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Research paper

Effect of manufacturing methods on the decay of ceramic materials: A case study of bricks in modern architecture of Madrid (Spain)

Elena Mercedes Perez-Monserrat [a,*], Fernando Agua [b], Rafael Fort [a], Monica Alvarez de Buergo [a], Juan Felix Conde [b], Manuel García-Heras [b]

[a] Instituto de Geociencias IGEO (CSIC, UCM), C/José Antonio Nováis 12, 28040 Madrid, Spain
[b] Instituto de Historia (CCHS-CSIC), C/Albasanz 26–28, 28037 Madrid, Spain

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ABSTRACT

The appearance and main decay forms in the fair-faced brick façades on the University Campus of Madrid's Faculty of Medicine were taken as a starting point to analyse certain building's construction characteristics and the clay and technology used in brick manufacture. The raw materials consisted in a mix of Miocene marl and red Triassic clays from the Spanish province of Jaén. The exposed face of bricks was characterised by a yellowish tone and smooth, uniform texture that afforded perfect dimensioning and inter-brick alignment. In some bricks this texture was lost, with a concomitant colour change, surface roughness increase and loss of material. Laboratory studies through polarised optical microscope (POM), X-ray diffraction (XRD) and field emission scanning electron microscopy with energy dispersive X-ray spectroscopy (FESEM-EDS) revealed similar composition in all the bricks, firing temperatures ranging between 800 and 850 °C and, with the exception of the exposed surface, not particularly careful manufacture.

1. Introduction

The history of brick dates back to the dawn of civilisation. Moulded adobe was developed in Mesopotamia around 5000 BCE, while with the invention of fired brick around 3500 BCE longer lasting structures could be built. The Greeks used fired bricks under the influence of Egypt and Mesopotamia; Rome and Byzantium inherited the Greek aesthetic, from where it travelled to the Far East. The Islamic version reached the Iberian Peninsula after crossing northern Africa. By the early thirteenth century AD brick was found in the rest of Europe, where its use largely conditioned construction progress between the Renaissance and the seventeenth century and where, as a relatively inexpensive material, it pervaded all layers of society. The eighteenth century brought techniques for its large-scale production and shipment across long distances. In the nineteenth and well into the twentieth century it became the standard material for industry and trade. Thereafter brick output gradually rose with the introduction of a wide variety of products and techniques able to support more innovative usage (Campbell and Pryce, 2003; Kornmann, 2007).

In Spain, the ceramic industry and the legacy of traditional manufacturing procedures with a strong Arabic influence are especially significant, primarily due to the abundance of raw materials and centuries of old trade relations with other Mediterranean cultures. While ceramic production areas are to be found all across the country, their presence is particularly significant in the provinces of Valencia, Toledo, Jaén, Madrid, Teruel, Castellón and Seville. Adell (1992) noted that enormous technological progress took place in the nineteenth century, when brick began to acquire importance of its own, adopting the industrialised procedures characteristic of the age. Modulation and industrialised manufacturing led to the development of different types of brick (such as hollow, perforated or pressed). As a building material, brick played an essential role in nineteenth century modernity. Moreover, in that century brick began to be sized to a length approximately double the width, giving rise to bonds with alternating length and width that could not be accommodated with the previous proportions (Adell, 1992; Rodríguez, 2007). Until that time, header (or Spanish) bonds prevailed in Spanish architecture. In Madrid, nineteenth century brick architecture was characterised by header bonds to attain the maximum possible number of joints, yielding highly subdivided wall surfaces.

When clay is fired changes take place in its mineralogy that depend essentially on the initial composition, kiln temperature, heating rate, firing time and prevalence of oxidising or reducing reactions (Fort et al., 2004; Maggetti, 1982; Maritan et al., 2006). Similarly, the procedures and technologies used in the making of ceramic materials have a

* Corresponding author.
E-mail addresses: empmon@geo.ucm.es (E.M. Perez-Monserrat), fernando.agua@cchs.csic.es (F. Agua), rafael.fort@csic.es (R. Fort), monica.alvarez@csic.es (M.A. de Buergo), juanfelix.conde@cchs.csic.es (J.F. Conde), manuel.gheras@cchs.csic.es (M. García-Heras).

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decisive effect on time-induced decay (López-Arce et al., 2013). The low thermal conductivity of clay is responsible of temperature gradients between brick surfaces and body during firing (Kingery et al., 1976). Brick colour, in turn, is indicative of the composition of the clay used in its manufacture and, especially, of the amount of iron oxides present and their oxidation state (Kreimeyer, 1987).

The many factors involved in the behaviour and alteration of the construction materials comprising Heritage structures must be taken into consideration when characterising and studying the types of decay present. For ceramic materials, that entails the kind of clay used as a raw material, the manufacturing technologies or construction methods. The researcher's tools for such studies include documentary sources, observation of the target materials and in situ and laboratory characterisation techniques, including chromatic determinations of brick surfaces to assess colour ranges, which could arrange the suitable background to accomplish bricks' replacement tasks if needed (Pérez-Monserrat et al., 2013).

The primary aim of this study consists in analysing how clay type, brick manufacturing procedures and the construction system used have conditioned the decay of the exposed face of the façade brick of the edifice hosting the Faculty of Medicine, University Campus of Madrid (Spain). The results obtained may thereby provide a scientific support for decision making in future restoration and conservation strategies in the case of some bricks need to be replaced.

