or potsherds mixed with (earthen?) mortar (STI annexes: QUIBELL 1898b, p. 7; CEDAE 1976, pp. 34-35, 47, pls. LV-LVI; LECUYOT 2017, pp. 142-144). Following reassessment of the potsherds found in the filling, it is now certain that the latter dates back to the Ramesside period and therefore that, in the original plan, the vaults supported a flat roof (LECUYOT 2017).⁶ It is worth noting that the filling is essentially composed of reused materials: sandstone chips from the cutting of stone components (probably from the temple) and pottery sherds. Still more interesting, on the flanks of STI magazines' vaults, mostly Nile pottery sherds (predominantly fragments of beer-jars) were used for the eastern storerooms, while Egyptian marl and imported amphorae sherds have been found on the vaults in the western rooms (LECUYOT 2017, p. 144), showing that two different places supplied the broken pottery collected for later reuse. The use of pottery sherds to fill the flanks of mud-brick vaults is also attested later, during the Coptic period, in the Kellia (HENEIN, WUTTMANN 2000, p. 76). In the annexes to Seti I's temple in Abydos, the gap between the vaults has been filled with mud-bricks instead (GHAZOULI 1964, p. 145, pl. XVII; KEMP 2000, p. 93, 96, fig. 3.10b).

Although the flat roof's function in domestic architecture is clear enough and well established, as the terrace was used for a variety of activities including cooking, sleeping and storage, the reasons for building a

flat roof on storehouses are not so obvious. The savings on wood made possible by a mud-brick vault have been suggested (GOYON *et al.* 2004, p. 125) and it is also true that a flat surface would have permitted easier movement on the terrace for upkeep purposes as well as to open and close the *oculi* (§ 3.5.5) as needs dictated. In paragraph § 3.5.6 the impact of vaulted roofs on storerooms' thermal performance will also be considered.

There are very few known examples of storehouses with flat roofs. On Sai Island, SAF5's M1 storeroom may have been covered by a flat roof as its walls are considerably thinner (0.42 m) than the masonry supporting the vaults in the adjacent rows (between 0.73 and 0.89 m thick: ADESTENDT 2016, pp. 71-77). A more notable exception is the so-called Treasury of Sanam, where a flat roof made of wooden beams and mud-bricks covered the columned storerooms (VINCENTELLI 2001, p. 78; VINCENTELLI 2015, p. 320). The reasons for this choice are not clear. However, among the factors identified by Roland Besenval (1984, p. 168) as determining the type of roofing chosen by the builders of a given society, the cultural factor (in this case, the building culture and/or absence of a local technological tradition) may have been decisive.⁷

Finally, no archaeological data exists on storehouse terraces' rainwater drainage systems. Gutters or slightly inclined roofs were probably used to facilitate water runoff. Impermeable plasters could have been used as a coating as well, but no evidence is currently available on this possible preventive measure.

3.5.5 Openings

One of the main issues involved in study of rectangular storerooms is the existence and location of possible openings. Apart from the door, which was supposedly only opened when the room was being loaded or unloaded, very little evidence is available on additional openings for ventilation and (possibly) natural light. The following examples are worth mentioning:

1. The window in the vestibule of one of the magazines in the abovementioned governor's palace in Balat/Ayn Asil (PANTALACCI SOUKIASSIAN 2019, pp. 184, 186-187, 189, figs. 2-3, 6). This small opening with a flared frame (20 cm wide on the inside and 40 cm wide on the outside) was located 1.90 m above the floor. The window opened onto what seems to be a roofed room (excavation of the storage building has yet to be completed).
2. In the annexes to Seti I's temple in Abydos, limestone clerestories about 59 cm high and 18 cm thick were located above each door in the corridors leading to

6 According to G. Lecuyot (2017, p. 145), only STI annexes had a flat roof because the walls of STA magazines did not reach the extrados level and the vault flanks would not be filled up to it. Due to the vaults' state of conservation, however, it is impossible to know how far up the filling reached.

7 In the absence of a synthetic study on the so-called Nubian vault in Kushite architecture, it is difficult to assess the origin and development of this technology in the Kushite building culture.

the storerooms (GHAZOULI 1964, p. 126, pls. VIIA, VIII-IX.). They let light and air from the porched courtyard into the corridors. No evidence of openings in the magazines walls themselves has been found.

3. *Oculi* (minimum diameter of 60 cm: CEDAE 1976, p. 33; surfaces of about 33 cm²: QUIBELL 1898b, p. 7) are set at regular intervals (3.66 m) at the apex of the Ramesseum's vaults (QUIBELL 1898b, p. 7; CEDAE 1976, pp. 33-34, pls. I, LIII-LIV). Judging from their appearance, the vaults were pierced after their completion and the openings' edges were lined with bricks to give them a roughly circular shape. Although their construction cannot be dated with any certainty, as they may have been part of the building's original plan or been opened later⁸, the regularity of their arrangement makes the first hypothesis more likely (CEDAE 1976, p. 34). This means that the *oculi* would have ensured the room's ventilation by letting warm air out during the day and cool air in during the night (for an example from the Egyptian vernacular tradition, see FATHY 1986, fig. 33). However, as it has already pointed out (LECUYOT 2017, p. 137), some sort of shutter had to enable these openings to be closed when required, in order to protect the rooms from intrusion (by pests or humans). Although there is no archaeological data on such a device, it may be supposed that it was similar to the ventilators of Egyptian tradition called *malqaf*, built of mud-brick and turned northwards (ENDRUWEIT 1994, pp. 89-104; KEMP 2012, p. 186, fig. 5.26; EL-NAGGAR 1999, pp. 342-343, figs. 430b, 432; BADAWY 1958, p. 123, figs. 2a, d-e). Other systems built on mud-brick vaults for ventilation of rooms also existed in the Coptic period (HENEIN, WUTTMANN 2000, pp. 117, 120, figs. 153-155).

Despite these few examples suggesting that storerooms may have been provided with some sort of openings, it is still not altogether clear how the two needs of ventilation and protection from pests were reconciled. It should be borne in mind that natural lighting was not necessary in storerooms as artificial light (torches and lamps) would have been sufficient for the activities carried out in them. However, without any additional openings, the door alone would not ensure sufficient air exchange for what were often very long storerooms, which could well have posed a problem in terms of internal temperature and humidity.

3.5.6 Discussion on rectangular storerooms' thermal and hygrometric performances

As previously stated (§ 3.5), in addition to materials and manufactured goods, rectangular magazines were also used to store long-life foodstuffs such as animal fats,

honey, wine and vegetable oils. Although the processing and packaging of such commodities might ensure their medium- and long-term conservation, they had to be stored in locations with thermal and hygrometric conditions that did not affect their properties. There has been little investigation of the ways in which architecture might have met these requirements as the poor state of the remains and scanty documentation make accurate assessments difficult. This is a common problem when dealing with storage architecture. Some attempts to estimate the thermal and hygrometric performances of underground (DOMINGUEZ *et al.* 2022; REYNOLDS 1979) and built silos (see the contribution by A. Bats *et al.* in this volume) have been made with the help of air temperature, relative humidity and multigas sensors. Fluid-dynamic computer models have been used to study the thermal performances of the Roman *Horrea* in Portus based on various reconstructions enabled by the archaeological data (PAGLIARO *et al.* 2015). This latter approach is promising in terms of functional interpretation of storage buildings, as it highlights what kinds of foodstuffs could have been stored inside them and which could not. Nevertheless, this method requires essential information in addition to the building's plan and supposed elevation, including the building materials' quality and properties. This is the most sensitive point as regards the storage buildings in the Nile Valley as the quality of mud-brick, earthen mortars, and plasters varies according to the recipes used, which can only be characterised by material analysis, a procedure rarely carried out on archaeological samples.

Although mud-brick buildings have generally been assumed to provide good thermal performances (KEMP 2000, p. 88), the correlation between earth as a building material and thermal comfort has to be clarified. Earth is a good thermal and hygrometric regulator but does not provide much insulation (HOUBEN, GUILLAUD 2006, pp. 156-157; HALL, CASEY 2012). It has a high thermal inertia, i.e. it responds very well to external temperature variations by reducing internal temperature differences. Nevertheless, although it stores heat during the day, keeping internal temperatures low, it also releases it in the evening and at night, gradually increasing the interior temperature. According to Hassan Fathy (1996, p. 91), in Gurna, maximum internal temperature was reached at about 7 p.m., five hours after the maximum external temperature. Similarly, in winter, internal temperatures are low in the morning because of the cold stored by the masonry during the night and released during the day. This explains the discomfort felt in traditional Egyptian mud-brick houses at certain times of the day and night, depending on the season (SPENCE 1996, p. 52; KEMP 2000, p. 88). It would therefore be more correct to speak of thermal delay when discussing the properties of mud-brick constructions.

⁸ The authors thank Thierry Joffroy for this suggestion.

Earth is also a porous, unsaturated material and is therefore a good hygrometric regulator, limiting condensation and related pathologies thanks to its clay content (MOEVUS *et al.* 2016; MOEVUS 2011, p. 15).

