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The Polychromy of English Medieval Alabaster Panels Preserved in Aquitaine (France) : From Material Analysis and Experimentation to Physical and Digital Reconstruction

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The Polychromy of English Medieval Alabaster Panels Preserved in Aquitaine (France): From Material Analysis and Experimentation to Physical and Digital Reconstruction

Maud Mulliez – Aurélie Mounier – Markus Schlicht

Abstract

The polychromy of English alabaster panels dating from the late Middle Ages and depicting religious scenes, which were displayed in painted wooden frames, was not a merely decorative feature of these works. Colour was an integral part of these pieces, essential for rendering their three-dimensional aspect. Some features of the reliefs become either unintelligible or distorted when deprived of their colours. However, given today's state of conservation, we can no longer form a precise idea of what the panels originally looked like. Therefore, it is necessary to reconstruct their medieval polychromy by gathering all available data in order to obtain as precise a picture as possible of their original appearance and to study them from an aesthetic as well as a symbolic point of view.

The «ALBATRES» research programme (LaScArBx 2018–2021) set out to study the polychromy of English alabaster panels in the Aquitaine region of southwestern France. Of the more than 100 panels identified, about 20 still bear significant traces of colour. Researchers from various disciplines came together to address the issue of colour, its physico-chemical composition, materiality, and application techniques, as well as its artistic significance and symbolism.

Close collaboration between several research laboratories and cultural institutions (namely, Ausonius, IRAMAT-CRPAA, the Institut Optique d'Aquitaine, Archeovision, and the Musée d'Aquitaine) enabled the study of colour traces through visual examination, macrophotographic documentation, and physico-chemical analyses. Then, in accordance with the precepts of experimental archaeology, a set of alabaster samples was painted using materials equivalent to those identified on the original panels. These samples were then used as visual and chromatic references for the digital reconstruction of three panels.

In addition, a physical copy of one panel – the «Assumption of the Virgin», housed at the Musée d'Aquitaine in Bordeaux – was created. It included carving, gilding, and painting. This process enabled a comparison between the physical and digital methods of reconstruction in terms of production processes as well as the results obtained.

Keywords: Alabaster, medieval sculpture, polychromy, pigments, Aquitaine, England, physico-chemical analysis, experimental archaeology, facsimile, digital restoration, sample re-construction

Introduction

Polychrome alabasters represent a significant part of the English contribution to European medieval sculpture. Panels depicting religious scenes were part of narrative cycles and assembled in the form of altar-

pieces. During the period between 1350 and 1550, many such panels were produced in the English Midlands. Although large numbers were destroyed during the English Reformation (after 1534), more

than 2500 of them survived, being either legally exported or smuggled to the European mainland for sale. With more than 100 panels preserved, the Bordeaux area holds one of the largest concentrations of these reliefs.

Most of them have unfortunately lost their original polychromy. Yet polychromy and plastic shape are two inseparable components of these works, so much so that it seems more accurate to speak of three-dimensional painting rather than painted sculpture. Further, the loss of their original colours considerably impairs their interpretation, intelligibility, and the aesthetic and symbolic evaluation that can be made of them today. Fortunately, some 20 panels

from the study area still yield valuable information on colouring.

They have been studied in the framework of the «ALBÂTRES» multidisciplinary research programme, which is part of the LaScArBx programme¹. The project connects a wide range of disciplines represented by scientific laboratories² and is conducted in conjunction with various institutions, such as the Musée d'Aquitaine, the Musée des Beaux-Arts de Libourne, as well as churches and public institutions that have allowed access to the artworks³. It brings together researchers specialized in art history, archaeometry, 3D and optical engineering, and experimental archaeology.

Alabaster Polychromy: Some Aspects of its Function

English alabasters have been extensively studied since the late 19th century but most art historical scholarly works have focused on aspects other than polychromy⁴. Yet the polychromy of English alabaster panels was not a merely decorative feature of these pieces. Rather, it was an integral part of the craft and was indissociable from the sculpture. Each panel was richly coloured, which may seem hard to believe given their current state of preservation. Some have lost all their polychromy, some still display a few patches of colour, and some others are quite well preserved – not to the extent that they immediately reveal their original appearance, but enough to reconstruct some semblance of it.

