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The main altarpiece of the Old Cathedral of Coimbra (Portugal): characterization of gold alloys used for gilding from 1500 to 1900

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Abstract: This paper surveys gilding methods and materials found in the original polychromy and three subsequent coatings applied to the main altarpiece of the Old Cathedral of Coimbra, between 1502 and 1900. Twenty samples from gilded surfaces were examined with optical and scanning electron microscopy for leaf thickness, and analyzed with energy-dispersive X-ray spectroscopy for alloy composition (semi-quantitative evaluation). By crosschecking the documentary data (archives and technical sources) with the analytical data, the results point out several aspects: 1) two recurrent techniques can be distinguished: water-based burnished gilding on bole, and oil-based matte gilding on mordant; 2) gold leaf thickness is clearly below one micron over time; 3) in 1502, 1583 and 1685, the hand-beaten gold corresponds to the highest grade of the metal (up to 23 carat gold). This degree of fineness corresponds to the required purity and its transcendental meaning in the religious context in which the precious metal was used. In 1900, the ternary alloy found, equivalent to 20 carat gold, is more pertinent with the restoration then carried out and perhaps with the need to save money. Research on the concentrations of characteristic trace elements present in the gold alloys is being pursued.

Résumé : *Le retable majeur de la* Sé Velha *de Coimbra a fait l'objet de quatre revêtements polychromes, parfaitement datés, de 1502 à 1900. Les dorures qui les caractérisent ont été étudiées à partir de vingt prélèvements, pour évaluer l'épaisseur des feuilles d'or (microscopie optique et électronique à balayage), la nature et la composition des alliages d'or (spectroscopie de rayons X à dispersion d'énergie). En croisant l'ensemble des données historiques, techniques et analytiques, il est possible de tirer plusieurs conclusions : 1) deux techniques de dorure sont récurrentes : la dorure brunie, à l'eau et appliquée sur bol, et la dorure mate, à l'huile et appliquée sur « or de couleur » ; 2) l'épaisseur des feuilles d'or est nettement inférieure au micron quelle que soit l'époque considérée ; 3) en 1502, 1583 et 1685, l'or battu est fin, supérieur à un or 23 carats. Ce titre est parfaitement en accord avec la pureté que l'on attendait alors du précieux métal et l'expression de transcendance dont celui-ci était le symbole. En 1900, l'alliage ternaire employé, à peu près équivalent à un or 20 carats, répond davantage aux besoins de la restauration entreprise à cette date et, peut-être, à un souci d'économie. Une recherche sur la concentration des éléments traces, caractéristiques de l'or suivant sa provenance, est en cours.*

Keywords: Altarpiece, analysis, gilding, gold alloys, manufacturing technologies, polychromy.

Mots-clés : *Alliages d'or, analyses, dorure, polychromie, retable, techniques anciennes.*

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1. Introduction

One of the most prestigious creations of its time, the main altarpiece of the Old Cathedral of Coimbra (Portugal) was commissioned in 1499 by Bishop D. Jorge de Almeida. The work was carried out by two migrant masters who came from Southern Netherlands, but worked in the Iberian Peninsula: Olivier de Gand (sculptor) and Jean d'Ypres (painter-gilder) (Fig. 1). This imposing Portuguese-Flemish altarpiece (thirteen meters high) still exhibits the colour scheme of the 16th century, which used abundant gold and blue, typical of flamboyant Gothic. In fact, it was totally or partially coated four times over the five hundred years of its existence. Research into the historical records allows us to date each campaign very precisely: in 1502 (gothic and original polychromy) (Garcia, 1923), in 1583 (refurbishment restricted to a few parts) (Garcia, 1923), in 1685 (new baroque polychromy) (Louro, 1983; Le Gac, 2004a) and in 1900 (complete restoration) (Vasconcelos, 1930). Gold coatings were applied systematically during these four periods and, in all cases, in the form of gold leaf. The use of very thin hand-beaten gold leaf[1] was already established on wooden sculptures in Northern Europe during the 11th century (Serck-Dewaide, 1991).

Numerous publications concerning sacred polychrome artworks contain reports of the use of metallic leaves applied on wooden substrates. The collective work entitled *Gilded Wood* (Bigelow *et al.*, 1991) remains the seminal publication in this field. However, studies focussing on the quality of the alloys, on the beating process, and on the thickness remain rather scarce, despite the pioneering work undertaken in Portugal by Natalia Alves[2] (1989), Maria Teresa Marques[3] (1998) and Isabel Ribeiro (Moura *et al.*, 2004).

The main altarpiece of Coimbra provides us with an excellent opportunity to examine the trade practices of gilders in Portugal between 1500 and 1900, and more specifically:

1) To study the different techniques applied for gilding the altarpiece.