In the light of this behaviour, special precautions had to be taken in planning a mud-brick storage building and keeping the products it contained in a cool, dry environment. Because their state of conservation is always fragmentary, such precautions are sometimes hard to identify in rectangular magazines.

Studies of ancient and vernacular Egyptian houses have shown that, in addition to a specific layout, several traditional methods were employed to improve mud-brick buildings' interior thermal comfort (BADAWY 1958; ENDRUWEIT 1994; SPENCE 2004; FATHY 1986). However, while a house's thermal comfort is a matter of its inhabitants' subjective perception (FATHY 1986, pp. 28-33), maximum temperatures reached in a storehouse should not cause any deterioration in the quality of the products stored in it.

The parts of a building most vulnerable to solar radiation are its walls, roof, and exterior floors (FATHY 1986, pp. 42-45, 49-51; FATHY 1996, p. 90). As far as ancient storehouses are concerned, various precautions taken to limit the rise of interior temperatures can be identified in their layout, while others may possibly have been linked to the use of passive cooling systems.

As regards layout, rectangular storerooms set in rows were well suited to limiting exposure to solar radiation as only a reduced surface of their masonry was exposed to the sun: the roof and external walls. However, the latter were usually the building's thickest masonry work, so limiting heat transmission from exterior to interior (FATHY 1986, p. 39). The roof is the most vulnerable part of this kind of building. However, it has already been pointed out that vaulted rooms have good thermal performances. In fact, the vault increases the room's height, so creating considerable space above the stored products, in which warm air can rise and eventually be transmitted outside via the roof (FATHY 1986, p. 50).

Turning to the more recent study and applications of Nubian vaults in Hassan Fathy's projects, we note that such vaults' flanks were not filled. The vault shape itself is naturally effective against heat. Its total surface area is larger than that of a flat roof, so the solar radiation's intensity is spread over a larger area. Consequently, the average amount of heat absorbed by the roof and transmitted to the interior is reduced. Moreover, for most of the day, part of the vault remains in the shade (especially if it has a north-south orientation), which means that the warmer part absorbs heat from the sun and indoor air and transfers it to the cooler outdoor air in the shaded part of the roof. Finally, according to the Bernoulli's principle, vaulted or domed roofs increase the air speed over their

curved surfaces which reduces the temperature of such roofs (FATHY 1986, pp. 50-51).

On the basis of this data, in vaulted Pharaonic magazines supporting flat roofs, one may wonder whether filling the vault flanks was an alternative solution adopted to create a thick buffer that provided greater protection from the sun's rays and limited the rise in internal temperatures in a context where, unlike dwellings, ventilation (i.e. openings) had to be reduced to a minimum. In fact, although it has been assumed that the thickness of these vaults ensured greater robustness and avoided cracking (GOYON *et al.* 2004, p. 130), it has also been pointed out that, as the Nubian vault only works by compression, it could be made of a single course of bricks (BESEVAL 1984, p. 33). One may therefore wonder whether the 4-brick courses of the Ramesseum's vaults, along with the thick filling covering their flanks, were created to provide better protection from the sun's rays. This possibility has already been considered for vaults of lesser thickness (PANTALACCI, SOUKIASSIAN 2019, p. 189). However, as we have seen (§ 3.5.5), rectangular storerooms seem to have been also provided with openings that let warm air out and ensured the ventilation required to maintain good thermal and hygrometric conditions.

Finally, the courtyard onto which magazines often opened was also a vulnerable part of the building as it was directly exposed to solar radiation. In some cases, trees and shrubs were planted in it in order to limit the effects, as is attested by the iconography. For an example, see the scene from Neferrenpet's tomb previously referred to (HOFMANN 1995, pl. XL). Furthermore, at least one, and usually three or four sides of the courtyard were provided with a porch, shielding the entrances to the storerooms from solar radiation (see Seti I's temple annexes in Abydos, for example: GHAZOULI 1964, fig. 3; Ramesseum's STI annexes: CEDAE 1976, pl. I; the Treasury of Shabaqo: LICITRA 2018, fig. 4; and the Treasury of Sanam: VINCENTELLI 2011, fig. 1).

3.6 Treasuries

Main features:

- ***Environment:*** Hybrid
- ***Storage life:*** Medium- and long-term (depending on context and type of stored product)
- ***Contents:*** Packaged, long-life foodstuffs, raw materials and/or manufactured items

Rows of rectangular storerooms could be found in the *Pr-hd*, the Treasury, one of ancient Egypt's main economic institutions, in charge of accounting, management and storage of raw and manufactured goods and long-life foodstuffs belonging to a temple, royal palace or town. Archaeological evidence has only succeeded in identifying three buildings as Treasuries: the Treasury of Thutmose I in North-Karnak (JACQUET 1983), the Treasury of the

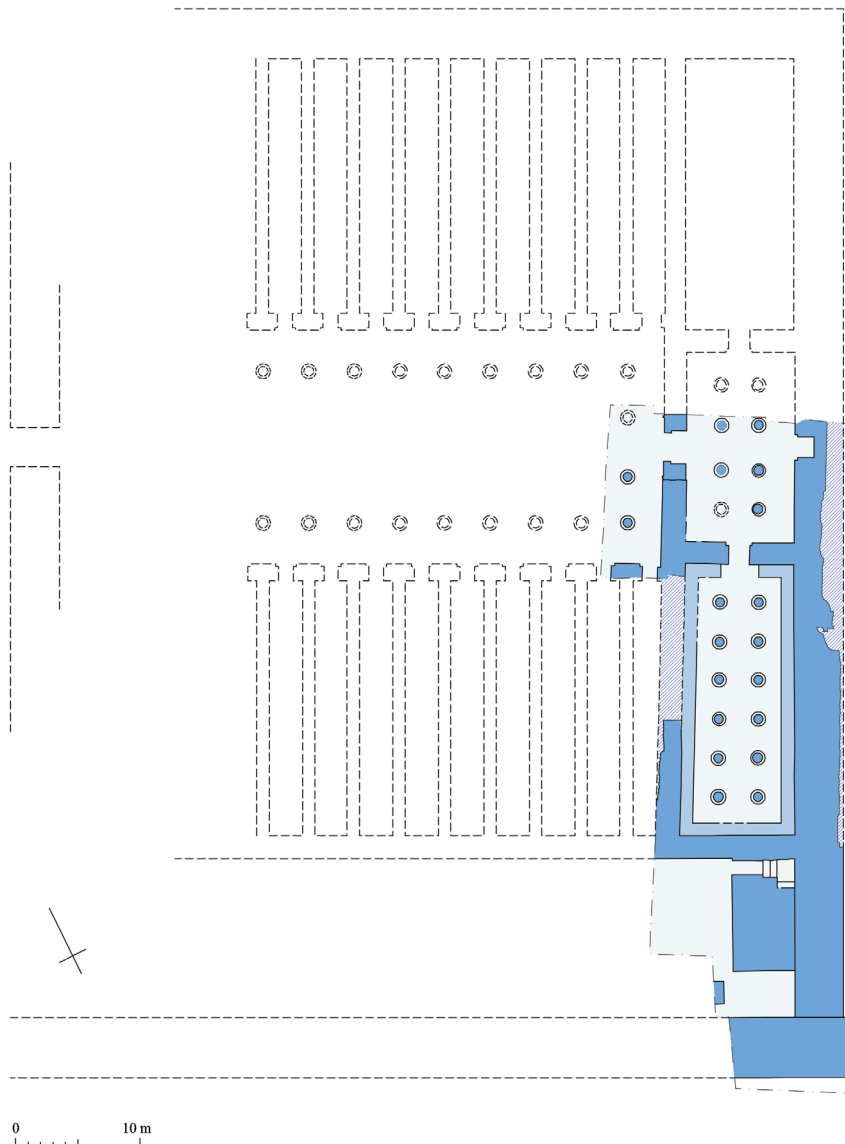


Figure 5. Plan of the Treasury of Shabaqo at Karnak.
© Mission du Trésor de Chabaka/N. Licitra.

funerary temple of Merenptah (JARITZ *et al.* 1999, pp. 27-32, 42-52; JARITZ *et al.* 2001, pp. 144-148), and the Treasury of Shabaqo (LICITRA 2014, 2018), but other storage facilities may be added to the list, all dating from between the New Kingdom and the XXVth Dynasty (LICITRA 2018, pp. 41-42).

Treasuries' main features are as follows (fig. 5):

- A rectangular plan and large surface area;
- Thick outer walls and a single gateway to control access to the building;
- One or more rows of rectangular magazines opening onto a porched courtyard or, more rarely, a hypostyle hall;
- Mud-brick masonry with some stone architectural elements such as thresholds, doorframes, columns and benches.

Treasuries were not merely storage facilities, even though storage was the main activity carried out inside them. Existence of worship areas⁹ and workshops is also attested in these buildings (LICITRA 2014, pp. 373-424).

3.7 Cellars and pantries

Main features:

- ***Environment:*** Hybrid

9 In Pharaonic Egypt, iconographical, textual and archaeological sources show the existence of places of worship inside storage facilities such as the "Treasury" (*Pr-hd*) and the "Granary" (*Šmw.t*) from the New Kingdom onwards (LICITRA 2014, pp. 391-400; MOUGENOT 2019). This tradition continued until the Ptolemaic Period: see the contribution by Giséle Hadji-Minaglou in this volume.