The inseparable link between alabaster panels and colour is also evident from the fact that the panels were displayed in wooden frames as altarpieces that were also painted and gilded. The whole must have been a riot of colour. Colour served a real purpose in medieval sculpture; it made the image much easier to read and was essential for rendering the volumes and distinguishing the different depth planes of the relief, allowing features to become discernible in a field that

would be invisible in monotone (as demonstrated by the copy of «The Assumption of the Virgin» before it was painted, see Fig. 7 c). Some features of the reliefs would be almost unintelligible without their colours. The rendering of eyes provides a good illustration. A globular shape was carved in the ocular cavity; if unpainted, this resulted in faces with a strange blank stare (as we find today in many works that have lost their colour). However, with painted lines and details, the shape of the eyes became very legible (Fig. 1). Furthermore, colour helped to make the scene represented through symbolic language intelligible⁵: for example, black and red are reserved for negative characters whose skin is coloured pink or brown, whereas positive characters have golden hair and white skin (uncoloured alabaster).

The research programme seeks to further our knowledge of all aspects of the polychromy of these artworks. In particular, technical aspects such as the materials and techniques employed by medieval painters will be explored. It also involves study of the functions of polychromy and our perceptions of it by determining and interpreting the selection criteria

1 ALBÂTRES. Polychromie, pigments, perception: les albâtres anglais de la fin du Moyen Âge conservés sur le territoire aquitain. Labex LaScArBx project (2018–2021): <https://lascarb.x.u-bordeaux.fr/Actions/Projets-de-recherche-en-cours/AAP8-RECHERCHE-PROJETS-RETENUS/Albatres-i7248.html> (3.11.2023; no longer online on 08.08.2024).

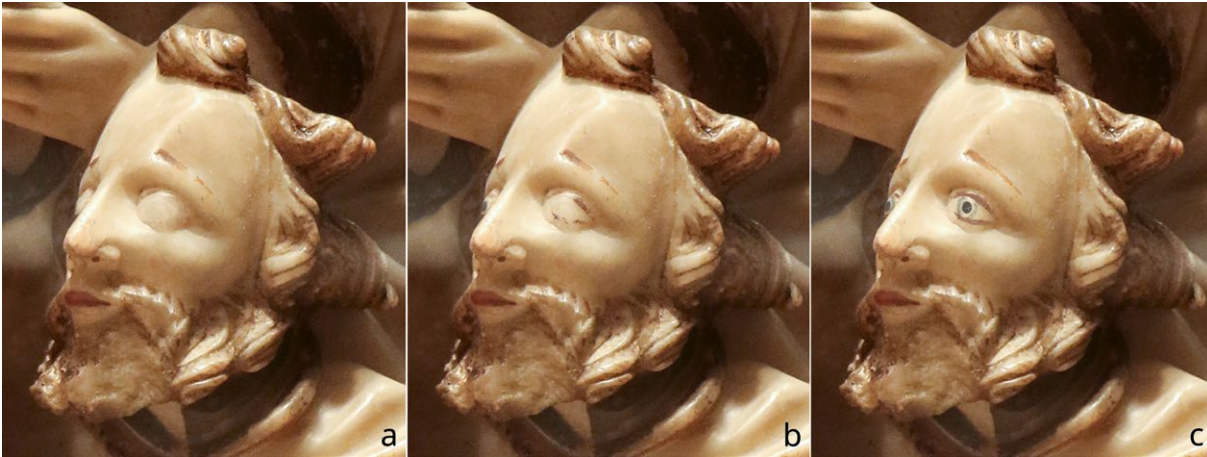
2 Ausonius (UMR 5607), CRP2A (UMR 5060), Archeovision (UMS 3657), LP2N (UMR 5298), INRIA.