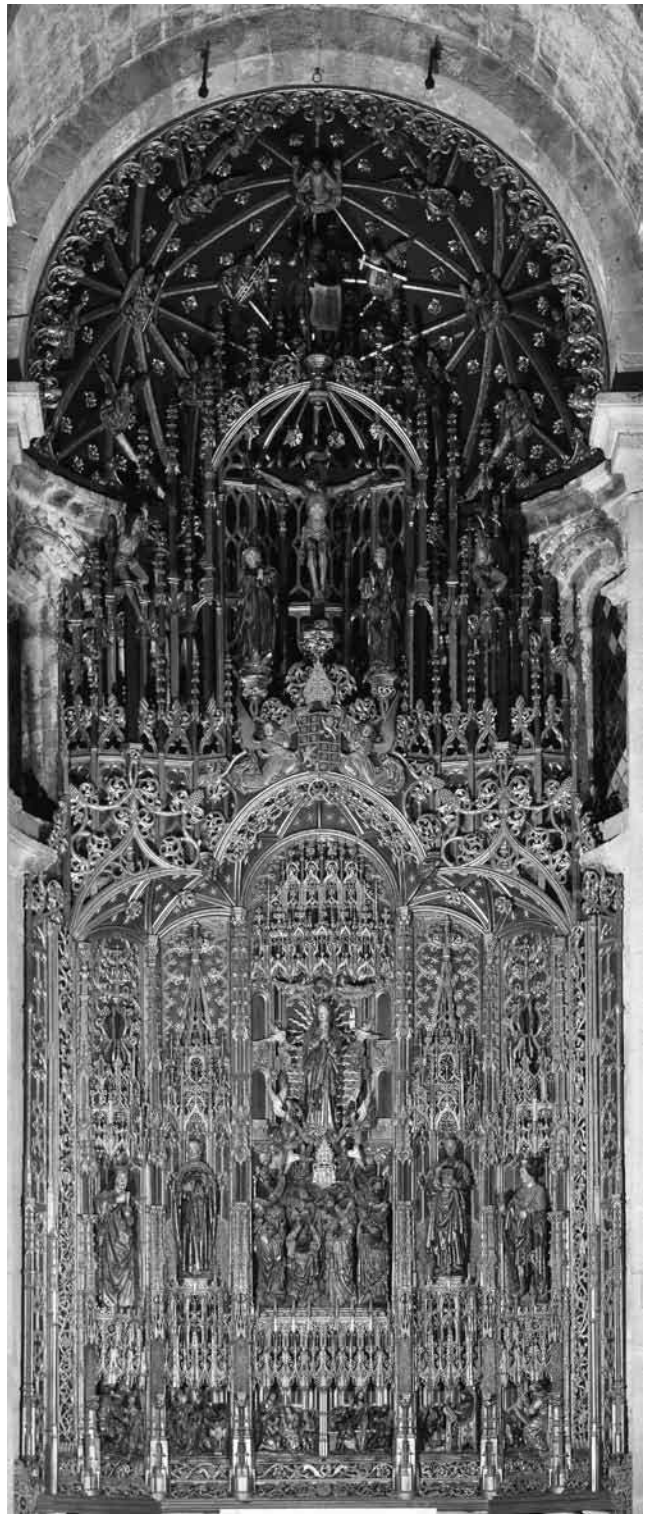

Figure 1: (See colour plate) Main altarpiece of the Old Cathedral of Coimbra (1502).
Figure 1 : (Voir planche couleur) Retable majeur de la Sé Velha de Coimbra (1502) © J. Pessoa.

1. Several specialists who talk about hand-beaten gold (Bigelow *et al.*, 1991) point out two terms in English: 'foil', to refer to thin metal that can support itself, holds its shape when bent, and may be attached mechanically; and 'leaf', to refer to even thinner limp metal that requires some adhesive to be laid on a substrate.

2. Natália Alves compiled many deeds executed by notaries related to the gilding of altarpieces in the North of Portugal in the 17th and 18th centuries, and found several technical aspects by crosschecking the data with goldbeaters' practices. This documentary investigation should be confronted with the tangible aspects of the altarpieces in question.

3. This research, dealing with the qualitative and quantitative analysis by TEM-EDS of the gold alloys used in Portugal on several baroque altarpieces, has unfortunately not been published.

2) To verify if the sets of technical particulars from each coating are pertinent to the written historical records and sources on gilding. In addition to medieval and Renaissance treatises, consulted for Western European practices, priority was given to ordinances and contracts written in Portugal from the 16th to the 19th century.

3) To search for information on the gold products, as well as on their specific output.

4) To study the caratage (ct) and thickness of the gold leaf wherever possible, taking into account the fact that only traces of the original polychromy and its refurbishment of 1583 remain today, as they were almost completely stripped off in 1685. The baroque re-polychromy, which is the stage most visible today, together with the restoration carried out in 1900 are therefore the two interventions which best allow systematic research.

2. Methods

Twenty samples were taken from the gilded parts of the altarpiece (architectural structure, several statuettes, and statues from the first and third tiers). They were mounted in synthetic resin and prepared as cross-sections. All layers were first examined by optical microscopy and scanning electron microscopy (SEM) for high magnification images. The composition of the gold alloys was ascertained using energy-dispersive X-ray spectroscopy (EDX), which permits major element point analysis and semi-quantitative evaluations. Because the samples were very small (0.5-1 mm^3) and the layers so well adhered to one another, the gold leaf could not be separated[4] from the surrounding materials, either below (such as bole) or above (such as paint: lead white, verdigris, vermilion). We therefore tried to ascertain the compounds of these surrounding layers by X-ray diffraction (XRD) and by SEM-EDX, and to consider how their elemental composition (Ca, Fe, Pb, Hg, Cu, Sb, Ti, etc.) might interfere with that of the gold leaf and with the level of impurities found within the gold.

3. Results and discussion

Techniques

Depending on the type of surface to be covered (architectural structure or statuary of the altarpiece), the means employed, and the final effect required, two recurrent gilding techniques can be distinguished:

l) Water gilding, on bole or '*assiette à dorer*', composed of ochre and/or clays bound in a proteinaceous medium (usually an animal glue or egg white), whose presence is meant to allow the gold leaf to be fixed by moistening the bole. Once dry, the gilded part can be polished with an animal tooth or an agate stone to obtain a brilliant and shiny finish, hence its name of 'burnished gilding'. For this method, the wooden substrate has to be properly primed with a thick white ground, which offers better compressive strength during the burnishing. In Southern Europe, such a whiting consists of calcium sulphate in its anhydrite form (gesso) and/or bihydrite form (gypsum), applied with a proteinaceous binder.