- **Storage life:** Short- to long-term (depending on container)
- **Contents:** Wide variety of packed foodstuffs

The pantry was a room devoted to storage of foodstuffs and other items connected with domestic activity. It was a small, usually vaulted space on the ground floor of a house or beneath it, which individuals could enter. Perhaps this is how an underground storage room identified at Tell el-Dab'a should be interpreted (MÜLLER 2015, p. 355). Several rectangular semi-buried structures were identified in the town of Ezbet Rushdi, including Cave L080, which was found at a depth of between 50 and 55 centimetres (CZERNY 2015, pp. 171-172, figs. 55 b-c). The walls are made of a single row of bricks positioned along their length and the floor is made of compact clay. There are also the two large vaulted cellars in House H84 on Elephantine, functioning as adjacent rooms on the building's ground floor (VON PILGRIM 1996, pp. 85-96, 214).

3.8 Cupboards, bins and niches

Main features:

- **Environment:** Hybrid
- **Storage life:** Short- to long-term (depending on container and product)
- **Contents:** Wide variety of packaged foodstuffs

Several additional storage areas have been discovered in ancient Egyptian and Nubian houses. They may have been used to store foodstuffs or small valuables. However, this category covers a variety of containers and needs further refinement.

A cupboard was a small room under the stairs which individuals could enter, standing or otherwise. In some houses in the workers' village of Tell el-Amarna, cupboards under staircases were used to store the chopped straw and grain required to feed animals (WOOLLEY 1922, p. 55). Similar features were also found in the Walled Village (EL-SAIDI, CORNWELL 1986, pp. 16-19, fig. 1.12), at Askut (BADAWI 1964, pl. XIVb), and at Tell el-Herr (MARCHI 2014, p. 45, n. 180).

A niche was usually small in size and located under the stairs or in the wall of a room where things could be stored. Niches under staircases were discovered on Elephantine, in the Middle Kingdom settlement, in house H70 (VON PILGRIM 1996, fig. 48, pls. 21d, 23c), and at Amara West (FAIRMAN 1948, p. 5, pl. III.1). In Tell el-Herr, niches are built in a variety of locations and come in various shapes: semicircular, trapezoidal, and rectangular (MARCHI 2014, p. 58). They measure between 30 and 40 cm in depth, with heights of 30 to 40 cm and widths of 40 to 70 cm, depending on shape. The niche in Unit 19 contained two complete

jars, and the one found in house 80 held an oil lamp. While niches' storage role has been established it is also possible that, in some cases, these small spaces were used for domestic cults (STEVENS 2003, pp. 152-153).

Bins are another type of receptacle found in Egyptian and Nubian houses. They are quadrangular, usually made of mud-bricks and often raised on stone slabs. On Elephantine, houses H69, H86, and H84 have yielded the remains of several semi-underground bins (VON PILGRIM 1996, p. 214). In house H86, two bins (0231 and 0215) were made with mud-bricks laid on the edge (VON PILGRIM 1996, p. 80, pl. 11b). Sandstone slabs are still visible at the base of bin 0215 and on the corners of bin 0231. In house H69, a mud-brick bin (060) still has an internal wall dividing it into two compartments. Archaeologists found several pieces of pottery under the layer of bricks left by the structure's collapse (VON PILGRIM 1996, p. 131). Finally, in house H84, bin 0221 was buried one metre deep and had plaster-coated walls. The discovery of remnants of grain along with pieces of cloth, interpreted by Cornelius von Pilgrim as grain sacks, confirms that bins could be used as storage places for packaged grain (VON PILGRIM 1996, p. 93, figs. 24-25). This type of construction is reminiscent of the discoveries made at Tell el-Amarna in the Main City (KEMP 2012, pp. 214-216). These underground plaster-coated brick receptacles were used to store various things, including grain. Bins were present in different rooms, including living rooms, and may therefore be considered as hiding places.

At Amara West, five storage bins arranged in an L-shape were found in the courtyard of house E.12.10 dating from the Ramesside period (N. SPENCER 2009, pp. 52-53, fig. 4, pl. 11, colour plate XVIII). They were raised above the floor by schist slabs on the sides, and another flat slab was used to create the base (fig. 6). The walls were made of mud-bricks coated with plaster. According to N. Spencer, these bins were used to store grain. Several sets of bins were also discovered near the temple (P. SPENCER 1997, pp. 89-91, pl. 73a). The bins from sector E.14.5 were rectangular, built of mud-bricks on stone foundations, with vent holes still visible on two of them. The most easterly receptacle has a round vent hole measuring 17 cm in diameter, and the westerly one has a rectangular opening of 27 x 20 cm, located 10 cm above its base.

These containers should be identified with caution as some of them may have been used for food processing (MOELLER 2016, p. 135), and in particular for activities requiring large vats, such as malting.



Figure 6. Bins in courtyard of Amara West villa E12.10. © Amara West Research Project/Neal Spencer. Courtesy of the Trustees of the British Museum.

3.9 *Thēsauroi*

Main features:

- **Environment:** Mixed storage (coexistence of different conservation methods: GERACI, MARIN 2016, pp. 108-115, airtight, ventilated, and hybrid environments)
- **Storage life:** Medium- and long-term
- **Contents:** Bulk and packaged foodstuffs

In the Greco-Roman Period, crops from rural areas were usually stored in large, sometimes multi-storey mud-brick buildings¹⁰ located in the main neighbouring settlements. Such storage facilities are usually referred to as “granaries” in the literature, while Greek papyri from Egypt call them *thēsauroi* (GERACI 2008, pp. 311-312). To avoid any confusion with granaries devoted to storage of cereals alone and with the very specific characteristics described earlier (§ 2), we will refer to these Greco-Roman storage complexes by their Greek name. As public establishments,

¹⁰ Evidence from Tebtynis indicates that *thēsauroi* could have been single-storeyed in the Ptolemaic period (see G. Hadji-Minaglou’s contribution in this volume) and that their transformation into multi-storey buildings took place later, in the Roman period.

thēsauroi centralised harvested products destined for Alexandria and (then) Rome, but were sometimes managed by private individuals who rented them (L. ROSSI 2019, p. 67). Geoffrey Rickman (1971, pp. 298-299) highlighted the differences between Egyptian *thēsauroi* and the *horrea* in the rest of the Roman Empire, and assumed that the particularities that distinguished *thēsauroi* had their origins in Pharaonic Egypt’s storage traditions. This interpretation has since been challenged (GERACI 2008, p. 310).

Several remarkably well preserved examples have been discovered in the Fayum at Tebtynis (HADJI-MINAGLOU in this volume), Bakchias (TASSINARI 2007; TASSINARI 2009), Karanis (BOAK, PETERSON 1931; HUSSELMAN 1952; HUSSELMAN 1979, pp. 56-62; CAPPERS *et al.* 2013, pp. 44-45; CLAYTOR, VERHOOGT 2018, pp. 9-28), Kasr el-Banat (Euhemeria: HUSSELMAN 1952, p. 66), and more recently in the Egyptian Delta, at Buto (MAZOU in this volume).

Despite the architectural remains’ good state of conservation, especially at Tebtynis and Karanis (fig. 7), many of the storage methods’ technical aspects remain unclear. As has already been emphasized (GERACI 2008, p. 310), the architectural variety of storage spaces in Greco-Roman *thēsauroi* suggests that they were multifunctional buildings where different methods of conservation

(airtight, ventilated, packaged and unpackaged goods), temporalities (probably medium- and long-term storage: L. ROSSI 2019, p. 66) and kinds of foodstuffs would have coexisted along with bread production (presence of stone mills and ovens in the courtyards).

Since Husselman's first contribution on Karanis' *thēsauroi* (1952), two main storage areas have been distinguished in these buildings: 1) rectangular vaulted storerooms with square underground bins¹¹ and 2) open or partially open square bins arranged in rows. In both cases the bins, whose floor level was between 1 m (Granary C65 in Karanis: HUSSELMAN 1979, p. 59) and 2 m (HADJI-MINAGLOU in this volume) below the corridors' floor level, were formed by thin cross walls between 1 m (Karanis) and 2 m (Tebtynis) high. It is generally assumed that people could walk on the top of them and get down into the bins using the footholds set at regular intervals on both sides of the walls (HUSSELMAN 1952, p. 59; HUSSELMAN 1979, pl. 22; HADJI-MINAGLOU in this volume; for additional examples from Karanis: BOEK, PETERSON 1931, pp. 18, 22; CLAYTOR, VERHOOGT 2018, p. 13, fig. 4). According to Husselman (1952, p. 72), the difference between the two areas depended on different storage temporalities (closed vaulted rooms with bins for long-term storage and open bins for short-term storage). It is interesting to note that both types are present in the Ptolemaic *thēsauros* of Tebtynis, meaning that this kind of building was already operating in this way in the 2nd century BCE.