3 We would like to thank, at the Musée d'Aquitaine, Laurent Védérine (director), Christian Block (curator in charge of medieval

collections), Isabelle Hoarau (registrar) and Amandine Bély (stonemason); at the Musée des Beaux-Arts de Libourne, Thierry Saumier and Caroline Fillon, the two successive directors, and Estelle Moulineau (registrar); at Saint-Michel of Bordeaux Patrick della Libera; and at the DRAC, Muriel Mauriac-Le Héron and Florie Alard.

4 In particular Brutails 1907; Le Noan-Vizioz 1957; Gardelles 1976; Gorguet 1984; Cheetham 1984; Cheetham 2003 and Murat 2019.

5 Schlicht et al. 2021, 35.



1 Detail of «The Adoration of the Magi» (New York, Metropolitan Museum inv. 25.120.485; 15th cent. A.D.). a) With remnants of painting of the eyes erased (as is often visible on panels when all painting has disappeared); b) As currently preserved; c) With the complete painting of the eyes reconstructed (cc)

and aesthetic uses of colours and gilding. This interpretative aspect involves reconstructing the original medieval appearance of some of the alabaster panels as accurately as is possible.

This approach will be presented here in two consecutive steps. We begin by presenting the study of the remnants of polychromy, and then proceed to undertake a full reconstruction of the polychromy of three panels. This division can indeed be broken

down further for the sake of clarity. The breakdown is somewhat artificial because the attempted reconstruction is part of the research itself and extends our knowledge. In reconstructing or even experimenting on the works, many questions must be answered⁶. Thus, in the process, we continually alternated between research and observation, on one side, and experimentation, re-creation, and reconstruction, on the other.

Studying the Remains of Polychromy and Re-Creating the Panels' Original Appearance

Investigation of the Remains

The remnants of polychromy were examined through various methods. First, a visual inspection was conducted to identify as many details as possible. This examination revealed several recurring patterns that could potentially aid in reconstructions. One notable example is the characteristic green background adorned with flowers in the lower sections of many panels, while the upper part was gilded and decorated

with regularly spaced dot-shaped elements made of gesso (Fig. 2)⁷. Additionally, garments' hemlines were highlighted in gold with coloured linings. However, during this visual inspection with the naked eye, some isolated instances or ambiguous features were also noted⁸.

In a next step, a macrophotographic survey provided us with highly valuable information regarding patterns and allowed for the identification of details such as variations in the thickness of the paint marks

⁶ On reconstruction and 3D modelling as research tools, see Vergnieux 2011, esp. 43: «Les modèles 3D comme outils d'aide à la recherche»; Mulliez 2020. This idea is also encapsulated in the way D. Laboury entitled his article on the reconstruction of the bust of Akhenaten, «Étude du buste d'Akhénaton du Musée du Louvre par restitution 3D polychrome» in Laboury et al. 2019.

⁷ Unfortunately, the gesso dots are rarely preserved, and their loss produces a very different effect: a gilded background with white dots instead of an entirely golden background with rounded bumps.

⁸ For example, a complex superimposition of layers applied on geometrical forms representing clouds (Fig. 10).



2 «Resurrection of the Dead» (Musée des Beaux-Arts, Libourne, inv. 02.1.44; first half of the 15th cent. A.D.). a) Complete panel; b) Detail of the lower ground, green and strewn with flowers; c) Upper background gilded and spotted with gesso dots that have all disappeared leaving white ovals

depicting white tear shapes symbolizing wing feathers, revealing insights into the painter's technique (Fig. 3 b). Macrophotography also allowed us to observe the paint stratigraphy; while this can at times be challenging, in Figure 3 c, we were able to discern the layering: gilding on top of a yellow ochre mixture; a blue layer surrounded in places by gilding (probably unintentionally), a red layer seemingly underlying the blue at the edges, and the presence of black and grey concretions. These observations provide clues about the sequence in which the craftsmen applied the various components. In this instance, it appears that the hemline was gilded first, followed by the application of the red layer for the gates to paradise (?), and finally the blue layer of the lining of Saint Peter's cloak.