2) Oil gilding, over mordant or '*or de couleur*', composed of a fat layer made of a drying-oil containing pigments rich in metallic oxides. The gold leaf was laid on when this layer was nearly dry. It cannot be polished, hence its generally accepted name of 'matte gilding'[5]. This technique requires less care in preparation and execution.

In both cases, there will be an influence on the tone of the gold from the coloured underlayers.

In **1502** we observe: 1) water gilding on the structure of the altarpiece, where the gold leaf is applied to an extremely fine bole of a very pale orange colour (Fig. 2); 2) oil gilding on tin leaf in the production of 'appliqué relief brocades'[6] which still exist in the niches in the first, third and fourth tier, and that perhaps once also covered the rich garments of the figures. Here, the gold leaf is laid on a translucent and reddish oil layer containing lead-based pigments. While a translucent red glaze, essentially organic, brings out the contrast of the brocade pattern in the first tier, we found evidence of a translucent greenish copper glaze in one cross-section from the third tier.

In **1583**, we observe only oil gilding, applied on the architectural structure without prior whiting, to refresh some parts. The topography of the gold leaf is very irregular. It has been attached to a thick dark red layer containing coarsely ground lead-based pigments, clays and iron-oxides (Fig. 2).

4. By washing, as M.T. Marques (1998) did when studying by TEM-EDS gold leafs sampled from baroque altarpieces.

5. Even though the surface of a non-burnished water gilding could achieve a poor reflective effect as well, leaving a low gloss surface, sometimes quite dull, without any brilliancy.

6. 'Appliqué relief brocade' refers to both the imitation of sumptuous brocades and the technique itself, by reproducing the relief design and gluing it to wooden and gessoed panels or sculptures. Following a certain pattern unit, motifs ranging from 4 cm to 20 cm high were engraved in wood or metal, allowing a production of a great number of gilded tin leaves. The richly woven texture of fabrics embroidered in gold thread was imitated by placing the leaves side by side. For further information, see Serck-Dewaide (1991).

The entire process clearly indicates that Fernão da Costa, who carried out the work in only eight days, did not have enough time to execute the gilding more carefully by applying water gilding and covering larger areas.

In **1685**, as stipulated in the contract of 1684, all the carved elements of the structure and the statuary were treated with burnished gilding (with the exception of flesh tone, hair, and beard), which was laid on an orange bole (Fig. 2). Water gilding was all the more imperative for the clothing once the technique of *sgraffito* ('*estofado*' in Portuguese) was also required by the commissioner. This other technique, closely connected with gilding (described in detail by Nunes [1615] and Pacheco [1649]), reproduced the brocade fabrics still in fashion. It involved painting a colour in egg tempera over burnished gilding and stripping off the paint selectively in different design patterns to expose the shiny gold beneath (Serck-Dewaide, 1991). A small raised hand moulded texture, meant to imitate to perfection the weft looped weave of Italian or Spanish brocades, was applied to complete the surfaces of the clothing (Le Gac, 2004b). Such final decorations are made in wax, hence water repellent; therefore, they are the only ones covered with oil gilding (not mentioned in the contract). Between the wax and the gold leaf, we found a very fine '*or de couleur*', whose complex elemental composition led us to believe that palette scrapings could have been boiled with oil.

In **1900**, during the restoration, 1) three movable groups of the predella were completely or partially replaced with new elements and then water gilded. The gold leaf was laid on a pinkish bole and carefully polished. 2) Matte gilding was used on the damaged elements of the architectural structure (moulding, stars glued on the flat areas, or small fixed figures). This matte gilding is applied on a thick oily layer of a light yellow colour[7], rich in lead, barite, cadmium and chrome compounds, which reveal the wide range of pigments available. In places, there are indications of a hurried application and lack of care: pigmented oil splashes over the blue background, and wrinkles on the gold leaf (it appears to have been laid on too soon, before the ground had dried out sufficiently). In contrast, the water gilding has been applied with a high degree of craftsmanship. Whether this indicates two separate gilders, or is a factor of viewing distance (the oil gilding is much further away), it is not clear.

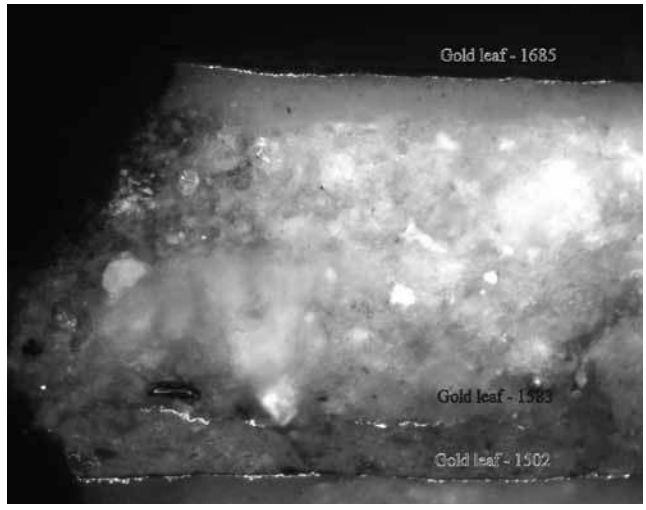

Figure 2: (See colour plate) Cross-section of the gilding (R-O1). Optical microscope, magnification 100x.
Figure 2 : (Voir planche couleur) Coupe transversale d'échantillon (R-O1) comportant trois dorures successives (MO 100x).

Gold-beating process and raw material

Up until the 18th century, gold leaf came from mint gold coins rather than from raw gold, described as '*or vierge*'. Sources, either concerning Portugal or other countries in Europe, refer to the use of "*ducados"* (Cennini, ca. 1400), "*scudi*" (Vasari, 1550), "*cruzados*" (*Livro dos Regimentos* 1572), "*piastres*" or "*anciennes monnaies d'Espagne*" (Diderot and d'Alembert, 1752), or very simply to "*moedas de ouro*" (Brandão, 1985). While some coins were undoubtedly pure gold, others would have been alloys. This suggests that gold-beaters must have known how to refine debased coin species by cupellation and quarting (Guerra and Gondonneau, 1998).

