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## Causes of Decay of the Aveleiras House Decorative Plasters (in Torre de Moncorvo)

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**Abstract** This paper presents historical and characterization studies undertaken to: a) clarify technical interpretation of lime-stucco and plasterwork by historic architectural treatises, and b) better understand the intentions of the early designers and plasterers: the used proportions and sizing of materials, the coverage achieved using different plasters, the nature and composition of the materials, and the causes and forms of decay of stuccos and plasters. Historical studies are important for determining the most effective courses of actions with regard to the preservation of cultural heritage, as respectful as possible to the original nature and materials of the historical buildings. The present paper includes the history of the stuccos and plasters as well as the characteristics of the materials used in plastering and the tools to model in relief. In addition, were carried out an “in situ” inspection and laboratorial analysis, as TGA, XRD, EDS and SEM on decorative and plain plasters from Aveleiras House. As a consequence of this study it was possible to quantify the percentage of binder in the mortars and to identify the causes of decorative plasters decay, suggesting their bio deterioration.

## 1 Introduction to stuccos and plasters of 16<sup>th</sup> - 19<sup>th</sup> centuries

Venetian buildings often have walls covered with beautiful stuccos applied above their white surfaces. During the 16<sup>th</sup> century, with the coming of the Renaissance and Baroque styles, the *barrel vault* or the *groin vault*, saw a resurgence in popularity. These were decorated with double or triple blades of ceramics and thin pieces of stone that were covered in a plaster consisting of lime and fine sand, over which was applied a final finishing coat. As described by Philipert de l’Orme, in his treatise of 1561, a further method of decorating vaults

was to use plastered lathwork (Fig. 1a). The lathwork was fixed in a wooden structure composed from a double stave of wood tied with wooden pins to form the skeleton of a vault formed from the intersection of ogival (gothic) arches [1].



Fig. 1 a) Wooden vault structure of support of a plastered ceiling (De l'Orme, 1561); b) Ceiling of Chapel Sacristy, 16th c., Aveleiras House, Torre de Moncorvo (2008); c), e), f): Plasters of Pombal Palace, Oeiras, 18th c. d) Running mould for the execution of interior cornice (SEGURADO, J, 1949).

Stuccos, until the 19<sup>th</sup> century, were applied over the rough-cast of masonry or over rendering coats applied to the lathwork of partition walls or ceilings. The renders were of a mortar composed of lime and gypsum. When gypsum was not available, marble powder, chalk, or white of Spain (calcite), was used. Such renderings provided a smooth surface to walls, ceilings and columns, and could also be used for elements with a variation in thickness such as cornices, mouldings and other decorative elements.

Antique *lime plasterwork* consisted of three layers. The “*rendering coat*” (the first layer) was made from lime/gypsum and sand (1:2) or lime/gypsum and a pozzolana and was coarse and rugous, with a varying thickness of 7-10mm; the finish of this layer could either be a simple plaster or an ironed plaster. This layer of plaster was applied with gauging trowels of different dimensions, busks, drags and steel small tools, according to the delicacy of work. The rendering coat was used for coring out the cornices or mouldings or was applied to the interior substratum of smooth plaster walls and ceilings. The next layer, the “*floating coat*” was a mixture richer in gypsum or lime, with fewer, finer aggregates in a ratio of 1:3; for use in mouldings and decorative elements, straw, rope, hair or horse-hair was added to increase the bond strength between layers. The floating coat was applied in a thin layer, between 1-2mm. If the plaster surface to which the rendering coat and the floating coat were applied was an exterior surface, then both these layers must be made entirely of a hydraulic lime mortar. The last layer,

applied in a thickness of 1-3mm, was the “*setting or finishing coat*”. This comprised either of lime/gypsum in a paste, lime/gypsum in a paste with coloured powdered marble, or simply a gypsum paste. The plaster obtained as lime in paste or milk of lime, could be ironed or polished. A mixture of lime and sifted marble powder in equal parts, made a solid, durable and shining plaster. When no marble was available chalk or gypsum were used.