Two more kinds of storage areas must be added to the list: individual vaulted underground storerooms located under corridors (for Tebtynis, see HADJI-MINAGLOU in this volume; for Karanis: HUSSELMAN 1952, p. 62) and courtyard floors (HUSSELMAN 1952, pp. 61-62 and fig. 3; HUSSELMAN 1979, pp. 56-62) and provided with trapdoors. For the latter, archaeobotanical evidence showed that, in a storage building (possibly a *thēsauros*) in Karanis East (4th-6th centuries CE), these underground chambers had been used to store safflower seeds (CAPPERS *et al.* 2013, p. 44). However, it is impossible to say whether they were kept in an airtight or ventilated environment (§ 2).

Due to the data currently available, technical examination of these four kinds of storage areas would be unsatisfactory, and more direct observations and analysis seem necessary in order, for example, to know whether seeds and grain were stored packaged or unpackaged (GERACI 2008, p. 322). In the meantime, the following observations may help to characterise them better.

The first question concerns their ventilation (and lighting). As regards vaulted rooms with bins, the excellent state of the Karanis buildings' conservation shows that

thēsauros C65's northern rooms on the second floor were provided with small windows with sloping sills, set in the upper part of the north rear walls (BOAK, PETERSON 1931, pp. 55-56, pl. XXX, fig. 59; HUSSELMAN 1979, plans 20-21). Furthermore, in *thēsauros* C123's southern vaulted rooms CCF-CCJ, a number of windows were preserved in the south rear wall (HUSSELMAN 1952, p. 60, fig. 2; HUSSELMAN 1979, p. 57). Small openings seem to have existed in the northern row's rooms as well since a "slitted window" was found in room CCI (north wall; CLAYTOR, VERHOOGT 2018, p. 124; HUSSELMAN 1979, pls. 66a, 97b). This is a crucial feature, proving that ventilation and some light were ensured in at least some of these rooms, influencing their thermal and hygrometric performances. Furthermore, if these rooms were ventilated, as seems to be the case, bulk cereals could have been stored in them if they were shovelled regularly, with the rooms acting as granaries. If so, it should be stressed that not all the bins would have been filled, as some of them would probably have been left empty (at least partly) for the necessary shovelling (GERACI, MARIN 2016, pp. 89-90, figs. 2-3). As regards rectangular storerooms, however, it remains uncertain what measures were taken to protect cereals against insects and pests. The vaulted underground storerooms located under corridor and courtyard floors did not receive any light or ventilation from the outside, as they were closed by a trapdoor and, as previously stated, it is uncertain whether or not they were airtight. In contrast, the open or partially open bins pose a regularly evoked problem (for example, TASSINARI 2009, p. 25; HADJI-MINAGLOU in this volume) because of the crops' exposure to pests, rodents, and birds. Husselman's (1952, pp. 71-72) explanation of *thēsauroi* operation (different storage systems to meet different needs), even though well grounded, does not clarify the storage method used in this part of the buildings. The existence of some kind of cover consisting of wooden planks or reed mats has been assumed (CLAYTOR, VERHOOGT 2018, pp. 20, 23), even though no archaeological traces of such devices have been found during excavations.

Another interesting issue raised by Husselman (1952, p. 71) concerns the ratio, in vaulted rooms containing bins, between space devoted to storage (in the bins) and empty space (between the tops of the bins and the vault), which appears to be out of proportion to the disadvantage of the former. Nevertheless, it may be assumed that this volumetric choice was intended to create enough space above the stored cereals where warm air could rise and be evacuated through the vault and (possibly) the openings in the upper parts of the walls (FATHY 1986, p. 50). Finally, the bins in the vaulted storerooms may have been covered with a (wooden?) floor. Boak and Peterson (1931, pp. 22-23) considered this possibility for one of the buildings in Karanis. Nevertheless, no evidence was found during the excavation, nor has any additional data

11 In the Ptolemaic *thēsauros* of Tebtynis, some of the rectangular rooms had no bins and a narrow, axial flight of steps led down to the magazine: HADJI-MINAGLOU in this volume, fig. 5, nos. 4-5.

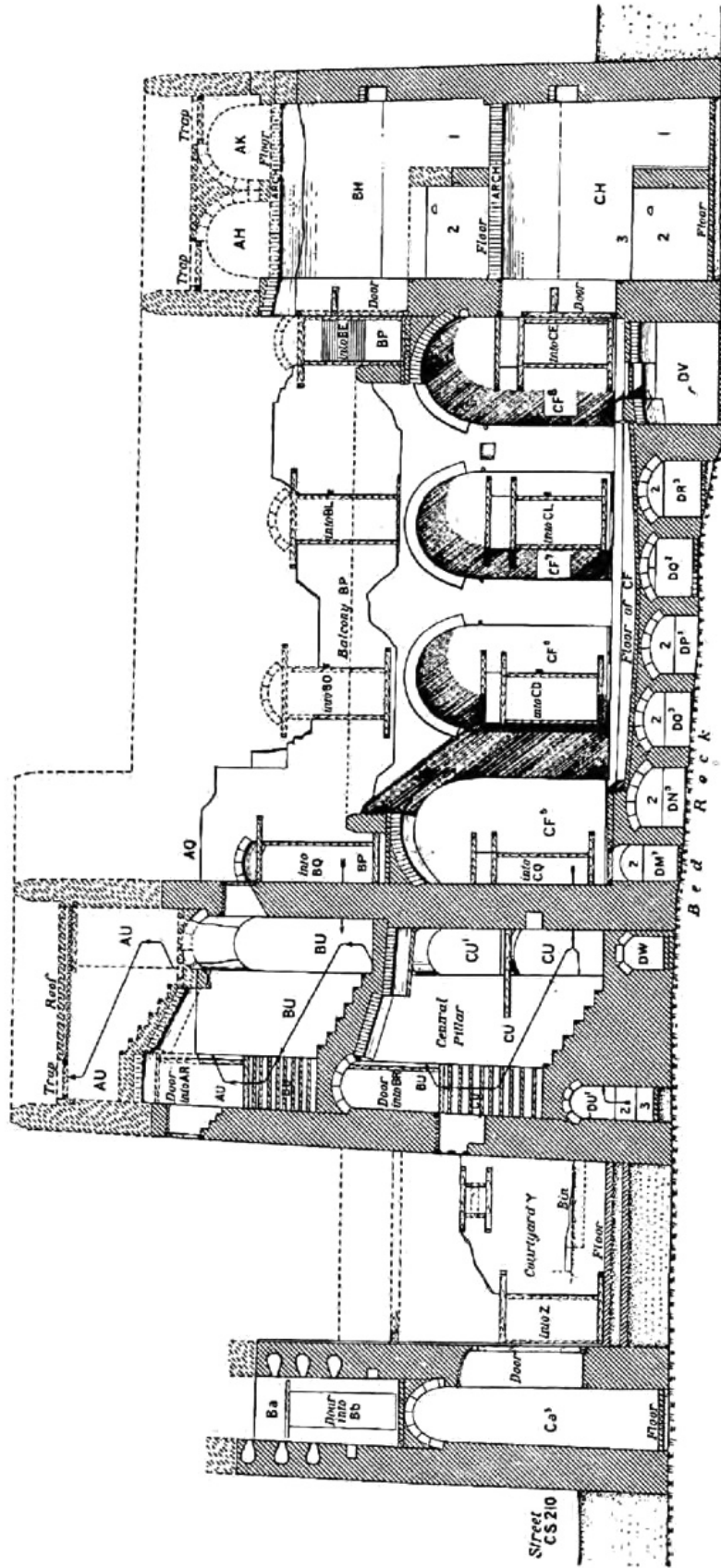


Figure 7. Thésaurus C65 of Karanis. E.M. Husselman, *Karanis Excavations of the University of Michigan in Egypt, 1928-1935. Topography and Architecture*, KMAS 5, Ann Arbor, 1979, plan 21 (Courtesy of University of Michigan Press).

Type of container	Advantages	Disadvantages	Summary
Sealed jar	<ul style="list-style-type: none"> • Airtight, so good protection against pests • Long distance transport • Durability • Bulk goods and liquids 	<ul style="list-style-type: none"> • Limited accessibility (airtight) • Limited quantities • Heavy container • Storage that requires accessories (jar stand) or adequate arrangement 	<ul style="list-style-type: none"> • Preferred storage method for transport and/or storage of liquids • Ceramic makes the transport load heavy but provides good protection against pests
Unsealed jar	<ul style="list-style-type: none"> • Accessibility • Proper protection against pests if there is a cover • Bulk goods and liquids 	<ul style="list-style-type: none"> • Not airtight, but food can be protected by a lid • Limited quantities • Heavy container 	<ul style="list-style-type: none"> • Short- or medium-term storage, depending on the product concerned. • It enables storage of small amounts of food while keeping it accessible
Bags	<ul style="list-style-type: none"> • Accessibility • Lightweight container • Transport • Easier storage if bags are of similar size 	<ul style="list-style-type: none"> • Limited quantities • Little protection against pests • Requires building accommodation • Need to turn the bags over regularly to evacuate gases if grain is stored 	<ul style="list-style-type: none"> • Storing grain in bags facilitates handling but does not enable long-term storage. • Bags must not be stored directly on the floor or against walls in order to prevent damage
Baskets	<ul style="list-style-type: none"> • Accessibility • Lightweight container • Transport possible if the goods are not in bulk 	<ul style="list-style-type: none"> • Limited quantities • Little protection against pests • Requires adequate storage space 	<ul style="list-style-type: none"> • Short- or medium-term storage, depending on the product concerned. • Must be kept away from pests in bins or niches

Table 2. Features of different kinds of containers.

supporting this hypothesis been collected in more recent archaeological work.