Thickness of the gold leaf and its performance

Early sources indicate that the thickness of the metal leaves was of great importance because: 1) it affects the spreading capacity and performance of the leaf; 2) a very thin leaf creates an illusion at a lower cost, since it can be applied to materials of inferior quality, giving the impression that they are made out of solid gold or silver; 3) while thicker leaves are well adapted to flat surfaces, thinner leaves are more suitable for carved elements.

Gold and silver, in thinly beaten leaves, will cover larger areas with a much reduced weight of metal. Table 1 summarizes the documents where we found one or more references to the type of gold used (mint gold coins or raw

7. We verify thus that gilders continued to use an '*or de couleur*', whereas, at the end of the 18th century, they were inclined to use '*mixtion*', an oil-based substance leaving an extremely thin layer when dry. In Portugal, at the very beginning of the 20th century, Castro da Silva (1900) reiterates both uses of '*or-couleur*' and '*mordente*'.

Date Author	Gold – Raw material	Weight at that time*	Weight in grams	Number of gold leaves	Gold leaves original dimensions*	Dimensions in cm + Surface in cm²	Ratio 1 *once* / leaves + output (square meters)
IstC Pliny	**Raw gold Italy / Roma**	**1 *once***	**28,6875 g**	**500 leaves *bractea Preanestinæ* 700 leaves *bractea quæstoriæ***	***Quatre doigts en carré*** quatre pouces de côté	**10,828 cm x 10,828 cm → 117,2455 cm²**	**1once / 500 ls → 586,23 m² 1once / 700 ls → 820,72 m²**
1437 Cennini	**Mint gold coins 1 *ducato* - Italy / Venezia**	**[c. 1 *gros*]**	**3,495 g**	**145 leaves**	**?**	**?**	**1 once / 1190 ls**
1550 Vasari	**Mint gold coins 6 *scudi* / écus d'or France – Louis XII (1498-1515) ?**	**[c. 1 *gros*]**	**6 x 3,496 g = 20,976 g**	**1 000 leaves**	***ottavo di braccio per ogni verso*** un huitième de *braccio* de côté un huitième de coudée de côté	**7,287 cm x 7,287 cm → 53,1 cm² 8,25 cm x 8,25 cm → 68,0625 cm²**	**1 once / 1368 ls → 726,41 m² → 931,09 m²**
1572 *Règlement*	**Mint gold coins 3 *cruzados* - Portugal**	**3 x 1,07 *gros***	**3 x 3.8387 g = 11,5161 g**	**500 leaves**	**?**	**?**	**1 once / 1246 ls**
1676 Félibien	**Raw gold France**	**4 *gros* or 5 *gros***	**4 x 3,586 g 5 x 3,586 g**	**1 000 leaves 1 000 leaves**	***Diverses grandeurs de feuilles***	**?**	**1 once / 2000 ls or 1 once / 1600 ls**
1690 Furetière	**Raw gold France**	**1 *once***	**28,6875 g**	**1 600 leaves**	***37 lignes en carré*** trente-sept lignes de côté	**8,3464 cm x 8,3464 cm → 69,66 cm²**	**1 once / 1600 ls → 1114,56 m²**
1750 Savary des Bruslons	**Raw gold «*Or en chaux*» or «*Or de départ*» France**	**5 to 6 *grains* 9 to 10 *grains***	**0,249 à 0,298 g 0,448 à 0,498 g**	**25 leaves *Petite mesure* 25 leaves *Grande mesure***	***Trois pouces en quarré*** trois pouces de côté ***Quatre pouces en quarré*** quatre pouces de côté	**8,121 cm x 8,121 cm → 65,95 cm² 10,828 cm x 10,828 cm → 117,2455 cm²**	**1 once / 2880 à 2407 ls 1899,36 à 1587,42 m² 1 once / 1600 à 1440 ls 1875,93 à 1688,34 m²**
1752 Diderot	**Raw gold France or Mint gold coins *Piastre* or other old coins species from Spain**	**1 *once* 7 *gros* ?**	**15 gros = 53,7895 g** }	**Total = 3 200 leaves Booklet with 25 leaves** } **Booklet with 25 leaves**	***Surface de 16 pouces en quarré le côté est de quatre pouces*** ***le côté de trois pouces et demi*** }	**10,828 cm x 10,828 cm → 117,2455 cm² 9,4745 cm x 9,4745 cm → 89,76 cm²** }	**1 once / 1706 ls → 2000,21 m² 1 once / 1706 ls → 1531,31 m²**
1766 *Guide*	**Raw gold ? *Marchands de Paris* / France**	**?**	**?**	**?**	***37 lignes au carré*** trente-sept lignes de côté	**8,3464 cm x 8,3464 cm → 69,66 cm²**	**?**
1778 Watin	**Raw gold France**	**4 *gros* or 5 *gros***	**4 x 3,586 g 5 x 3,586 g**	**1 000 leaves 1 000 leaves**	***Diverses grandeurs de feuilles***	**?**	**1 once / 2000 ls or 1 once / 1600 ls**
1830 *Dictionnaire*	**Raw gold**	**0,065 g [2 *onces*, 2 *gros*, 9 *grains*]**	**0,065 g 65 g**	**?**		**→ 3,068 m² → 3068 m²**	**1 once / ? → 1354,53 m²**
1992 Perrault	**Raw gold**	**1 kg**	**1000 g**	**100 000 leaves Booklets with 25 leaves** }	**7 cm x 7 cm = 49 cm² or 8 cm x 8 cm = 64 cm²**		**1 once / 2870 ls → 1406,30 m² 1 once / 2870 ls → 1836,80 m²**

* Units of weight: 1 *once* (8 *gros*) = 28.6875 g ; 1 *gros* (72 *grains*) = 3.586 g; 1 *grain* = 0.0498 g – Units of length: 1 *ligne* (12 *points*) = 2.2558 mm ; 1 *pouce* (12 *lignes*) = 2.7070 cm; 1 *coudée* [cubit] = 66 cm.

