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Materials characterisation and damage assessment of the ancient kiln of Kirra, Greece

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I. EXTENDED ABSTRACT

The aim of the study was the development and implementation of a methodology for the characterization and damage assessment of the building materials of a prehistoric kiln excavated at Kirra, Greece. Northeast of the center of the modern settlement of Kirra is the archaeological site where the kiln was found. The kiln was excavated in 1984 and 1989 by the French School at Athens and is dated to 1450-1400 BCE [1]. The kiln is of the updraft type, and it's mainly constructed by mudbricks (Fig. 1). Based on Hasaki's typology, it's classified as a type Ie kiln since it is circular with three parallel walls on the long axis [2,3].



Fig. 1. The kiln as it is preserved today **Fig. 2.** 3D reconstruction of the kiln with depth measurements

Mud brick structures are dramatically susceptible to water as it triggers different deterioration phenomena, the results of which are clearly visible in the many decay features on site. For this reason, the excavation is temporarily covered by a typical “Dexion” type canopy for protection from rainwater. A pump is also installed near the entrance of the combustion chamber to pump out groundwater and restrain rising damp.

Although mud brick has been used in different structures worldwide since the early Neolithic times and is therefore encountered in many archaeological contexts, there is no consensus on the best practice for its documentation, analysis, and preservation. Because of the significant efforts necessary to preserve inherently unstable earthen structures, as well as the significant costs of the development and

implementation of sustainable conservation and maintenance methods, the preservation of ancient mud brick architecture remains a challenge and is still not standard practice.

A methodology was developed and applied in this work to characterize the building materials, to examine the preservation state of the kiln, and to document its pathology in order to design conservation treatments:

- Photogrammetry was used to create 3D models of the kiln before any interventions (Fig. 2).
- Environmental monitoring was performed by collecting climate and microclimate data with the use of a data logger. The data logger measured the air temperature (T) and the relative humidity (%RH) in hourly intervals and stored the data. For the macro scale, climate conditions data were collected from meteorological stations near the archaeological site.
- Sampling was carried out from different parts of the kiln to characterize the building materials and to study the weathering phenomena. Samples were studied with Optical Microscopy (OM), Scanning Electron Microscopy coupled with X-ray Spectroscopy (SEM/EDS), and X-ray Diffraction (XRD).
- Non-Destructive Testing (NDT) was applied by using infrared thermography to investigate the sources of moisture, a hygrometer to measure the moisture content, and a penetrometer to estimate the compressive strength of the building materials.

The structural elements of the kiln show extensive and irregular weathering. Advanced loss of material has been observed, which has resulted in a gradual change in the shape of mudbricks and mortars. The weathering of swellable clays gradually leads to the collapse and loss of the kiln's building materials. Aqueous solutions transfer soluble salts which, depending on the conditions, crystallize near the surface, causing deterioration. Furthermore, aluminosilicate minerals and clays can induce significant "hygric stress".

The ways in which mud bricks and clay mortars can become contaminated with salts are the soil, from which salts may be carried into the kiln's building materials by rising damp, and sea-salt particles blown by the wind. Salts cause damage to mud bricks in several ways. The most important is the growth of salt crystals within the pores of an element, which can generate stresses that are sufficient to overcome the brick's tensile strength and turn the brick to a powder.

There is evidence that another important decay mechanism is related to what is called "differential stress." This decay mechanism includes the effects of clay swelling, differential hygric stress, and stress from differential expansion rates of material in pores (such as salts). The general idea is that treatments, salts, water films, —anything that causes the building material's surface to react differently than the interior— can result in a shear stress, and, eventually, surface parallel detachment (e.g., flaking). For example, significant shear stress is generated when, during an increase in relative humidity, the surface of clay-containing brick swells while the interior of the brick remains dry. Osmotic swelling (salt-activated clay swelling) is probably another significant decay mechanism in the case of Kirra's kiln.

Conforming to the internationally agreed principles for the protection and management of archaeological heritage, foreshadowed by Flinders Petrie in 1904, earthen structures should not be left exposed after excavation if provision for their conservation, maintenance, and management is not guaranteed.

The preservation of mudbrick structures is relatively complicated and expensive. Research has focused on the circumstances that enable preservation and the influence of climate and weather over time. Conservation treatments should address these two processes as soon as possible after exposure of the structures. Our assessment of a range of conservation methods leads to the conclusion that reburial is among the least objectionable methods of preservation, despite its drawback of returning the excavated buildings to a situation where they are invisible to both researchers and the public.

Reburial can be proposed as a temporary emergency treatment or as a means of providing long-term protection. Although it hides the original elements from view, the procedure is reversible, allowing future study or additional conservation treatment. Besides any necessary treatment before reburial, the method is non-invasive and greatly reduces the immediate need for detailed conservation as well as long-term maintenance.

II. REFERENCES

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