To conclude this overview of Egyptian *thēsauroi*, we should mention the attempts made to identify the various components of these storage facilities referred to in the written sources based on the archaeological evidence. According to several Greek papyri from Egypt (GERACI 2008, pp. 308-310; MAZOU *et al.* 2019, p. 239) a *thēsauros* usually includes the following features:

- The *aulē*, the courtyard: apart from the Ptolemaic *thēsauros* of Tebtynis (HADJI-MINAGLOU in this volume), which is the earliest one, in all the other (and later) buildings known in Buto (see L. Mazou's contribution in this volume), Karanis, and Bakchias, this is one of the plan's main features. It provides access to the rows of vaulted storerooms as well as space for various production activities. Bakeries are documented by the many millstones, millstone bases and ovens discovered in the courtyards of the *thēsauroi* of Karanis (HUSSELMAN 1952, p. 68).
- The *tamia* (HUSSON 1983, pp. 275-276; GERACI 2008, p. 316): they have been related to the vaulted rooms with bins in the *thēsauroi* of Karanis (HUSSELMAN 1952, pp. 66-67; CLAYTOR, VERHOOGT 2018, p. 20) and, more recently, to the bins themselves by Lucia Rossi (2019, pp. 59-60 and in MAZOU *et al.* 2019, p. 239) who identifies the vaulted rooms with the *apothēkai*. According to the written sources, *tamia* were usually located on the ground floor, arranged in rows, closed with a door and sealed.
- *Noubasi* corresponding to some kind of depot (HUSSON 1975, pp. 212-214; HUSSON 1983, p. 178).
- *Siroi* which were underground bins or pits for storage of all kinds of dry seeds and grains (GERACI 2008, pp. 309, 320-321; for lentils stored in the *thēsauroi* see

L. Rossi 2019, pp. 64-65) identified by Husselman (1952, p. 67) with the underground rooms located under the *thēsauroi* courtyards and corridors, while Claytor and Verhoogt (2018, p. 20) identify them with the bins in the vaulted rooms.

- One or more *purgos*, i.e. towers, several examples of which are known from the *thēsauroi* in Karanis.

This overview illustrates the complexity of *thēsauroi* operation and the difficulty in characterising it. The subject is therefore one of the *Storage in Ancient Egypt and Sudan Research Group's* priority focuses, and will be addressed in the near future during a scientific meeting devoted to this subject.

3.10 Excursus: other containers stored in buildings, rooms and recesses (table 2).

When foodstuffs were not stored in bulk, in a silo or granary, they were put in a short- or medium-term storage building, a room, or in units such as niches and bins. Containers could be of various shapes and sizes and, as they could be made of different raw materials (plant fibres, wood, clay, etc.), their degree of conservation (and subsequent visibility in the archaeological record) can vary (PEÑA-CHOCARRO *et al.* 2015, pp. 385-386). Ceramic vessels – usually closed forms, mostly jars – tend to be the best preserved evidence, while leather bags, basketry, and wooden boxes are rarely conserved (their imprints are sometimes preserved on mud floors).

Sealed jars

Sealed storage jars might contain several types of foodstuffs, either liquid or in bulk. Such jars were multi-purpose as those with low porosity could be used to stock different products in succession, as needs dictated (RZEUSKA 2007; DEFERNEZ, MARCHAND 2016; SCHAUB 1996).

Because they were securely sealed, their contents were protected from pests, they could be moved without risk of overflowing and could be transported over long distances. They were very common in ancient Egypt and Nubia. However, a distinction should be made between oval and flat-bottomed jars: whether or not they could be set on the ground without toppling over indicates their use.¹² Storage in sealed jars was for short-, medium- or long-term conservation alike. The system was especially useful for transport. Storage life was flexible, depending on needs and what foodstuffs were stored. For example, sealed containers were often used to store liquids, even over the short term.

Unsealed jars

Several kinds of ceramics for short-term storage of foodstuffs can be included in this category, which covers a range of shapes with variously sized mouths, with or without lids. The lids provided limited but recurrent access to the contents, which were probably liquids or semi-processed products such as flour. Although archaeologists have identified very few cloth or wickerwork lids, the ceramic lids unearthed testify to practices of this kind. A distinction should be made between small-diameter stoppers and lids 20 or more centimetres in diameter. Wide-mouthed jars with lids were used to store products to which recurrent access was required, such as various kinds of raw or processed grain. They were hybrid-environment containers: every time they were opened, air got in. However, their thick ceramic walls provided good protection against pests (insects and rodents). Narrow- and wide-necked jars were storage ceramics for use in the home, probably in chests or cellars. However, narrow-necked jars could play a dual role: for transport (if they were well sealed) and storage alike. If their narrow bases made it impossible for them to be stored upright, jar supports or pits could hold them, or they could be propped up against a wall when a number of them were stored in a room.

Storage in unsealed jars enabled preservation of food in a hybrid environment: their walls provided ample protection against pests. If a lid (made of fabric, leather or ceramic) was used, protection was reinforced depending on the hardness of the material it was made of. Storage of grain in unsealed ceramics closed with a lid seems to have been unusual in ancient Egypt, although it would be interesting to examine the larger vats further in this respect. This mode of storage is technically similar to Greek *pithoi* (CHRISTAKIS 2005; ZURBACH 2017).

12 Features such as cavities or jar supports may also have facilitated storage, see, for instance, the examples from Balat/Ayn Asil § 3.5).

Bags and Baskets

Storing cereals and pulses in bags or baskets was a short-term measure, even when the bags were placed on a floor with ventilation from underneath. Cereals packaged in such a way could heat up quickly as they could not be shovelled regularly, and pests could penetrate the bags and degrade the grain (insect infestation, rodent droppings and holes in bags). However, various techniques were implemented to reduce losses, and where storage was necessary it was advisable to arrange the bags horizontally on a pallet (or other system enabling ventilation from underneath) and away from walls (GERACI, MARIN 2016, fig. 1). With such an arrangement, there was much less storage space available than for bulk storage. The advantage of bags was that they made grain easier to handle. Smaller baskets could be placed in storage bins or cellars, which helped protect foodstuffs. The use of baskets for storage of cereals appears to have been more problematic due to the grain's fineness. Baskets were therefore more commonly used for other kinds of foodstuffs such as bread, fruit and vegetables. Nevertheless, short-term storage of grain in baskets was possible, especially if a cloth was placed inside to prevent the grain from escaping. Storage in bags and baskets was for short-term conservation in a hybrid environment.

To conclude, a great many storage systems are known to have existed in the northern Nile Valley during the Bronze and Iron Ages and up until the Greco-Roman Period. Therefore, when analysing food storage capacities and patterns, we need to consider all the possibilities available, not just the buildings. For food storage, grain storage in particular, a wide range of possibilities is known to have existed, as is shown in fig. 8.

Any analysis of archaeological remains should start with consideration of the "assemblage" of storage systems taking its cue from the notion of "ceramic assemblage". By taking account of all the storage facilities available to a social group, it becomes possible to introduce temporality into stock management. This means that the silo was not a household's only food reserve, as it could not be opened daily. Daily food supply depended on other reserves in the living area itself: bins, cupboards, perhaps some upstairs rooms, and domestic annexes. The chronological opening of the various storage facilities, in accordance with conservation or social imperatives, is documented by ethnography (SEIGNOBOS 2005, pp. 107-110).

