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Preparing the foundation for stable gilding: Scientific evaluation of the durability of Baroque *gesso* gilding grounds

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ABSTRACT

This paper follows two earlier papers about Portuguese *gesso* gilding grounds, a typical decoration from the 13th to the 18th century but with a special focus on the Baroque period. It concentrates on understanding the reasons why these gilded surfaces are so durable. The main concerns of the people involved in the production of the gilded surfaces, as revealed in contemporary historical documents, are the quality and durability of the decorations. The investigation of 'durability' involved the study of factors not explored before regarding materials and practices commonly used to produce gilded wooden surfaces in South Europe. The paper discusses the probable effects on durability of loading a binder with a filler, of the shape and size of the filler particles, of the interaction of filler and binder, and of using a multi-layered system; it discusses the science underlying the use and behaviour of particular gilding materials and practices.

This paper is followed by a second paper focused on technological choices. Together they aim to contribute to understanding why Portuguese gilders clearly chose double-structured *gesso* grounds in preference to other possibilities, and to aid on conservation decision-making and the design of new strategies for the treatment and preservation of these historical gilded surfaces.

1. Introduction and overview

This paper explores the possible reasons for the remarkable durability of the gilded and polychrome surfaces on Portuguese altarpieces and sculptures. It presents part of a larger research project about *gesso* gilding grounds,[1] which was aimed at understanding why gilders had chosen to use specific materials and practices to produce gilded surfaces.

These carved and gilded wooden objects date from the late 13th to the 18th centuries, a large number of them dating from the Baroque period; they are partly polychrome but the major areas are gilded. Although some have not survived this was usually because they were replaced with a later altarpiece, or because the building itself was in extremely poor condition (eg. had a leaking roof), many which are still in situ in Portuguese churches, and housed in normal conditions, have survived in remarkably good condition through centuries. Of particular relevance to this paper, the gilded layers are generally intact and retain their spectacularly glossy appearance.

In addition to this physical evidence, research focused on historical documents, related to the production of these decorated objects, reveal that gilders believed that the use of specific gilding materials and practices played a key role in the durability of gilded surfaces. Therefore, the aim of this part of the research project was to establish the scientific reasons for this durability which was well understood empirically by the gilders.

For water gilding grounds, early Portuguese documents

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[1] The research involved study of contemporary historic documents, samples taken from original sculptures and altarpieces, and reconstructions. Previous papers covered documentary and analytical data related to the materials and practices used to produce gilded surfaces and a further paper discusses the reasons why craftsmen decided to use these materials and practices (Pombo Cardoso and Pye, 2016a; 2016b; 2016c).

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stipulate the loading of size glue with two different fillers (*gesso grosso*[2] and *gesso mate*[3] powders) and the building-up of a double-structured *gesso* ground consisting of a coarse *gesso grosso* layer covered by fine *gesso mate* layer and finally by a layer of bole. By contrast, in some northern European countries a single-structured chalk[4] ground covered with a layer of bole was the tradition (Pombo Cardoso and Pye, 2016a; 2016b).

Ambient fluctuations of temperature and especially of relative humidity (RH) are the principal stimuli that induce stress and consequently damage to gilded objects, as both wood and size are hygroscopic materials (Mecklenburg and Tumosa, 1991a,b; Michalski, 1991a; Mecklenburg et al., 1995a, 1998). Therefore a significant cause of damage to these objects can be attributed to the development of mechanical stresses as the different materials and layers that compose them respond differently to RH fluctuations, leading to formation and propagation of cracks and eventually to flaking of the gilded coat (Berger and Russel, 1991; Hagan et al., 2005; Mecklenburg, 1991a).

Both *internal stresses* and *hygroscopic stresses* were investigated here as they are the main types of stress that threaten the durability of gilded wooden artworks. *Internal stresses* in gilded coatings are created during the formation of the various layers as they dry, due to movement restrictions. *Hygroscopic stresses* are created by external factors, such as RH fluctuations, and occur because the different materials and layers that compose the gilded objects react at different rates to these external factors (Keck, 1969; Rowe, 1981; Okhamafe and York, 1984; Perera and Eynde, 1987; Gibson et al., 1988).

These stresses influence the future mechanical characteristics of the material, and the long-term behaviour of the coating depends on the various stresses that it develops, both during its formation and during its service life, i.e. its 'stress history' (Perera and Eynde, 1987). The overall practical effects of stress are flaws, crack formation and crack propagation, each of which depends on the stresses imposed and on the mechanical properties of the material, including the ability of the material to accommodate or to dissipate the stress.