Table 1 : Weight* of gold used for the beating process and output by square meters obtained with the beaten gold leaves, according to several documentary sources.
Tableau 1 : Poids d'or utilisé pour la batte, et « rendement superficiel » des feuilles battues à partir de quelques sources anciennes.*

gold), the weight of gold required for the beating process**,** the number of leaves obtained and/or their dimensions. The number of leaves obtained from an approximate weight of 28 g increases significantly over time. The number of leaves rises from 500-700 in the 1st century (Plinius) to 1190 in the 14th century (Cennini), to 1366 in 1550 (Vasari), to 1600-2000 in 1690 (Furetière), until 2407-2880 in 1750 (Savary des Bruslons). The increase of the area covered is also significant, successively from 726-931 m^2 in the 16th century (Vasari, 1550), to 1114 m^2 during the 17th century (Furetière, 1690), and 1587-1899 m^2 in the 18th century (Savary des Bruslons, 1750).

The observation of all the gold leaves of the main altarpiece of Coimbra with SEM (magnification up to 5000x) reveals thicknesses clearly below 1 µm, varying between 0.24 and 0.45 µm. These dimensions are not absolute, since there are other parameters to consider: 1) gold, even burnished, presents an irregular surface on a micrometric scale; 2) if flaking off, the gold leaf seems to be thicker than in reality; 3) overlaps can falsify the findings as well; 4) if sample cross-sections are not precisely positioned, any slight deviation can be sufficient to modify the apparent thickness of all the layers.

Although Cennini (ca. 1400) recommended "*the use of thicker gold on panels and thinner gold on mouldings and leaves*", we have not studied this aspect. In the altarpiece, the flat surfaces are reserved for the application of the colour blue. The other parts of the architectural structure and the statuary are all carved in the round, resulting in more or less complex volumes and an unclear demarcation between flat and rounded areas.

Caratage (ct) and gold leaf quality

On the entire set of results obtained by SEM-EDX, Au is present in the highest quantity. Its purity is such that, between 1502 and 1685, gold appears to have been the sole metal acceptable. The elemental composition of the gold shows very minor amounts of Cu and sometimes, but rarely, Ag. Most of the time, the readings for Cu and Ag fall below the margin of error. Nevertheless, every time a peak for Cu or Ag appeared in the spectra, even if very weak, those elements were taken into account, in case they were present as traces. The original gilding (1502) has a high Au content (wt%), more than 99%; the one from 1583 shows a little Cu (one analysis, among the four we carried out, indicated that it contains 1.6% Cu); and Cu was found as well in 1685, from circa 0.5% to 4.5%, according to the specific decorative surfaces (water or oil gilded). These results indicate that either high purity native gold alloys were used for making the gold leaf, when Cu reaches a concentration of ca. 1% (Guerra and Calligaro, 2003), or that Cu was intentionally introduced in the fabrication of the very thin leaf to modify its hardness[8], and, perhaps, colour. The last, 1900 gold leaf is of lower quality. It clearly corresponds to an Au-Ag-Cu alloy – the so-called 'ternary alloy' obtained when the three metals are intentionally mixed together – in which Au is nearing 83%, and which is approximately equivalent to a 20 ct gold alloy.

In interpreting the results from the perspective of the History of Art in general and of the history of the altarpiece in particular, it is useful to consider the following aspects:

At the **end of the 15th century**, and according to guild regulations, for Brussels in 1454 and Antwerp in 1470 (Pagès-Camagna, 2002) for example, only fine gold could be used by the painter-gilders on altarpieces. Jean d'Ypres would not only have been fully aware of such restrictions, but would have also imported this practice with him (as he did for many other techniques applied by the workshops of Brabant that we found on the altarpiece of Coimbra). In Portugal, however, the control over materials was the privilege of the commissioner. Taking into account the awe-inspiring spectacle Bishop D. Jorge de Almeida sought to produce with his imposing project (Vasconcelos, 1930), he had no reason not to impose the greatest refinement, and therefore the use of a very pure gold[9]. This aspect has been verified by the present study.

In **1583**, the amounts of money assigned to the purchase of materials and the manpower necessary for refurbishing the altarpiece were limited. Only 1100 real were allocated for the gold leaf. At that time, a "*milheiro*" (a "thousand", i.e. ten booklets of a hundred gold leaves each) cost between 3000 and 5000 real, depending on where it was obtained (Lisbon or Oporto), but perhaps also on how the gold was produced, its thickness and fineness. As the analyses show, very pure gold has been utilized, indicating that Fernão da

8. Fully aware that "*Gold in its perfect pure form is soft*" and that "*the more metals are hard, the more they can have a beautiful polish*" (Diderot and d'Alembert, 1765), we wonder if the presence of copper in gold leaves was meant to make the alloys slightly harder and turn the gilded surfaces more brilliant when burnished. In any case, it appeared that the intentional addition of copper did not hinder beating the gold to obtain leaves of an extreme thinness.

9. Different types of gold leaf were fabricated at that time and are specially mentioned to be used for artistic purposes in contracts written in Portugal in the 15th and 16th centuries (Garcia, 1923). The '*ouro meão*' or '*ouro meado*' – the so-called '*Zwischengold*' in German, '*oro di metà*' in Italian and '*party gold*' in English – made up part of the set. The '*ouro meão*' corresponds to a gold leaf and a silver leaf beaten together, equal in strength to a single metal leaf, whose gold side is used as the outer surface. Considering its deceptive appearance and low cost, associated with its poor aging, its use for artworks was proscribed in Lisbon in 1539, and again in 1572.