4. Building materials and techniques

Earth was used as a building material in mud-brick, mortar and plaster production as well as for cob masonry. In all these cases, it had been mixed with water and usually tempered with vegetable matter (straw and chaff) and sometimes with mineral aggregates such as sand. Proportions of the different ingredients in the mix vary depending on the quality of the soils used and

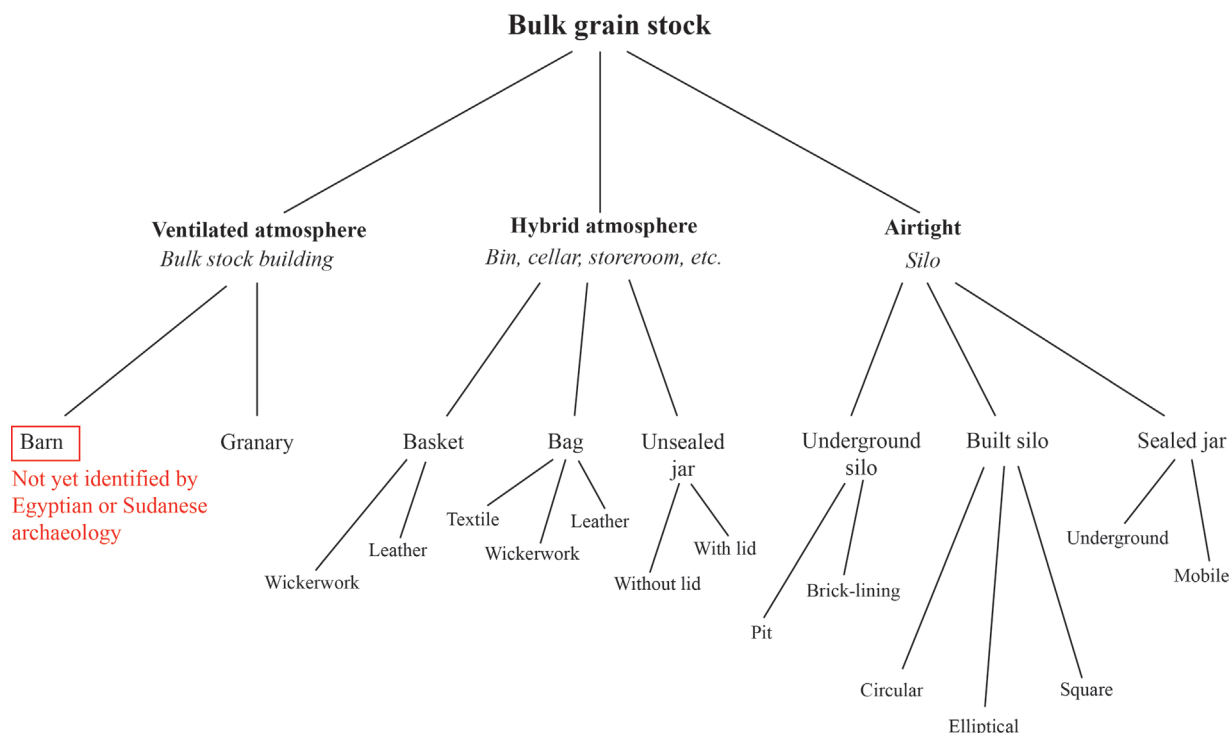


Figure 8. Summary diagram of grain storage systems attested by texts and archaeology in ancient Egypt and Nubia.

the techniques employed. Water content in the mix for cob is usually between 15 and 20% and around 33% for mud-brick moulding (DOAT *et al.* 1985, pp. 95, 112). Variations may depend on the quality of the soil used and the tempering agents.

In earthen storage buildings stone (mostly sandstone and schist) has been used much less often, generally for particular architectural elements mentioned in § 4.4.

4.1 Mud-bricks

Ancient Egyptian moulded rectangular mud-bricks (*db.t*, *Wb* V, 553.7-554.18) are made of a mix of sand, silt, clay, and water, mostly tempered with chopped straw and chaff. The presence of ashes, charcoal, bones, potsherds and small artefacts often observed can result from an intentional or accidental addition (KEMP 2000, p. 82). The brick sand-silt-clay ratio can vary from one site to another or even in the same building or feature. However, particle-size analysis run on soil samples collected from several archaeological sites (Hierakonpolis: DICKINSON 2014; East-Karnak: FRENCH 1981; Tell el-Amarna: FRENCH 1984, pp. 193-194, table 14.2; Tell el-Retaba: TRZCIŃSKI *et al.* 2016, p. 52, fig. 11 and ZAREMBA *et al.* 2017, pp. 114-115, fig. 7; Tell Timai: LORENZON *et al.* 2020, p. 122, table 2) shows that ancient mud-bricks usually have a high content of sand (no less than 50%, mostly between 60 and 70%: KEMP 2000, pp. 80-82 and fig. 3.1. For bricks with a lower sand content, see DICKINSON 2012), with the medium to very fine sand fraction often being predominant on gravel and

coarse sand ones (e.g. FRENCH 1981, p. 275; FRENCH 1984, pp. 192-193, 195, 200). Adding of vegetal matter to the mixture has several advantages since it reduces shrinkage and limits cracking, speeds up the drying process, reduces the brick density, improves its insulation properties, and increases its tensile strength (HOUBEN, GUILLAUD 2006, pp. 88-89). Accordingly, fibres appear to be the favourite temper of ancient Egyptian brick-makers, even if, to a lesser extent, sand-tempered mud-bricks of good quality are also known (MILLET in this volume), the sand having similar properties as a temper (KEMP 2000, p. 82). Alluvial sediments seem to have been preferred by the brickmakers, but depending on the local environment and the available resources desert marls could also have been employed (V. EMERY 2011, p. 2; KEMP 2000, pp. 79-83).

The use of straw in brick-making is often mentioned in Egyptian written sources. For instance, in Papyrus Reisner III, straw (*dh3*, *Wb* V 481.1-7) for bricks is transported in bags by boat (SIMPSON 1969, p. 25, pl. 12, l. 25-18). In Papyrus Anastasi IV, a complaint about the unavailability of straw for brick production (pAnastasi IV, 12.5-12.6: GARDINER 1937, p. 48; CAMINOS 1954, p. 188) echoes the Old Testament passage recounting of the Israelite obliged to make bricks without straw being delivered by the Pharaonic administration (Exodus 5:6-19; NIMS 1950; KITCHEN 1976).

Once the wanted volumes of sediment(s) were carried into the manufacturing area and the biggest lumps were broken up with a hoe, water was added, and the mix

was kneaded along with chopped straw and chaff. Plant tempering material included mainly by-products of the different processing stages of cereals often crushed before their use (CAPPERS *et al.* 2016, p. 1123). To a lesser extent, unintentionally added seeds and fruits, cereal field weeds, and any other botanical material present in the proximity of the crop-processing or the mud-brick production areas are also well documented (HENDRICKX *et al.* 2010, pp. 164-165; POKORNÁ, BENEŠ 2014).

Compared with vernacular traditions of Egyptian brick-making, the mixture made of sediment(s), water, and vegetal matter was probably left to ferment for at least a day or two (V. EMERY 2009, p. 2). As a matter of fact, polysaccharides contained in plant material consolidate the earthen mix by creating a microscopic framework between the different mineral particles. Nevertheless, to transform them into a good stabiliser and binding agent, fermentation in water is needed to separate the elementary cellulose fibres from the cell wall (VISSAC *et al.* 2017, pp. 14-15, 18; VISSAC *et al.* 2018).

Similarly, dung was also sometimes added to the mix (see, for instance, HENDRICKX *et al.* 2010, pp. 164-166 and table 3). As a matter of fact, animal excrements contain vegetal matter coming from pasture and fodder plants. Being partially digested and decomposed, these plant fibres are, therefore, smaller than chaff and chopped straw. Along with the latter, they ensure a good variety in cellulose fibre size distribution going down until the macromolecule level. Accordingly, the framework they create effectively links all the mineral particles of different sizes, from the grain of sand to the clay platelets (VISSAC *et al.* 2017, p. 16). In Egyptian vernacular traditions donkey dung is also used as a good waterproofing additive for mud bricks and earthen roofs (NIMS 1950, p. 27).

A recently published ostrakon from the Temple of Millions of Years of Tuthmose III reports three recipes of what has been assumed to be mud-bricks (HAGEN 2021, pp. 6, 35, pl. 43, T3.A56). The text mentions two kinds of soils: *sjn* (*Wb* IV, 37.11-38.2) and *nms*, straw (*dh3*), and sand (*šj*, *Wb* IV, 419.23-420.9). There is no mention of water, meaning that the brick-maker did not need this information, probably as having an empirical understanding of the water quantity required to get a suitable mix for moulding. All the amounts are expressed in fractions of a volume whose identity is not specified (a woven basket?). According to J.R. Harris, the *sjn*-soil has to be matched with Marl clays (HARRIS 1961, p. 203). However, *nms*-soil seems to be an *apax* for an unidentified kind of sediment. Bricks made of soils taken from different sources are often observed in archaeological excavations, even if rarely characterised by material analysis. However, evidence of this practice is also attested in a later Greek papyrus mentioning the use of two different soil sources for brick production in the Fayum (NOWICKA 1969, p. 28, n. 2).

Once the fermentation ended, the mixture was kneaded again by adding water until the desired texture for moulding was obtained. Likely, the moulding process did not differ much from the practices documented in recent times (for a summary, see: V. EMERY 2011, p. 3) and illustrated in the well-known scenes from New Kingdom Rekhmire's tomb (TT 100; BADAWY 1956, pp. 64-65; V. EMERY 2011, p. 5).

Apart from models uncovered in foundation deposits, a wooden mould (*ht-db.t*), dating back to the XIIth Dynasty and likely used in brick production, was discovered by W.M.Fl. Petrie at El-Lahun (Manchester Museum inv. 51; internal dimensions: 28.8 x 14.6 cm; ht. 8.4 cm; PETRIE 1890, p. 26, pl. IX, no 23; A. GRIFFITH 1910, p. 13, no 51). The resemblance with contemporary Egyptian wooden moulds is noteworthy and reveals the persistence of practices over time. In both cases, they are single, rectangular moulds with a sole handle located in the extension of one of the long sides (usually the right one for right-handed brick-makers). The only detail which differs is how the wooden pieces are assembled: with tenons and mortises for the old mould and with metal nails in contemporary specimens.