The decoration in bas-relief and in framing (interlaced, leaves, laurel wreath), was realized with little salience. The outlines were drawn to a natural scale and were pricked and outlined in coal dust, a strong plaster was then used to fill in the shape of the decoration and fixed bossed nails were used as additional supports to the plaster. The decoration, which was applied to a pre-plastered surface, was shaped and wetted intermittently to prevent it drying out quickly [2].

The *gypsum plasterwork* was created equally in three layers with a gypsum base. The third and final layer was a stucco made from a pure white superior gypsum which was passed through a sieve of fine silk prior to mixing. The plaster was kneaded in water where it was dissolved with Flandres glue. For a white plaster, colourless fish glue could be used; where coloured plasters were to be used, varied glues, of animal or vegetable nature could be used. The glue increased the adherence of the plasters to their support, and reduced the set of the plasters making them easier to work. To colour plasters, coloured pigments were diluted with glue in water.

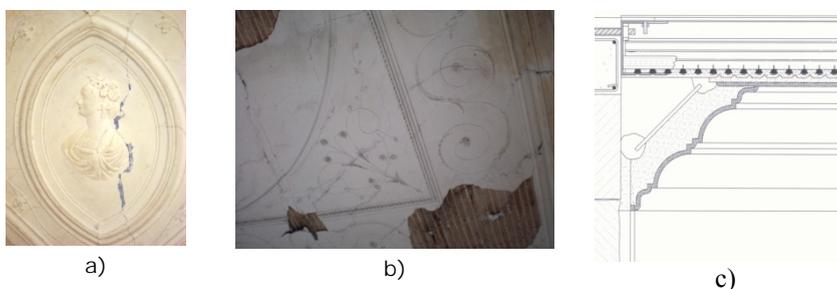
To create a marble imitation (Italian “*scagliola*”) the pigments to produce the base colour were added to the last layer (Fig. 1e). To create the marble veins the colours were diluted with glue in water and were placed in moulding cakes of different colours to produce coloured pastes that were then cut into strips and introduced into thin furrows in the fresh plaster. The ironed polish seen on some plasters was produced either with plaster and glue, wax and soup or paste of lime and wax, all with different textures. As soon as the plaster was dry, the polishing with a pumice-stone and water or with jasper or crushed chalk, or by rubbing with a felt lightly covered with wax, was performed. The brown or black plastered surfaces could be decorated with mouldings representing flowers, fruits, arabesques and human figures [3].

The *ceilings of plastered tight lathwork* were formed from laths constructed in a trapezoidal section which was nailed transversally to the inferior surface of the support beams. The laths were fixed by the narrower bases and their greater bases were spaced 1cm apart. The inferior face of the laths must be perfectly horizontal in plan to allow them to be wedged tightly together in case they were dropped. The *rendering coat* consisted of a mortar of lime, sand, and sifted gypsum (between 1:1 and 1:2) in a layer 0.04m thick, placed 0.01m under the inferior face of the laths. The *floating coat* (0.02m thick) or “the browning plaster” – of gypsum/lime and dark gypsum (gypsum, air lime in paste and fine sand with the ratio 1:2:1, or 1:1:4), or lime and marble powder– was applied with the laying trowel or with the hawk upon the dry filling layer. The surface was left rugous in order to facilitate the adherence of the next layer. The mortar of the *setting coat*

(0.01m in thickness) consisted of gypsum or lime plaster (gypsum, lime mortar and thin sand with a ratio of 1:3) or lime paste and marble powder to which a setting retarder could be added. The surface was caressed with felt-floats and was rubbed lightly with a damp linen cloth [4] (Fig. 1d).