Finally, images and non-invasive physico-chemical analyses were conducted to identify the materials

used, mainly pigments and binders. Observations with a portable microscope sometimes revealed the stratigraphy and the conservation state of the layers. Previous studies have shown that the emission of yellow fluorescence under UV light can indicate a lipidic binder⁹. This tentative identification of the binder was conducted in alabasters and the presence of a lipidic binder was confirmed by fibre optic reflectance spectroscopy (FORS) in the near infrared range (NIR).

Other spectroscopic non-invasive analyses¹⁰ were carried out to characterize the colour materials (pigments). The spectra indicate the presence of elements or characteristic bands that could be identified. These analyses were essential as an initial step before proceeding to the experimental part, in order to identify the materials and techniques used. Some colours were challenging to define, and the analysis helped in determining the original pigment before degrada-

⁹ Mounier et al. 2011.

¹⁰ Fibre optic reflectance spectroscopy in visible (FORS-VIS in 200–1000 nm) and near infrared (FORS-NIR in 1000–2500 nm)

ranges were used to identify pigments and binders respectively. Portable fluorimeter with LED (LEDµSF) confirmed and completed the results.



3 «The Saved Entering Paradise» (Libourne, inv. 02.1.45; first half of the 15th cent. A.D.). a) Complete panel; b) Macrophoto-graph of an angel's wing painted in cinnabar red dotted with white teardrop shapes and black dots probably representing feathers, and gilded background; c) Macrophoto-graph of the intersection of the red door and Saint Peter's garment with its blue lining and golden hemline

tion, thus identifying the original colour. All results from the analyses of the Aquitaine corpus have been compiled into tables, indicating approximately 60 different kinds of stratigraphy¹¹.

Experimentation to Ascertain the Original Appearance of Colours

Since our aim was to understand the original appearance of each component of polychromy, we next

turned to the methods of experimental archaeology in order to produce a series of replica alabaster samples based on the results of our analyses and observations. Despite the limited number of elements identified, it was impossible to determine whether the pigments identified were mixed or superimposed. Therefore, each case had to be considered, even though it is generally accepted that medieval painters and dyers avoided mixing pigments (except to obtain pink), as M. Pastoureau has explained in great detail¹². For this reason, more than 70 samples were required to re-create all the combinations (Fig. 4. 5).

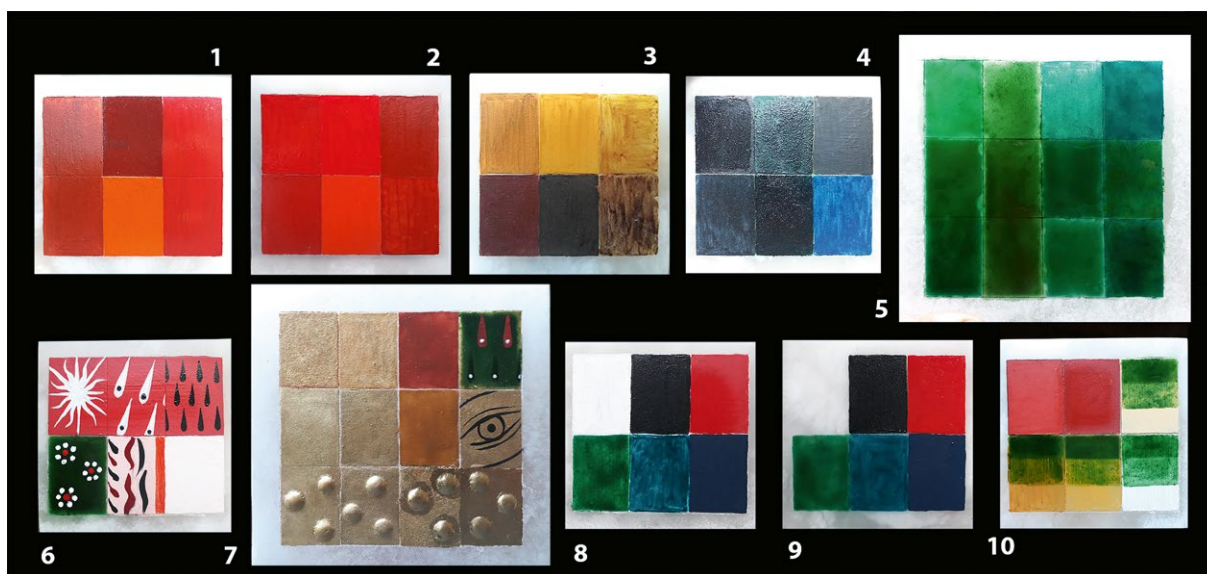
11 For details, see Mounier et al. 2020.