4.2 Cob

Cob has been regarded as the oldest earthen architecture technique (AURENCHE *et al.* 2011, pp. 19-20) and is still used today in Sudan, where it is called *jalous*. Cob archaeological masonries are often difficult to recognise during excavation, but some remains have been identified in the Kerma granaries in Gism el-Arba (§ 3.3). To our knowledge, no macroscopic characterisation of archaeological cob masonries from Sudan exists in the scientific literature. The following description of the building material and technique is therefore based on personal observations made by Nadia Licitra during construction of the wall surrounding the Dukki Gel archaeological concession in January and December 2021.

The term cob refers to a stacked earth building technique in which earth lumps are piled up without formwork to build a wall. Several variants have been identified and the traditional Sudanese technique can be compared with the method involving hand-stacked cob units (KNOLL *et al.* 2019, pp. 13-14, 17). A mix of earth and water is prepared, tempered with straw to improve its cohesion and tensile strength (HOUBEN, GUILLAUD 2006, pp. 176-177). The mix is then kneaded with the feet and sometimes left to stand for a few hours or more. It is then transported to the construction site in wheelbarrows and unloaded in piles – each equivalent to the wheelbarrow's full volume – along the location of the wall to be erected. One cob-maker works near the piles, shaping packed earth lumps with his hands and rolling them in the dust before passing or throwing them (depending on the distance between them) to a second cob-maker. The

latter, working backwards, piles up the lumps and shapes them with his fingers. From times to time, he evens the wall's two vertical faces with his hands or a stick. Once a layer of several dozen centimetres has been raised this way, the following is stacked on top. When the wall is finished, the individual lumps are no longer visible: only the lines between the layers, covered with cracks, can be distinguished.

4.3 Mortars and plasters

Mud mortar is a building material quickly hardening during drying (BESEVAL 1984, p. 22) and used to bind together mud-bricks (AURENCHÉ 1977, p. 118). It is usually made of soil mixed with water, mineral aggregates such as coarse and fine sand and/or organic matter like straw (WINKELS 2022, p. 234, n. 1). In some cases, we have observed the presence of small amounts of gravel and/or potsherds. In ancient Egyptian architecture mortar was extensively used between courses and horizontal joints were usually well laid down. Vertical joints, on the contrary, were often very thin and devoid of mortar (KEMP 2000, pp. 89, 92 and fig. 3.4a).

On the other hand, mud plaster is a building material similar to mud mortar in composition but includes only fine sand among the mineral aggregates. It could be applied on walls, floors, and roofs of earthen buildings at the time of construction and was regularly reapplied later for maintenance. There is no significant evidence in the scientific literature for surface treatments applied to cob masonries (for granaries, see § 3.3), while the mud-brick walls of most of the storage buildings referred to in the provisional typology (§ 3) were treated in a similar way. The first layers (levelling coat), usually thicker and coarser, evened out the masonry surfaces, while the last ones (finishing plaster) were thinner and almost liquid when applied (AURENCHÉ 1977, pp. 80-81; WINKELS 2022, p. 234, n. 1).

Archaeological reports rarely describe earthen mortars and plasters, and it is often uncertain if they are made of alluvial or desert clay (WINKELS 2022, pp. 238-244), while the presence of white (likely gypsum) plaster is rarely recorded (see, for instance, N. SPENCER 2014, p. 35 and FRANKFORT, PENDLEBURY 1933, p. 72, pl. XXV.1).

As in numerous vernacular traditions, it is likely that, at least for plasters, some additional organic additives, such as vegetal juices and oils, animal fats, resins, etc. were used to improve their qualities (VISSAC *et al.* 2017; see also MAYOR, PELMOINE in this volume for the use of *cissus populnea's* sap in plaster recipes). In this regard, material analysis carried out to identify the presence of such additives – more particularly, the potential adding of donkey dung for its waterproofing properties mentioned above (§ 4.1) – would be essential to move forward with a more precise knowledge of ancient recipes.

Layers of plaster and other coatings were essential to ensure a building's good thermal and hygrometric performances. This was especially true for storage facilities, which required special precautions in order to keep foodstuffs in a cool, dry environment. In this respect, the importance of keeping wall plasters in good condition is mentioned in two papyri from the Greco-Roman Period. In the contract of P. Lon. II, 216 (94 BCE) from Soknopaiou Nesos for sub-lease of a *thēsauros*, the tenant is responsible for maintenance of wall plasters and their waterproofing, along with the proper conservation of foodstuffs (GERACI 2008, p. 308; HUSSELMAN 1952, pp. 66-67). P. Mich. V, 226 (37 BCE) from Tebtynis also relates of a *thēsauros* which could not be used after the end of its lease because it was no longer provided with doors or wall plasters (GERACI 2008, p. 310; HUSSELMAN 1952, p. 67).

Although Greek and Latin authors describe several surface treatments recommended for storage facilities (GERACI, MARIN 2016, pp. 102-103, n. 77), no written source records methods and substances used in ancient Egypt and Nubia and we can only rely on archaeological remains. Material analysis can be very informative in identifying additives and substances used to improve plaster's qualities (VISSAC *et al.* 2017). However, to our knowledge, no samples from storage facilities have yet been analysed. This is a promising field well worth investigating.

Two specific archaeological contexts are worth mentioning in greater detail.

The first is the floor of magazines M12 and M14 of sector SAF5 on Sai Island, which is made of irregular slabs of schist *liées au plâtre* (AZIM 1975, p. 113; the latter is elsewhere described as "lime mortar": ADENSTEDT 2016, p. 42). Judging from the pictures taken following the excavation, such mortar was extensively used and largely covered the stone slabs (AZIM 1975, pls. X, XII). Because no material analysis has been carried out, it is impossible to say whether it is a gypsum- or a lime-based coating, although the former is more likely. Gypsum and gypsum-lime mortars and plasters were used throughout the Pharaonic period (WINKELS 2022, pp. 245-250), whereas lime-based mortars and plasters were employed more sporadically and for very specific architectural features before the Ptolemaic period, during which their use became more widespread (WINKELS 2022, pp. 250-254; GOYON *et al.* 2004, p. 70).

On the other hand, although earthen plaster usually covered the walls of storage rooms in Greco-Roman *thēsauroi* (for examples, see BOEK, PETERSON 1931, p. 29; TASSINARI 2009, p. 25), in the buildings in Karanis the yellowish plaster commonly used was coated - especially in the underground bins - with a black wash (made of ash?) whose composition is unknown (BOEK, PETERSON 1931, p. 29; HUSSELMAN 1952, pp. 60, 67). A similar coating has been observed on the walls of building BNE 231 in Bakchias, which also seems to have been used to store cereals (TASSINARI 2009, p. 43).

4.4 Stone

Stone architectural elements are often found in storage facilities and are associated with specific parts of buildings. In Nubian tradition granaries (§ 3.3), alignments of sandstone blocks are used to support the raised floor, while some rectangular storerooms (§ 3.5.2) and other storage facilities (B. REDON in this volume) have stone floors made of sandstone or schist slabs whose function, as previously stated, cannot yet be explained satisfactorily.

Schist slabs laid on their sides supported shaped-earth storage bins in Amara West (§ 3.8).

Stone was also used quite regularly for rectangular storerooms' thresholds and doorframes (for example, see GHAZOULI 1964, pp. 145-155; CEDAE 1976, p. 82; LICITRA 2018, p. 50, fig. 9), in some cases inscribed with royal titles.

5. Research perspectives

The general overview provided in the previous chapters shows how rich and complex the subject is. During exchanges with members of the *Storage in Ancient Egypt and Sudan Research Group*, its study's priorities soon became clear.

First of all, the vocabulary used by historians and archaeologists needs to be standardised with buildings designated by terms reflecting their functions and kinds of storage methods employed. In this regard, the terms “silo” and “granary” should always be used to distinguish the kind of storage strategy used (airtight, hybrid or ventilated environment, see § 2). The architectural vocabulary used in archaeological descriptions must also be standardised. As far as building materials are concerned, special attention must be paid to the distinction between cob and wattle-and-daub, modelled and moulded mud-bricks, and to their characterisation - even if only at macroscopic level - along with description of mortars and plasters. Similarly, features and building techniques should be recorded in such a way as to prepare for interpretation of kinds of storage temporality and strategy, stored products, agronomic methods, etc. With this in view, the Research Group has drafted a “recording sheet” (see Appendix 1), which is not intended to replace the locus / stratigraphic unit record form, but rather to complement it and prepare for subsequent socioeconomic analysis. The sheet provided in Appendix 1 will evolve to take account of feedback received by its users, while data produced will be recorded in a shared database with a view to producing crosscutting and thematic studies.

Secondly, ethnographic and ethnoarchaeological comparisons need to be further exploited as they are a fruitful line of research for better understand of building practices, storage strategies and possible volumes of archaeological remains. This approach, which has already been tested for the Kerma granaries in Gism el-Arba

(MARCHI 2017, p. 210), is well worth developing, even by addressing geographical areas that are distant from each other but share comparable climatic and/or environmental conditions with the region under study. Anne Mayor's and Thomas Pelmoine's paper in this volume shows the usefulness of extending the scope of the research to other geographical areas where different human groups may have used similar responses to overcome similar technical problems.