Costa did not compromise by using a low-grade and cheaper alloy; he rather respected the transcendental meaning of the most precious metal above all others in the religious context in which it had to be used.

At the **end of the 17th century**, the gilding of the altarpiece was a matter of priority for Bishop D. João de Mello, and while the changes represented the cutting edge of the new baroque polychromy, the dichromatic (gold and blue) character of the gothic coating was preserved. The contract signed in 1684 insisted on the gold being "*subido", i.e. of a very high grade, "bem corado*", colourful, and "*brunido*", burnished on all the parts to be gilded (carved elements of the structure and statuary). These adjectives, used to characterize "the gold"[10] occur in a great number of Portuguese contracts of the 17th and 18th centuries (Brandão, 1984-1985; Alves, 1989; Le Gac in Serck-Dewaide *et al.*, 2004). The contract is very explicit: Manuel da Costa Pereira, the painter-gilder who was in charge, had to use fine gold, of a saturated yellow, and obtain a brilliant finish using the water-gilding technique. The mention of the colour is significant because, up to the 18th century, the quality of gold or silver was very often evaluated based on their visual aspect[11]. Any reference to colour would also be intended to differentiate 'fine gold' (24 ct gold) from 'common gold' (23.25 ct gold, redder, containing up to 12 grains of silver [2.08%] and 6 grains of copper [1.04%]), and from 'pale gold or green gold' (16 ct gold, a lot less yellow, containing up to a third of silver). These three types of beaten gold leaf were officially recognised at the beginning of the 18th century (Savary des Bruslons, 1723; Diderot and d'Alembert, 1752). It should be pointed out again that the gold caratage is not specified in the altarpiece contract. The mention of the gold caratage is practically – not to say totally – omitted in the contracts of this period[12]; hence the importance of finding a deed signed by the same artist in 1686 for the gilding of another altarpiece, in which it was stipulated "*to use a pure twenty four-carat gold similar to the one employed on the main altarpiece of the Cathedral [of Coimbra]*" (Garcia, 1923). This demand is all the more exceptional because it refers to a perfectly pure gold. According to Furetière (1690) and Savary des Bruslons (1723), this was extremely difficult to obtain: "*gold can never be refined up to this [level] – 24 carats – there are always some small fractions missing*". Diderot and d'Alembert (1768) add: "*it is enough that the test tube reports 23 carats to the gold leaf be reputed fine, as the missing weight cannot be prejudicial to the highest-grade gold*".

We therefore conclude, considering the results we obtained by SEM-EDX, that Manuel da Costa Pereira respected the terms of the contract. Taking into account the enormous amount of gold present, the gilding shows great consistency, both in quality and execution, despite the participation of many individuals organised in a workshop, as was usual at this period for large-scale operations. Such homogeneity is dependent first on the goldbeater, in Portugal, who had to produce all the "*milheiros*" necessary for the gilding of a single artwork (Brandão, 1985; Alves, 1989). It seems, however, that the differences observed in the gold caratage between water gilding and oil gilding were likely due to the painter-gilder himself or one of his craftsmen. The results for oil gilding clearly show that it was a deliberate choice to use a low-grade gold on statuettes, where gilding was required on the small wax ornaments (which had been first applied to the garments of the small figures). We were not able to establish if the use of ca. 21.5 ct gold leaf was a matter of economy – a low-grade gold cannot be noticed on very small objects – or if it was rather an aesthetic concern, that of differentiating burnished gold from matte gold.

The caratage of the gilding used in the **1900** restoration does not comply with the purest commercial grade accessible at the time (a 23 ct gold), that was especially manufactured, among other gold alloys for indoor exposure, in Lisbon, by *A Favrel Lisbonense* (Varella, 1901) (Table 2). Both caratages identified by SEM-EDX (20 ct and c. 19.5 ct) correspond to Varella's yellow greenish gold alloys: either "*cidrão claro*" ("light citron" – 20 ct gold) or "*verde 1ª*" ("extra fine green" – 19 ct gold)[13]. Once again, was the quality of the gold leaf chosen for an economic reason or an aesthetic one? The gold alloy used in the gilded surfaces would have resulted in an obvious change of hue, from an original warmer tone to a pale one, reinforced by the very light yellow ground over which the gold leaf was laid. While the restoration appears

10. In French, as well as in Portuguese, the word 'gold' ('*or*' / '*ouro*') in use at this time means 'gilding' ('*dorure*' / '*douramento*'), the latter being rather reserved to textile art (gold or silver wire, in lamella and filé).

11. Until the 18th century, the sworn assayers from The Royal Mint used the touchstone (a small tablet of dark stone) to assay precious metal alloys. On one hand, they left on the touchstone a visible trace of each reference gold alloy, fabricated as a little stick and whose caratage was well known (known as '*toucheaux*' in French); and on the other hand, they did the same with the metal alloy they had to control. "*According to the degree of conformity they found between the color of this latter metal and the color of a determined reference alloy, they were able to decide on its purity*" (Diderot and d'Alembert, 1765). We thus understand better why commissioners accorded such extreme importance to the colour of the gold alloy.

12. Among hundreds of contracts they red, Natália Alves found only three (dated 1712 and 1737) that refer to the gold alloy caratage, more specifically to a "*23.5 carat gold"* (Alves, 1989) and Fausto Sanchez Martins (1994) found one contract (dated 1710), that stipulates the use of a "*twenty-three and two thirds carat gold*".

13. The list of colours available in England in 1929, published by Andrew Lins (1991), shows that the designation of gold leaves according to their alloy quality varies from one country to another, and from date to date. The one that we are considering is not standardised.

