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Case study

Enlightening the use of materials and techniques in earthen architecture in southeast Brazil during the first coffee cycle (19th century)

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ABSTRACT

The broad ensemble of fine rural and urban constructions erected during the first cycle of coffee production in Brazil (1820–1880) in the middle valley of the *Paraíba do Sul* River in southeast Brazil, is a legacy of earthen architecture of exceptional importance. A rare example of simultaneous presence of three different earthen architecture techniques (wattle-and-daub, adobe and rammed earth), this heritage faces threat of disappearance due to lack of public concern and loss of know-how directed to earthen techniques. In this paper, the physical and chemical analysis of a large set of samples of local soils and masonry elements formed the basis for a discussion on raw materials and techniques originally used in the construction of those buildings. The information gathered in this work is intended to contribute in the rescue of the immaterial heritage related to building practices in colonial and post-colonial Brazil and to support conservation and restoration actions.

1. Introduction and research aims

Earthen architecture was introduced in Brazil in the 16th century by the Portuguese [1–3] and for four hundred years wattle-and-daub (WD), adobe (AD) and rammed earth (RE) were the preferred options in building techniques. From the second half of the 19th century, industrialised materials gradually replaced traditional raw materials and, from then on, there has been a progressive loss of earthen architecture heritage. This decline has affected both the material and immaterial heritage, i.e., buildings as well as the craftsmanship related to this vernacular form of architecture. The need for preserving existing buildings and rescuing the traditional knowledge associated with earthen techniques and the use and handling of raw materials is evident, as shown by several initiatives worldwide in recent years, reviewed in [4].

This paper presents a case study focused on 19th century earthen constructions located in the middle valley of the *Paraíba do Sul* River (South-East Brazil) (Fig. 1). The investigation aimed at analysing physico-chemical properties of earthen materials and soil profiles in order to enlighten likely criteria adopted by the original craftsmen at the time of selecting raw materials and possible treatments practices prior to masonry assembly.

2. Materials and methods

2.1. Sites and samples

The investigation considered buildings located in the municipalities of Queluz (QZ), Areias (AR), São José do Barreiro (SJB) and Bananal (BA), the core of coffee production in the province of São Paulo during the 19th century (see also [5]) (Fig. 1).

Set in the depression of the middle valley of the *Paraíba do Sul* River, the area exhibits oxisol as the main soil order on the slopes and the interfluves of rounded hills, developed on crystalline rocks and eluvial/colluvial deposits [6]. More specifically, in the area extending from the North of Queluz to the East of Bananal, a yellowish red (5YR 5/6) oxisol with clayey texture predominates; yellow oxisol occurs close to the left margin of the *Paraíba do Sul* River and red oxisol in the southeast end of the area. Yellow (10YR 7/8) to pale brown (10YR 6/3) inceptisols prevail on the rugged and mountainous reliefs (Fig. 1). Inceptisols have clayey and medium texture and may contain rocky phases and be associated with rock

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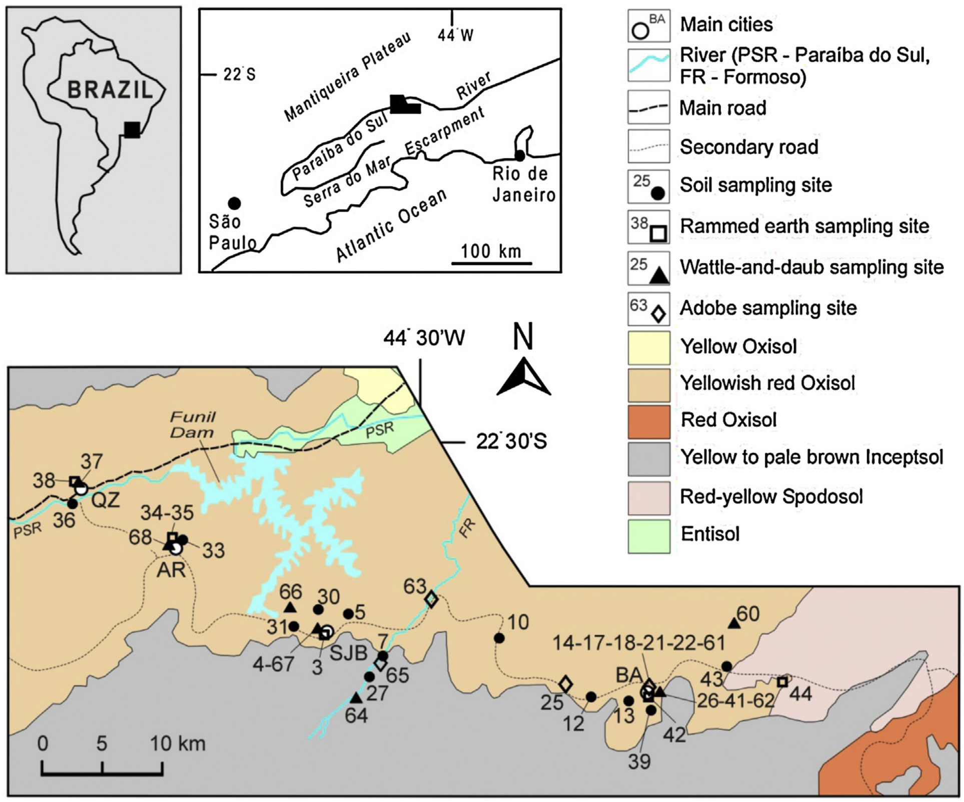