## 2 Study Case – plastered ceilings of Aveleiras House

### 2.1 *Diagnosis of identified anomalies*



**Fig. 2** a) Decorative plasters, in the “Adam Style”, of English influence; b) cracking and unfastening of parts of the plaster; c) repair suggestion of plastered ceiling (CAVALHEIRO Photos; 2007)

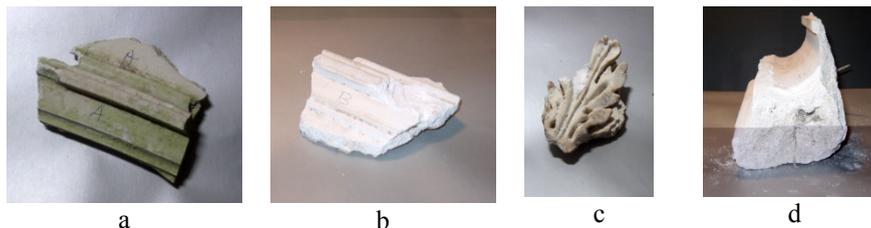
The anomalies presented in this chapter were identified in a case study of the early 19<sup>th</sup> century decorative ceilings of the main floor of Guerra’s House (of Aveleiras), in Torre de Moncorvo [5] (Fig. 2).

The building is in a poor state of conservation, with collapsed roof sections creating subsequent degradation to the interior subjacent zones. The ceilings and lath work present damages including: cracking, standing up and putrefaction of plaster; dirt stains, biological colonization and mould; fissures and disintegration of the mortars; and the absence of support laths for the plaster. The ceilings of plaster, which consist of wooden laths nailed to the structure of the roof, were affected by deformation of the supports owing to the progressive camber of beams caused by water retention.

This structural phenomenon created deformation of the ceilings which in turn produced cracking, loss of adherence of plaster and loosening of the plaster. The occurrence of water infiltration from the roof or floor, produced the putrefaction of the laths, the oxidation of the nails of fixings and volumetric expansion which led to the further decline of the plaster ceilings. The difference in behaviour between the masonry walls and ceilings, resulted in the appearance of cracks in the connexions between those constructive elements, namely in the coves. The poor execution of the different plaster layers, due to inadequate soaking during

application, led to the presence of quick lime; this combined with a deficient mix design has resulted in weakened areas and the loss of adherence between the different layers of plaster and the appearance of fissures.

### 3.2 *Laboratorial analysis of the plaster from Aveleiras House*



**Fig. 3** Samples of plastered ceilings from Aveleiras's House: a) Sample colonized with algae of green colouration; b) Sample from a ceiling; c) Decorative motive; d) Sample of a cornice cove.

Samples of plasters and mortars from different parts of Aveleiras House were submitted for the following analyses: *thermo gravimetric analysis* (TGA, by *TA Instruments/SDT2960*), to quantify the binder percentage in the mortars; *x-ray diffraction* (XRD, by *PAN'alytical, X'Pert Pro*), to study the mineral components of external surfaces and cross sections of the mortars and to identify altered minerals and soluble salts; *energy dispersive spectroscopy* (EDS) in conjunction with images of the sections obtained by *scanning electron microscopy* (SEM, by *Philips-FEI/Quanta400* with EDS), to characterise the crystalline structure of the materials, detect modified minerals and salts, detect biological agents like algae and lichens, to determine the proportions of different components, and to detect fine fractures in the stratum.