Colour	Caratage	Dimensions	Nº of leaves	Cost (*real*)
Amarello Yellow	23 ct	**Nº 5** 93 mm x 93 mm	1000	23$000
			25	0$600
		Nº 4 86 mm x 86 mm	1000	21$000
			25	0$540
		Nº 3 84 mm x 84 mm	1000	19$000
			25	0$490
		Nº 2 81 mm x 78 mm	1000	17$000
			25	0$440
		A 65 mm x 63 mm	1000	14$000
			100	1$500
		AA 59 mm x 57 mm	1000	13$000
			100	1$400
		A: 65 x 63 mm	5	0$090
Amarello Yellow	22 ct	**Nº 5** 93 mm x 93 mm	1000	20$000
			25	0$520
		Nº 4 86 mm x 86 mm	1000	18$000
			25	0$460
		Nº 3 84 mm x 84 mm	1000	17$000
			25	0$440
		Nº 2 81 mm x 78 mm	1000	16$000
			25	0$410
		A 65 mm x 63 mm	1000	13$000
			100	1$400
		AA 59 mm x 57 mm	1000	12$000
			100	1$300
		A: 65 x 63 mm	5	0$080
Vermelho Red	23 ct	**Nº 5** 93 mm x 93 mm	1000	23$000
			25	0$600
Córado Deep	22,5 ct	**Nº 5** 93 mm x 93 mm	1000	22$000
			25	0$560
Cidrão Fino Fine Citron	22 ct	**Nº 5** 93 mm x 93 mm	1000	21$000
			25	0$540
Cidrão Escuro Dark Citron	22 ct	**Nº 5** 93 mm x 93 mm	1000	21$000
			25	0$540
Cidrão Claro Light Citron	20 ct	**Nº 5** 93 mm x 93 mm	1000	20$000
			25	0$520
Verde 1ª Extra Fine Green	19 ct	**Nº 5** 93 mm x 93 mm	1000	19$000
			25	0$500
Verde Fino Fine Green	18 ct	**Nº 5** 93 mm x 93 mm	1000	18$000
			25	0$460
Verde Claro Light Green	15 ct	**Nº 5** 93 mm x 93 mm	1000	16$000
			25	0$410
Branco White	12 ct	**Nº 5** 93 mm x 93 mm	1000	14$000
			25	0$360

Table 2: Gold alloys for indoor exposure, available at A Favrel Lisbonense in 1901.
Tableau 2 : Alliage d'or en feuilles pour dorure d'intérieur, disponibles chez A Favrel Lisbonense en 1901.

well blended nowadays, we wondered whether, at the time of application, there had been an attempt to visually 'integrate' the new gilding. In the samples of the most recent oil gilding, we did not find any tinted layer above it which would have provided a certain patina.

Further investigation: Origin of the gold supply

These preliminary results, compared with the precisely dated documents to which we had access, and with published studies on the circulation of gold in the past (Godinho, 1971; Guerra and Calligaro, 2003), led us to formulate some theories about the provenance of this metal: for the first metal leaf (1502), it is possible that the gold came from Northern Africa, for the second (1583) from Western Africa, for the third (1685) *via* the Spanish from the mines of Colombia, and for the fourth (1900) from Brazilian ores. It proved difficult to confirm the provenance of the gold in this study for various reasons: the very thin layers of gold (0.24-0.45 µm) available for study, and their location, surrounded by materials whose elemental composition could compromise the characterisation of trace elements in the gold. Indicators, such as the presence of Pt in the gold leaf from 1685, or Pd in the leaf from 1900 (Guerra and Calligaro, 2003), could provide a certain provenance. However, attempts to identify them using particle induced X-ray emission (PIXE) or synchrotron radiation X-ray fluorescence spectroscopy (SR-XRF) did not yet provide satisfactory results. This study is currently being pursued.

On the main altarpiece of the cathedral of Coimbra, different gilders applied the procedures of their time while perpetuating an age-old craft tradition that changed little since the one described by Cennini (ca. 1400). This study has revealed new information, but in order to understand how widespread these practices were, we must rely on further research. We look forward to further information on three Oporto gilded altarpieces provided in the study of Bidarra *et al.* (2009) in order to broaden our understanding of the gilding techniques used in Portugal, particularly during the baroque period.

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References

Alves, N.M.F., 1989. *A arte da talha no Porto na época barroca. (Artistas e clientela. Materiais e técnica), Volumes 1 and 2*. Porto, Câmara Municipal do Porto.

Bidarra, A., Coroado, J. and Rocha, F., 2009. Gold leaf analysis of three baroque altarpieces from Porto. *ArcheoSciences* 33.

Bigelow, D. *et al.* (eds.), 1991. *Gilded Wood: Conservation and History*. Madison, Connecticut, Sound View Press.

Brandão, D. de P., 1984-1985. *Obra de talha dourada, ensamblagem e pintura na cidade e na diocese do Porto. Documentação I, séculos XV a XVIII-Vol. I / Documentação II, 1700-1725 – Vol. II / Documentação III, 1726-1750 – Vol. III*. Porto, [s.n.].

Castro Da Silva, F.L.T. de, 1900. *Algumas indicações sobre a arte de dourar*. Lisboa, Typografia do Commercio.

Cennini, C., [ca. 1400] 1991. *Le Livre de l'art* (*Il libro dell'arte*). Traduction critique, commentaires et notes par Colette Déroche. Paris, Editions Berger-Levrault.

Correia, V. (ed.), 1926. *Livro dos Regimentos dos Officiaes mecanicos da mui nobre e sepre leal cidade de Lixboa* [1572]. Coimbra: Imprensa da Universidade.