Furthermore, experimental archaeology is an invaluable tool for material history. It enables hypotheses to be tested in line with protocols established from historical sources. As a first step, development of a protocol makes it possible to take stock of historical documentation and a hypothesis' feasibility (for experimental archaeology methodology, see VERLY, LONGELIN 2019). Several tests are necessary in order to carry out a comprehensive study, and observations must be scrupulously recorded. Such rigour is what distinguishes experimental archaeology from re-enactment, which plays a role in mediation for the general public. Archaeological experimentation is therefore of significant value as far as studies of storage are concerned, as societies today no longer regard conservation in the way they once did. The invention of refrigeration was a fundamental turning point in social practices, and these days it is difficult to imagine how foodstuff deterioration once conditioned daily life along with food access and circulation. The difficulty in conserving onions in Senegal (one of the country's main agricultural products) described in GANDREAU *et al.* in this volume illustrates this issue very clearly.

A number of experimental archaeology projects have focused on ancient societies' storage practices. Very few have been published and one of the most promising, concerning medieval storage pits in southern France, is still underway.¹³ For ancient Egypt, we started a project on mud-brick silos in 2021 with the support of Sorbonne University, CRAterre laboratory (AE&CC/ENSAG/UGA), and the *Fondation des Treilles*. The first tests, whose results are presented in this volume (see the contribution by A. Bats *et al.* in this volume), provided better understanding of the building practices involved and the grain storage process itself, thanks to collaboration with specialists in earthen architecture and “ancient cereals”.¹⁴ As always in experimental archaeology, further tests will be needed and this research is only at its beginning, but the results

13 Preliminary results are available here: <https://ensilage.hypotheses.org>.

14 “Ancient cereals” is an agronomic term used to describe grains that are not the result of modern selection and processing. Their genetics, and therefore their properties, are similar to those of ancient specimens. This choice is of capital importance in experimental archaeology in order to reduce biases that might impact the results of scientific experiments.

obtained – the observations made on the building process in particular – already show the approach’s potential in rediscovering and recovering ancient know-how.

Archaeometric analysis, including botanical and archaeozoological studies of food residues, remains essential, not only to identify the foodstuffs stored but also to re-establish the lost association between the product and the place where it was stored, which is of capital importance to the study of conservation practices.

Finally, only an interdisciplinary approach can effectively address the subject’s complexity and the socioeconomic issues involved, which not only pertain to the ancient world but are also relevant to modern-day societies. In addition to historians, archaeologists, and architects, the study of ancient storage practices can have useful implications for farmers, agronomists, and anyone interested in ancient and traditional ways of life and in the challenges of sustainable development. F. Sigaut studied ancient storage systems with an agronomist’s eye¹⁵ back in the 1970s and 1980s, and these days increasing numbers of agronomists are looking for ecological, low-cost solutions that do not require pesticides, refrigeration, or artificial ventilation.¹⁶ Drawing inspiration from old and traditional solutions, understanding the chemical processes involved in food preservation and the behaviour of micro-organisms are essential today. The contribution by D. Gandreau *et al.* in this volume is an excellent example of how ancient practices and know-how can be examined and updated in order to find sustainable, low-cost solutions to protection and development of local products. During the discussion following the paper (in the 2021 workshop), it was interesting to see how architects’ questions on technical data relating to the product to be stored, the building material used and the social and economic context were similar to those raised by archaeologists in their attempts to understand the technical and functional aspects of ancient storage facilities. While the study of ancient practices can help find practical solutions for contemporary storage building projects (as the contribution makes clear), it is also true that the design process and its experimentation can assist archaeologists in interpretation of archaeological remains.

5.1 Appendix 1. Recording and analysis of storage buildings: a suggested sheet

The many discussions between members of the *Storage in Ancient Egypt and Sudan Research Group* showed the need to standardise our vocabulary for description of storage facilities. It also became apparent that many questions relating to the study’s analytical phase had to be taken

into account during an excavation in order to guide archaeological investigation. To meet these needs, we developed a storage building record sheet (table 3). Adeline Bats’ PhD thesis provided the inspiration for the form (BATS 2019), which was itself based on Frédéric Gransar’s research (GRANSAR 2000). Nadia Licitra’s work, as part of her postdoctoral research at the CRATERRE laboratory, further enriched the architectural approach. The general layout and categories included were widely discussed with Research Group members.

The document is not intended to replace the stratigraphic unit record sheet but rather to complement it. It is addressed to archaeologists, as well as to ethnoarchaeologists, who can observe buildings that are still in use (in this regard, we also refer to the record sheets published by Anne Mayor and Thomas Pelmoine in their contribution in this volume). Not all the fields have to be completed: it depends on available evidence. One of its main purposes is to question the researcher throughout the excavation or study. Proposals in italics are given as a guide. To facilitate the sheet’s completion, we also recommend consultation of the previous paragraphs dealing with the various possibilities referred to in the fields.

For the moment, the sheet is available in English and French.¹⁷ An Arabic version will be available in the near future. It is an open science tool that can be modified and readapted in the future, depending on feedback from the scientific community, which is why we invite our colleagues to provide us with feedback. Future updates will be available on the Research Group website.

15 <http://www.francois-sigaut.com>.

16 For example, see the ANR SilArchaeoBio Project <https://anr.fr/Projet-ANR-21-CE27-0013>.

17 The sheet is available for download on the Research Group’s website: <https://stockagenil.hypotheses.org/fiche>

GENERAL INFORMATION	
Form Number	<i>E.g. 0001</i>
Designation	<i>E.g. Storeroom, silo, bin, etc.</i>
Country	<i>E.g. Egypt, Sudan, other</i>
Site	<i>E.g. Gisl el-Arba, Karnak, other</i>
Sector	
Building	
Dating	
Context	<i>E.g. Storage complex, household, etc.</i>
Localisation	<i>E.g. In the urban environment, on periphery, etc.</i>
Dimensions	<i>E.g. Length, width, height, diameter (for circular silos: internal and external diameters)</i>
Building materials	<i>E.g. Wood, mud-bricks, fired bricks, ash, plaster, plant fibres, alluvial/desert/gypsum clay mortar and plaster, stone, sand, earth, etc.</i>
Construction techniques identified	<i>E.g. Moulded/modelled mud-brick, cob, etc.</i>
State of preservation	<i>E.g. Good, fragmentary, bad...</i>
Description	<i>Foundations: type, depth, width of foundation trench, type of backfill (ash, sand, etc.), underground facilities, etc. Elevation: type of floor (rammed earth, mud-bricks, stone, raised floor, etc.), presence of a floor, presence of a staircase to access the terrace, openings (doors, windows, trap doors, oculi, etc.), pillars and columns, internal fittings (benches, compartments, shelves, ducts, platforms, niches, etc.), treatment of internal and external surfaces, any decorations. Roofing: vaulted, flat (beams, plant fibres and earth/brick), domed. Type(s) of access: door, top opening, etc. Other openings: oculus, window, vents, etc.</i>
Type of volume	<i>Constant, variable</i>
Surveillance	<i>Presence of (thick?) walls to protect the structure? Single access?</i>
Bibliography	
Parallels	
Comments	
Image 1 + caption	
Image 2 + caption	
INTERPRETATION	
Restitution of volumes	<i>If data enabling restitution of elevations.</i>
Estimation of construction time	<i>Based on access to materials, number of bricks needed, roofing, etc.</i>
Estimation of the fragility of the building	<i>E.g. Known lifespan from excavation, wall thickness, etc.</i>
Type(s) of product(s) stored	<i>E.g. bulk grain, packaged foodstuffs, processed goods, etc.</i>
Data that allows the identification of the stored product	<i>Macro-remains, jar labels, archaeometric analysis, etc.</i>
Type of container	<i>If not stored in bulk. E.g. marl amphora, bag, basket, vessel, etc.</i>
Environment	<i>Airtight, ventilated, hybrid.</i>
Product access	<i>How is the product brought into the storage building? How is the product removed? Is there access to the product during the storage period?</i>
Estimated storage time	<i>Short-, medium-, long-term</i>
General circulation and access	<i>How do you get around inside the building or storage facility? How do you move around outside the building or storage facility?</i>
SOCIOECONOMIC ASPECTS	
Storage of seeds	<i>Yes, No or potential</i>
Storage for daily use	<i>Yes, No or potential</i>
Storage for trade	<i>Yes, No or potential</i>
Potential hideout	<i>Yes, No or potential</i>
Symbols of prestige	<i>Yes, No (row of silos, large warehouse, etc.) or potential</i>
Socioeconomic scale	<i>Domestic, family, community, public / institutional (see WARDEN 2017; BATS 2022)</i>

GENERAL INFORMATION	
Other activities	<i>Crop processing (near dumping area, storage of farming tools), transport, workshops</i>
ETHNOGRAPHIC COMPARISONS	
BIBLIOGRAPHY	
File author	
Date of writing	
Dates of file updates	
GPS data	

Table 3. Suggested sheet for storage buildings recording and analysis.

