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

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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 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 microscopy (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.

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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 early thirteenth century AD 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 brick began to acquire importance of its own, adopting the 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.

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
decisional conductivity of clay is responsible of temperature gradients be-
tween 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 restorations 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 modernised.
The campus was the origin of the current Complutense University of
Madrid (UCM). The Faculty of Medicine, designed by Miguel de los San-
tos Nicolás, was built between 1930 and 1935. This large-scale, complex
building was severely damaged during the Spanish Civil War (1936–
1939) and reconstructed in 1941

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 ratio-
nality 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 par-
aperst, resting on a Cantilevered impost and capped by a narrow ledge
(Fig. 1b) which is only slightly cantilevered and has no dripstone.

In areas, the fourth storey parapet sealing has recently been replaced
with ashpaltic material.

2. Materials and methods

2.1. Methodology and sampling

Three types of studies were conducted: a review of historical docu-
ments, bricks examination on façades and in situ and laboratory charac-
terisation 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 manufac-
ture the bricks was contrasted with the respective national geological
maps (MAGNA, scale 1:50,000). Brick bond, colour, and decay were ob-
served in situ.

In situ testing included the measure of bricks dimensions as well as
their surface colour and moisture with spectrophotometric and hygro-
metric 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 mea-
surements 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 sam-
pled (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, micro-
structural 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 dis-
persive 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.](image-url)
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