12 Pastoureau 2012, 199.

Localization	Iconographic theme	Analyses type	Red pigments	Yellow pigments	Blue pigments	Green pigments	Gilding	White pigments	Black pigments	Alabaster	Binder
BORDELAIS											
Aquitaine Museum	Virgin Assomption	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF; Lab analyses: stratigraphy, MEB/EDS & Raman	Cinnabar, red ochre, umber?, minium; cinnabar + red ochre	Yellow ochre		Verdigris + oil or resinates?	Gold on minium + red ochre + oil		Carbon black?	Gypsum	Oil
	Flagellation	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar, minium, red ochre			Copper green + indigo?				Gypsum	
	Saint-Anne	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar, red ochre; cinnabar + lead white			Copper resinates					
Lormont	Adoration of the Magi	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar & red ochre	Yellow ochre	Indigo + verdigris	Copper resinates + glaze	Mixtion on yellow ochre + oil	Lead white + oil?		Gypsum	Oil
ENTRE-DEUX-MERS											
Cambes	Entombment + Marie-Madeleine	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar	Yellow ochre		indigo + yellow ochre?					Oil
	Flagellation	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar, red ochre	Yellow ochre	indigo on yellow ochre	Copper resinates	Gold on yellow ochre + minium + oil?			Gypsum	Oil
	Trinity	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar, cinnabar or minium + lead white	Yellow ochre		indigo + yellow ochre	Gold on yellow ochre				

Localization	Iconographic theme	Analyses type	Red pigments	Yellow pigments	Blue pigments	Green pigments	Gilding	White pigments	Black pigments	Alabaster	Binder
LIBOURNAIS											
Libourne Museum	Gate of Paradise	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF; Lab analyses: stratigraphy, MEB/EDS & Raman	Cinnabar, minium + cinnabar, red ochre	Organic yellow?	Azurite	Copper green	Gold on red ochre				
	Hell, Leviathan	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar, red ochre; minium + cinnabar; cinnabar + lead white; cinnabar + red ochre	Yellow ochre		Copper residue and other green non-identified					
	Resurrection	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar, red ochre, cinnabar + lead white, minium + ochre?	Organic yellow? + resinates or indigo?		verdigris or resinate? Glaze	Gold on yellow ochre + oil				
MEDOC											
Castelnau	Crucifixion	Obs: UV lamp & Dilite microscope; In situ analyses: FORS-VIS, NIR, LED μ SF	Cinnabar	Yellow ochre	Azurite	Copper residue	Yellow ochre underlayer + oil	Lead white			Oil

4 Analytical results of all the alabaster panels in the Aquitaine region with traces of polychromy extant, classified by colour



5 The 84 model samples encompassing all combinations of polychromy resulting from the analyses and observations conducted on the Aquitaine corpus, consisting of ten alabaster plaques

Using the same (or equivalent) materials as those identified on the original panels, each case was re-created according to the following process (with a few exceptions explained below). Firstly, a measure of pigment powder was re-ground with a spatula or a glass muller and then mixed with a measure of linseed oil as a binder. Once the mixture reached a homogeneous state, it was applied to the alabaster sample. Consistent with what our analysis suggested, colours were mostly applied directly on the stone without a base layer. However, we experimented by applying the same pigments with and without a primer in order to compare the differences in application and visual effects.