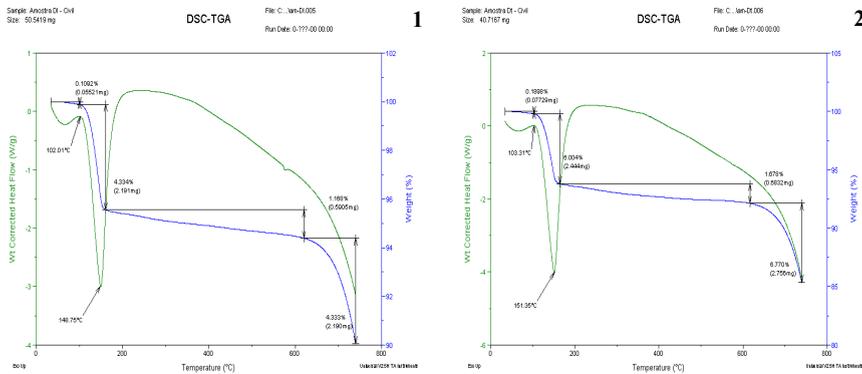
The results obtained through *mineralogical analysis* of one sample of plaster using XRD, indicated that the mineralogical components prevalent in sample are calcium sulphate ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) (69%) and calcite ( $\text{CaCO}_3$ ) (31%). The samples were also subjected to TGA to quantify the binder percentage in the plasters (Table 1 and Fig. 4). EDS analysis of samples A, B (Fig. 5) and D, indicated the presence of quartz ( $\text{SiO}_2$ ) and traces of dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ), in samples A and D. The binders of these plasters are gypsum and lime and the aggregates are essentially of a calcareous and siliceous nature. The plasters have a low content of soluble salts, (less than 1%). Sample A, colonized with algae, showed a superior percentage of K, Na, and S ions, and oxides of  $\text{Na}_2\text{O}$ , MgO,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{SO}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{Fe}_2\text{O}$ .

The micro-analysis obtained by SEM on a cross section of a sample of plaster without biological colonization (Fig. 6 -Micro-analysis 1) indicates that the initial layer of plaster closer to the support had coarser aggregates and less binding material than the finishing layer of plaster. The micro structural analysis of the exposed surface of the plaster sample, (see Fig. 6 - micro-analysis 2 and 3) revealed prismatic and acicular crystals of calcium sulphate, and scaly and rugous

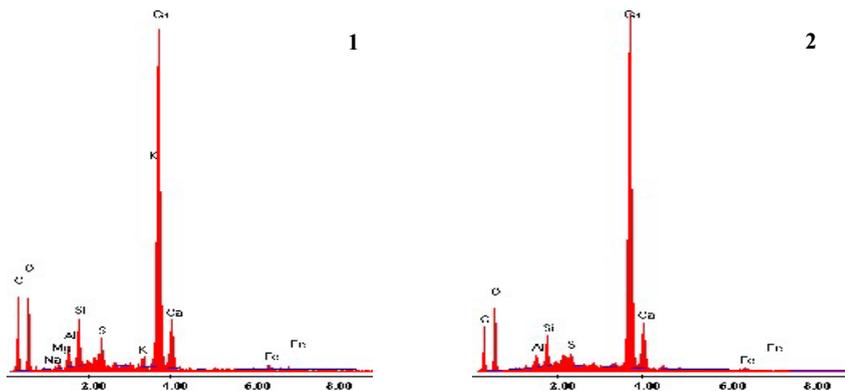
particles of small calcium carbonate crystals, which present exfoliation planes of trituated calcareous stone but do not present any specific morphology of micronized calcium carbonate.

**Table 1** TGA analysis of the samples, in wt% of quicklime or gypsum

Samples	A	B	C	DI	DT
Quicklime (CaO)	14.06	8.50	18.65	5.52	7.64
Gypsum (CaSO <sub>4</sub> ,1/2 H <sub>2</sub> O)	49.72	78.35	49.38	23.25	36.36



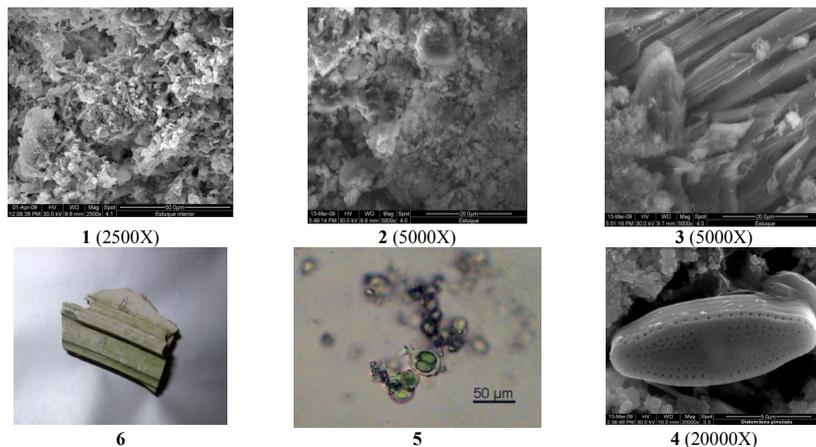
**Fig. 4** Thermo-gravimetric Graphs of sample D: 1) DT, surface of plaster; 2) DI – internal layer of plaster from near the support.