Diderot, D. and D'Alembert, J.L.R., 1752 / 1765 / 1768. *Encyclopédie, ou dictionnaire raisonné des Sciences, des Arts et des Métiers, par une Société de gens de Lettres*. Paris, Chez Briasson, David, Le Breton & Durand, Vol. II (1752) / Neufchastel, Chez Samuel Faulche & Compagnie, Vol. VIII (1765) and XI (1768).

Félibien, A., 1676. *Des principes de l'architecture, de la sculpture, de la peinture et des autres arts qui en dépendent. Avec un dictionnaire des termes propres à chacun de ces arts*. Paris, Chez Jean-Baptiste Coignard.

Furetière, A., 1690. *Dictionnaire Universel, contenant generalement tous les Mots François, tant vieux que modernes & les Termes de toutes les Sciences et des Arts, Volumes 1-3*. La Haye, Chez Arnout & Régnier Leers.

Garcia, P.Q., 1923. *Artistas de Coimbra. Documentos para as suas biografias*. Coimbra, [Imprensa da Universidade].

Godinho, V.M., 1971. *Os descobrimentos e a economia mundial, Vol. 1-3*. Lisboa, Editorial Presença (2nd edition).

Guerra, M.F. and Calligaro, T., 2003. Gold cultural heritage objects: a review of studies of provenance and manufacturing technologies. *Measurement in Science and Technology* 14: 1527-1537.

Guerra, M.F. and Gondonneau, A., 1998. As tecnologias de fabrico das ligas amoedáveis e a proveniência dos metais amoedados: perspectivas abertas pelas novas técnicas de análise elementar, in F.A. Magro (ed.), *Actas IV Congresso Nacional de Numismática*. Lisboa, Associação Numismática de Portugal, 369-402.

Le Gac, A., 2004(a). Le retable majeur de la Sé Velha de Coimbra (Portugal) et sa polychromie de 1685, in *Retables in situ. Conservation & restauration*. Preprints des 11es journées d'étude de la Section Française de l'Institut International de Conservation, Roubaix, 24-26 juin 2004. Champs-sur-Marne, SFIIC, 111-124.

Le Gac, A., 2004(b). Les techniques de polychromie des "Broderie d'application" et des "bouclés par la trame" – Etude préliminaire, in A.I. Seruya (ed.), *POLICROMIA. A escultura policromada religiosa dos séculos XVII e XVIII. Estudo comparativo das técnicas, alterações e conservação em Portugal, Espanha e Bélgica. Actas do Congresso Internacional, 29-31 Outubro 2002*. Lisboa, Instituto Português de Conservação e Restauro, 79-94.

Lins, A., 1991. Basic properties of gold leaf, in *Gilded Wood. Conservation and History*. Sound View Press, Madison, Connecticut, 17-23.

Louro, J.M.S., 1983. O restauro do retábulo da Capela-mor da Sé Velha no séc. XVII. *Mundo da Arte* 13: 60-63.

Martins, F.S., 1994. *A arquitectura dos primeiros colégios jesuítas de Portugal: 1542-1759*. PhD Thesis, Faculdade de Letras, Porto, 2 volumes.

Marques, M.T.R., 1998. *Análise do revestimento metálico de talha dourada por MET/EDS*. Relatório de Stágio / Licenciatura (M.A. in Science), Universidade de Lisboa, Portugal (Unpublished).

Moura, C., Barreiro, A. and Ribeiro, I., 2004. Os bustos-relicário. Alguns casos notáveis da escultura seiscentista de barro em Alcobaça, in *POLICROMIA. A escultura policromada religiosa dos séculos XVII e XVIII*, 63-70.

Nunes, P., [1615] 1982. *Arte da Pintura. Symmetria, e Perspectiva*. Fac-similé de l'édition originale, Introduction de Leontina Ventura. Porto, Editorial Paisagem.

Pacheco, F., [1649] 1990. *Arte de la Pintura*. Madrid, Editorial Cátedra.

Pagès-Camagna, S., 2002. La polychromie des sculptures brabançonnes du Musée du Louvre sous l'œil du microscope, in *Retables brabançons des XVe et XVIe siècles. Actes du Colloque du Musée du Louvre, 18-19 mai 2001*. Paris, La documentation Française, 103-126.

Savary des Bruslons, J., 1723/1750. *Dictionnaire Universel de Commerce. Volumes 1-3*. Paris, Chez Jacques Estienne.

Serck-Dewaide, M., 1991. The history and conservation of the surface coating on European gilded-wood objects, in D. Bigelow *et al.* (eds.), *Gilded Wood: Conservation and History*. Madison, Connecticut, Sound View Press, 65-78.

Serck-Dewaide, M. [*et al.* / Belgium], Campoy, M. [*et al.* / Spain], Le Gac, A. [*et al.* / Portugal], 2004. Les techniques utilisées dans l'art baroque religieux des XVII^e^ et XVIII^e^ siècles au Portugal, en Espagne et en Belgique, in A.I. Seruya (ed.), *POLICROMIA. A escultura policromada religiosa dos séculos XVII e XVIII. Estudo comparativo das técnicas, alterações e conservação em Portugal, Espanha e Bélgica*. *Actas do Congresso Internacional, 29-31 Outubro 2002*. Lisboa, Instituto Português de Conservação e Restauro, 119-155.

Varella, J.N., 1901. *Preço corrente de A Favrel Lisbonense. Fabrico de ouro e prata em folhas e em pó*. Lisboa, Typografia do Commercio.

Vasari, G., [1550] 1996. *Le tecniche artistiche*. Introduzione e commento di Gerald Baldwin Brown. Vicenza, Neri Pozza Editore.

Vasconcelos, A. de, 1930. *Sé-velha de Coimbra (Apontamentos para a sua história)*. Coimbra, Imprensa da Universidade.