As observation indicated that colours were applied as uniform fields, in a coat that covered as completely as possible with no gradation, we aimed to achieve the same effect with our samples.

Red Samples

Red is the colour with the most shades, as three pigments were identified – cinnabar, minium and red ochre¹³ – and because there was a large variety of tones within the red ochre group (three were tested).

Red pigments are very easy to apply and pleasant to use: it is quite simple to obtain an evenly coated surface, which seems to have been the desired effect at the time.

Yellow and Brown Samples

Yellow tones are not as easy to use as red pigments, brown ochre or raw umber, especially the organic pigments such as *stil de grain* and bourdaine-bucktooth¹⁴. Even with extensive grinding when incorporating the pigment into the binder, it is very difficult to achieve a homogeneous texture. Applying it to the surface of the alabaster is also challenging, as it tends to form small clumps that stick to the brush bristles. Perhaps, we did not find the right technique.

Yellow ochre is easier to apply than organic pigments but not as simple as red and brown ochres. This difficulty in application may have been a criterion in the choice of the material used by medieval craftsmen. Indeed, the use of yellow colour in English alabaster is very rare (at least when visible, as it is mainly used as a bolus under the gilding). This rarity is also likely due to the symbolic associations of yellow¹⁵.

¹³ Mounier et al. 2020.

¹⁴ On these organic pigments see Mounier et al. 2016; Perego 2005, 895.

¹⁵ See Pastoureau 2012, 231 f. M. Schlicht also discusses yellow, in: Schlicht et al. 2021, 30.

Blue Samples

The plaque of blue samples had to be made twice because the first was lost during the many exchanges among research laboratories (although it was later found). This mistake ultimately proved useful, as it allowed for a comparison between the two plaques and demonstrated how much the experience gained during the two experiments paid off. We found that verdigris and indigo, identified by FORS-VIS & NIR, required extensive grinding before they could be mixed and applied effectively. Additionally, a better effect was achieved if the pigment and binder were mixed together in advance and left to stand for a while before application.

Green Samples

The FORS-NIR analyses indicate a copper green, which may be either verdigris or copper resinate¹⁶. The use of copper resinate is well known in the literature, and from visual examination, the backdrop of the lower part of most panels matches the appearance of copper resinate.

Copper resinate is a special case in our work. First, it is not strictly a pigment, but a mixture of verdigris and Venetian turpentine that is heated. The resulting substance is quite viscous, with a tone that varies according to temperature and the duration of heating. Once dry, the surface remains very shiny, but may become matte over time (nowadays, resinate-painted surfaces look somewhat matt). It is also rather transparent like the alabaster itself; however, this characteristic does not seem to have been sought at the time, at least in this context, since the panels were fitted into a frame with a backing that did not let light through.

Furthermore, copper resinate is no longer commercially available and had to be especially re-created from old recipes, such as the one from the 17th century by Théodore Turquet de Mayerne¹⁷.

Gilding Samples (and Gesso Dots)

Gilding was used to underline the hemlines of many garments and in depicting hair and other details, but above all to cover the background of the upper parts

of the panels, which were also studded with dots whose volume enlivened the surface. Those gesso dots have often fallen off, creating a very different effect (Fig. 2). The production of these relief elements also had to be tested, which was no easy task. Alabaster powder was ground and mixed with rabbit skin glue according to medieval recipe treatises¹⁸. This involved working with a hot glue that unfortunately cools very quickly. When one manages to obtain a roughly shaped dot, it has to be glued to the alabaster support. It does not always hold up as one hopes. Even when trying to work with tools, it tends to get onto one's fingers and it sticks quite fiercely. Attempts were made to work with a runnier mixture of powder and glue dropped from the spatula to form a more regular rounded shape directly. Unfortunately once dry, it failed to stick to the ground. An air bubble formed in the middle and only the edges of the gesso dot adhered. The first technique therefore proved the more successful but required patience to master. Once dry, the dots had to be sanded to a regular shape.