In Portuguese churches RH values usually range from 70% to 80%, however these values of RH during summer can drop to 45% due to the very high temperatures outdoors (between 27 °C and 42 °C) (Almeida, 2004; Casanova, 2002; Professor Vasco Peixoto de Freitas,[5] pers comm. 2007). These fluctuations can promote damaging conditions for gilded surfaces.

1.1. Key literature

A group of publications about painted surfaces, including ground layers, provided a breakthrough in understanding the physical and mechanical behaviour of painted and gilded coatings (Berger and Russel, 1991; Mecklenburg, 1991a, 1991b; Mecklenburg and Tumosa, 1991a, 1991b; Michalski, 1991a, 1991b; Mecklenburg et al., 1995a,b; Mecklenburg et al., 1998; Hagan et al., 2005). However, these studies do not cover issues such as the role of a multi-layered system, nor of the different size and shape of the particles of the fillers in the different layers, nor of other effects of loading a binder with a filler, nor of the interaction between the binder and fillers. To investigate these aspects it was decided to research literature in other fields and compare the information yielded to results of experimental work on archaeological reconstructions of gilded wooden pieces, and with qualitative stress measurements. Recent pharmacy literature was found to be particularly important as it covers research into tablet coatings, which in reality provide a very similar situation to the gilded coatings. The tablet coatings are made of a polymer (binder) often loaded with solid particles (filler) and the aim is for durability during the tablets' shelf-life. Literature on engineering, polymers and industrial paint was also very informative being particularly helpful in the understanding of aspects such as crack propagation, stress measurements and physical ageing of polymers. But principally, it shed light on the beneficial effects of using a multilayer system on the durability of the gilded coatings. Finally, studies on archaeological ceramics, old lime mortars and modern concrete were also important as they refer to aspects such as the importance of a multilayer system and the role of aggregates in prevention of crack propagation.

2. Experimental work

The experimental work involved the manufacture of archaeological reconstructions of gilded surfaces, guided by the documentary and analytical evidence. These were then exposed to RH fluctuations, the main stimuli which induce damage to gilding, in order to evaluate the durability of the different grounds and of the different individual layers. To achieve this, both gilded reconstructions with double-structured grounds, and examples with single-layered grounds were assessed (see Appendix and Pombo Cardoso and Pye, 2016b).

Qualitative stress measurements[6] were undertaken during layer formation of the size alone, of the three different pastes (*gesso grosso*, *gesso mate* and chalk pastes) and of the two different systems (double-structured *gesso* system and single-structured chalk system) (see Appendix for full description).

The stress measurements were intended to evaluate the contribution of each layer and of the two different layered structures (double-structured system vs. single-structured system) to the durability of the gilding grounds. In addition, they were aimed at supporting the experimental work on the gilded reconstructions and to aid in drawing conclusions.

3. Results of experimental mechanical tests and discussion

3.1. Investigation of the effects of RH fluctuations on gilded wooden reconstructions

To summarise the results: bearing in mind that on non restrained wood cracks always occur perpendicular to the direction of stress, the *gesso grosso* layer alone seems to be more affected by high RH (i.e. tensile stress) as it cracks parallel to the grain of the wood. Conversely the layer of *gesso mate* seems to be more affected by low RH (i.e. compressive stress) as buckling occurs (Mecklenburg and Tumosa, 1991b; Michalski, 1991a; Mecklenburg et al., 1998). Though *gesso grosso* alone shows the earliest signs of deterioration (cracks parallel to the grain followed by the formation

[2] *Gesso grosso* was produced by burning natural gypsum at high temperatures. The result was a product mainly composed of anhydrite ($CaSO_4$).

[3] *Gesso mate* powder was produced by slaking *gesso grosso* powder for several days in water, which in this way rehydrates back to gypsum ($CaSO_4 \cdot 2H_2O$).

[4] Specific variety of limestone and therefore mostly composed of the mineral calcite ($CaCO_3$), formed by the sedimentation of marine micro organisms (nanofossils).

[5] Prof Vasco Peixoto de Freitas coordnated several studies about humidity problems in Portuguese buildings.

[6] As a coating stressmetre was not available (see Appendix) quantitative measurements were not possible to undertake, therefore stress measurements following the same principle were done by comparison of the deflection inflicted on a stainless steel blade gauge, by each paste, i.e. these were qualitative measurements.