1.1. The Faculty of Medicine within the medical ensemble of the University Campus of Madrid (Spain): overall and façade design

In 1927, King Alfonse XIII established a new university campus where faculties and technical schools could be clustered and modernised. The campus was initially built to house, among others, the Faculties of Medicine, Pharmacy and Dentistry, all flanking the same square, and a university hospital to be built on a nearby hill. This campus was the origin of the current Complutense University of Madrid (UCM). The Faculty of Medicine, designed by Miguel de los Santos Nicolás, was built between 1930 and 1935. This large-scale, complex design was influenced by the architecture prevailing in USA universities and the League of Nations headquarters at Geneva (Switzerland). The building was severely damaged during the Spanish Civil War (1936–1939) and reconstructed in 1941–45. The upper terraces were rebuilt in 1956 and in 1977 the property was listed as a Cultural Heritage asset (Chías, 1986; VVAA, 2003).

The building features a reinforced concrete structure. Some stone materials are used for the socle, imposts and mouldings, whereas a fair-faced brick closes the façade. The simplicity, uniformity and rationality of the façade design meet criteria of economicity and functionality. Vertically, it is symmetrically divided into alternating panels and openings, and horizontally into three distinct components: a tall socle, the main body (with four storeys) and a setback attic with a terrace (Fig. 1a). The fourth storey and attic have on its upper part parapets, resting on a cantilevered impost and capped by a narrow ledge (Fig. 1b) which is only slightly cantilevered and has no dripstone. In some areas, the fourth storey parapet sealing has recently been replaced with asphaltic material.

2. Materials and methods

2.1. Methodology and sampling

Three types of studies were conducted: a review of historical documents, bricks examination on façades and in situ and laboratory characterisation of the bricks.

Information on the construction and reconstruction of the edifice hosting the Faculty of Medicine and over building materials provenance was found in the University Campus of Madrid's General Archives (AGUCM). The information on the source of the clay used to manufacture the bricks was contrasted with the respective national geological maps (MAGNA, scale 1:50,000). Brick bond, colour, and decay were observed in situ.

In situ testing included the measure of bricks dimensions as well as their surface colour and moisture with spectrophotometric and hygrometric techniques, respectively. Brick measurements were taken in three areas (Fig. 2): the façades facing west, to the right (Area 1) and left (Area 2) of the main entrance, and the north setback attic (Area 3, probably reconstructed) on the right wing of the building. In situ measurements were carried out on 39 bricks, with colours representative of all the bricks in each area (blue for Area 1, red for Area 2, and green for Area 3), and were numbered from 1 to 39 (14 in Area 1, 11 in Area 2 and 14 in Area 3). On these 39 bricks, or others with a similar colour, 11 samples were taken for laboratory analyses (labeled No. 1 to No. 11). The south end of the parapet crowning the main entrance was also sampled (Area 4, represented by purple colour). In this latter Area samples labeled No. 12 and No. 13 were obtained (Fig. 2). Fig. 2 and Table 1 also provides height averages of bricks coming from the four Areas.

Laboratory characterisation of the bricks (samples labeled No. 1 to No. 13, from Areas 1 to 4) included macroscopic examinations of hand samples and thin sections, as well as petrographic, mineralogical, microstructural and elemental composition analyses (Table 1), respectively with polarised optical microscopy (POM), X-ray diffraction (XRD) and field emission scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (FESEM-EDS).

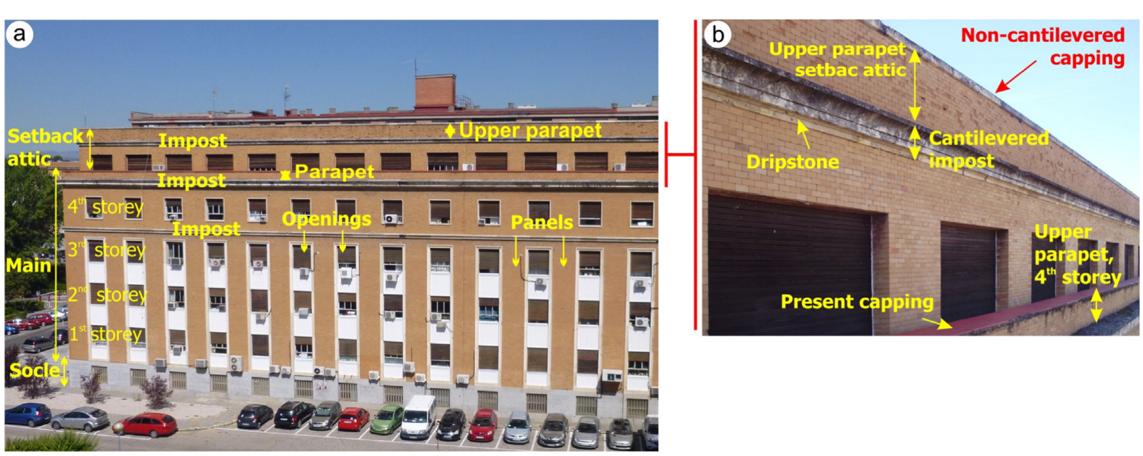

Fig. 1. Façade design of the edifice hosting the Faculty of Medicine. a) three main components (from bottom up): socle, main body (four storeys) and setback attic with terrace. b) detail of the setback attic: the narrow ledge capping the upper parapet and the cantilevered cornice-like impost, fitted with a dripstone, can be seen.

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