Two gilding techniques were also the subject of our experiments: shell gold¹⁹ and gold leaf²⁰. The first was tried out on a yellow ochre and red ochre bolus, and the second on a mixture also coloured with red or yellow ochre with a little red lead (minium) and then with red lead alone. The visual effect of both techniques is quite different. The appearance of shell gold is akin to glitter, whereas gold leaf produces a more even finish. It can be seen that using red lead alone produces an even smoother effect.

Pattern Samples

A series of samples was used to create patterns and experiment with the superimposition of pigments (Fig. 6). Three samples were made on a cinnabar red background, one on copper resinate, and two on different shades of pink. The lead white used for the patterns is sold ready-mixed with linseed oil because of its toxicity, to avoid the dispersion of the powder. The paste is quite thick but does not cover completely. It creates impasto effects, leaving the support visible in the furrows left by the brush hairs. This is not in keeping with medieval renderings. Perhaps a more fluid material with the addition of oil should have been used, and two coats applied where necessary.

¹⁶ Mounier et al., 2020.

¹⁷ MayePS fol. 31.

¹⁸ Cennini, 14th cent.; Moine Denys, 12th cent.

¹⁹ Small particles of gold are amalgamated with gum arabic and sometimes honey, then deposited using a protein or lipid binder.

²⁰ The gold leaf had a thickness of about 1 µm.



6 Gilding and gesso dots. a) Detail of background with two original gesso dots in place and one disappeared; b) Experimenting at making gesso dots; c) Problem of adhesion of a gesso dot to the alabaster support; d) Gilding on gesso dots with different mixtures (including the use of red lead for the fourth sample and the dots of the third sample where it seeped)

The carbon black applied on the cinnabar red and on the white of the tears themselves, when wrought on a cinnabar background, took more than two weeks to dry. Drying was faster on the pink background made with a mixture of lead white and a very small proportion of cinnabar and minium. This difference can be explained by the drying properties of lead colours. As for the minium and, to a lesser extent, the red ochre, they retracted on the support during application. Here, rubbing off the paint that did not stick improved adhesion. A little ox gall was added as a surface-active agent to improve the surface tension of the mixture. The rubbing operation alone might have been enough; it also has the effect of matting the surface.

Comparison Samples: With or Without a Primer

Even if the scientific and art historical literature²¹ suggests that no undercoats were applied on the alabaster panels before colouring, we tested whether applying

oil to areas of alabaster without colour might be helpful for certain pigments. We also sought to compare the application of the same pigments on a lead white base layer and on a primer of linseed oil with a few grains of minium to speed up the drying process.

The first observation, after several months, was that the linseed oil, which seeped well beyond the samples to which it was applied, had already yellowed considerably. As for the colour rendering, it differed slightly between the two plaques, since the lead white stood out more in the less covered areas of each sample, creating an impression of unevenness.

Ad hoc Tests

Various tests (Fig. 10) were conducted during the production of the copy as new questions emerged. For instance, we aimed to assess the variation between cinnabar applied on a layer of red oxide or mixed with this same oxide in relation to the wings of four of the Assumption angels. The outcomes differed significantly for each of the two samples.

²¹ Cheetham 1984, 26; Land 2011, 66; Pereira-Pardo et al. 2018.

Colourimetric and Appearance Measurements

Colourimetric measurements were then taken on the samples to establish a digital palette for the reconstructions (Fig. 8). A spectrophotometer was used, and the $L^*a^*b^*$ transformed into RGB values to be integrated into the infographic software (in our case, Mudbox).