Fig. 1. Map of soil orders of the study area (modified from references [7] and [8]), with the location of sampling sites (black circle–soil, black triangle–wattled-and-daub, open diamond–adobe, open square–rammed earth).

outcrops [7,8]. Spodosol occurs at the eastern part of the area and Entisol close to the *Paraíba do Sul* River [7].

A set of 140 samples was collected in this area: 109 specimens of earthen masonry (of which, 30 of WD, 48 of AD and 31 of RE) and 31 sub-soil samples. All soil samples were collected at 12 sampling sites distributed along the old road that has connected the cities of Queluz and Bananal ever since the 19th century (Fig. 1). Samples of earthen materials were collected at 25 sampling sites mainly located in the urban areas and their surroundings.

2.2. Macroscopic characterisation of samples

All samples were characterised for colour and texture. Colours were described by visual comparison with the Munsell soil colour charts [9]. Grain-size distribution of fine earth (particles < 2 mm) in selected samples of soil and earthen materials was determined using a Microtrac Bluewave particle size analyser, and textures were classified according to [10,11]. A total of 54 samples was analysed (27 soil, 9 WD, 10 AD and 8 RE samples). Standard charts (e.g. [12]) were used for estimating the relative proportion of rock fragments (> 2 mm). The size of rock fragments was estimated by measuring the particles judged to represent their maximum size, as in [13]. The composition of particles was defined by visual determination of macroscopic properties of minerals and rock fragments.

It is worth mentioning that the presence of vegetal fibres was observed in all AD samples, although no quantitative analysis was undertaken on this aspect in this study.

2.3. X-ray diffraction analysis

Thirty selected samples (10 soil samples and 20 specimens of earthen masonry, of which, 4 WD, 9 AD and 7 RE), were analysed by X-ray diffraction (XRD) as whole sample oriented-powder for determination of their mineral compositions. Each sample was manually crushed and homogenized using an agate mortar and pestle. An aliquot of the powder was pressed into the sample holder. Samples were scanned from 2 to 65 degrees 2θ. All the XRD analyses were carried out on a Bruker D8 Advance Da Vinci diffractometer operated at 40 kV and 40 mA, CuKα radiation, and at a scanning rate of 0.1°2θ/min. Minerals identification was performed using the DRXWin software [14] and the powder diffraction file of the International Centre for Diffraction Data (ICDD).

2.4. X-ray fluorescence for major elements analysis

Elemental analysis for Si, Al, Ca, Fe Ti and K was performed by X-Ray Fluorescence on 108 samples (31 soil samples and 77 earthen masonry specimens, of which 18 WD, 34 AD and 25 RE), in triplicate. For the purpose, the portable Tracer III Spectrometer (Bruker) was used. The equipment was operated in the bench-top mode at tube voltage and current of 15 kV and 25 μA and with an acquisition time of 30 s (under internal vacuum and without any excitation filter). The quantitative results were obtained on the basis of the calibration for soil, ceramics and mud rocks provided by Bruker. The results used in the discussion correspond to the average of the triplicate analysis of each sample.

3. Results

3.1. Munsell colour characterisation

The set of soil samples and earthen materials exhibits colours ranging from reddish to yellowish, including hues 2.5YR, 5YR, 7.5YR and 10YR. The graphs of Fig. 2 show that 5YR is the hue most commonly observed in soil samples and is found among the earthen materials, although is missing in WD. Hue 10YR is observed both