**Fig. 5** Spectra of chemical analysis of the plasters of Aveleiras’s House; 1) Sample A, external surface of the plaster (with algae); 2) Sample B, external surface of the plaster (without algae).

The microscopic image of samples of plaster with algal colonisation showed biological colonisation was more prevalent in the more humid areas of the ceilings. The microscopic image in Fig. 6 corresponds to the visualisation of a

sample of plaster which contains green algae. The images obtained by *SEM* on samples of plaster with algal colonization, (Fig. 4), indicate the presence of algal Diatoms of two orders, centric (or *Centrales*) and pinnate (or *Pennales*). They are, therefore, unicellular organisms which have one carapace or siliceous wall denominated frustule, localized externally to the plasmatic membrane. These structures, left by the algae, are seen on the surface of sample A.



**Fig. 6 Micro-analysis:** 1) Sample B, cross section of surface of plaster. 2) & 3) Sample A, surface of plaster, deposited algae having been removed. 4) Plaster colonized by algal diatoms. *Microscopic image:* 5) Visualization of sample showing the region which contained green algae (Chloroficeas). 6) Sample A with algae.

### 3 Discussion / conclusion

The 19<sup>th</sup> century decorative plastered ceilings of Aveleiras House have distinct layers of lime-based mortars, covering the *Castanea Sativa* lathwork, nailed to the supporting beams of oak, chestnut, or pine wood. Thin section analysis of those plasters showed the difference in aggregate/binder ratio and aggregate size. The innermost layers closest to the supporting lathwork, have coarser aggregates and a higher aggregate/binder ratio, in the order of 3:1, similar to the mortar compositions of the historic architectural treatises (sand, gypsum and air lime, with 4:1:1 ratio). The outermost layers have very fine aggregates and higher proportions of binder, with 1 part of aggregate to 1, 2 or 7 parts of binder. Rondelet states that the ratio of the *setting coat* must be of 3 parts of lime mortar and sand to 1 part of gypsum; however, he believed that aggregates never exceed the binder in this layer.

The plastered ceiling, represented by sample A, contains 2.80% of Magnesia which has a destructive effect in the plasterwork; sample A could be broken into

pieces by hand easier than the other samples analysed. The higher proportions of K and Si in this plaster indicate the probable employment of silicate of potash to increase the hardness of the mortar, a common practice in the 19<sup>th</sup> century [6].

The lack of bonding between some areas of the plasters to the supporting lathwork indicates that the innermost plaster in contact with the wood laths is separated and totally disintegrated. Due to the decayed roof, the wood and the plastered ceiling have absorbed infiltrated rain water, which can only escape through evaporation and osmosis through the plaster of high permeability. The consequence of the presence of this stagnant water is the solubilisation of the plasters and their disintegration. This decay process is intensified by the development of microorganisms in the deteriorated areas. They inhabit fissures and holes in different layers of the plasterwork, leading to the decrease of its cohesion and consistence and a consequent loss of bonding. Algae have also contributed to the disintegration of the decorative plasters, as is represented by sample A. Many of the porous and damp surfaces of plasters are dominated by communities of algal *Diatoms* which produce  $H_2CO_3$  and organic acids, which promote carbonate dissolution in the algae/plaster interface.

## 4 Acknowledgements

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