Enhancements in colour rendering were achieved using a special device developed at the Institut Op-

tique d'Aquitaine to create a shader that closely approximates the appearance of the panels' surface. This component of the programme is still an ongoing effort. All the data will eventually be integrated into the 3D model of the panels to improve the recreation of their probable appearance.

Reconstructing the Polychromy of Several Alabaster Panels

Three panels from the corpus were selected for a detailed study aimed at establishing their full digital and/or physical reconstruction²². Such reconstructions offer a more precise understanding of the panels' original appearance, which is invaluable for exploring various related aspects such as the tastes and customs of a particular period, symbolisms, and more.

As outlined earlier, the initial steps involved visual examination and macrophotography, followed by physico-chemical analysis. This process allowed us to outline a preliminary plan for the reconstruction of the polychromy in the form of 'maps' showing the distribution of colours, serving as the foundation of our work but providing an incomplete idea of the panels' likely appearance.

The initial alabaster panel chosen for this study was the 'Assumption of the Virgin', housed in the Musée d'Aquitaine in Bordeaux. Despite its unique characteristics compared to other more standardized examples, this panel presented an invaluable subject for examination. Our collaboration with the museum provided particularly favourable conditions for study and allowed us to work alongside the museum's stonemason to create an alabaster copy. The possibility to compare a digital reconstruction with a physical one proved to be of immense value.

Physical Reconstruction

Using a pantograph, a precision measuring instrument used by stone carvers for faithful reproduction,

A. Bély produced a replica of the panel illustrating the 'Assumption of the Virgin' in the workshops of the Musée d'Aquitaine (Fig. 7 a). In this scene, the Virgin is depicted standing with her hands open, encircled by eight angels on her right and left in registers divided by cloud-like elements. One angel is positioned peculiarly beneath her, supporting her feet with its hands, with a view from above showing the crown of its head and its wings (Fig. 10 a).

After initial rough-carving of the alabaster block²³, the shapes were progressively hollowed out, and the details of each figure and background were meticulously carved, consistently referencing the original model and using traditional tools. The surface received thorough polishing, with a total working time of approximately 60 hours²⁴.

Following this, the gesso dots for the background were modelled and glued, preparing the copy for painting and gilding in accordance with earlier analyses and observations. After an initial mishap involving applying a layer of red ochre on the wings of four of the side angels, the gilding process commenced. If one initiates the painting of other areas prior to applying gold leaf, these areas must be fully dried before the gold leaf is incorporated; otherwise, the leaf or gold dust may adhere to the wet paintwork, resulting in issues such as those encountered with the angels' wings. A blend tinted with ochre and minium grains was methodically applied section by section (Fig. 7 b), ensuring that the gold leaf could be delicately placed at the precise instance when the surface was slightly tacky but no longer wet. Then, colours bound with linseed oil were applied one by one, starting with the

²² On reconstruction as a research method as well as a goal in itself, see n. 6 above.

²³ The provenance for this was Spain, as for all samples.

²⁴ Given that it takes longer to copy than to carve directly.



7 a) Copying in progress of the original panel of *‘The Assumption of the Virgin’* with a pantograph; b) Painting and gilding of the facsimile in progress; c) The resulting copy

areas where overlap was intended. Adhesion to the alabaster surface, which was more highly polished than the experimental samples that had been smoothed but not polished, proved highly successful. Certain superimposed patterns, like the eyes, presented challenges as the underlying layer seemed to be plasticized. These areas necessitated dissolution or removal using very fine steel wool before the application of a new layer. Additionally, some colours needed to be applied in multiple layers to obtain a uniform and even finish.

In total, the application of gesso dots, gilding and painting consumed 35–40 hours to complete, but with experience, an estimated 20 hours may suffice.

Digital Reconstructions

The process of digital reconstruction was similarly applied to the panel of *‘The Assumption’*, a piece illustrating *‘The Saved Entering Paradise’* from the Musée des Beaux-Arts of Libourne, and another panel portraying *‘The Coronation of the Virgin’* from Saint Michel de Bordeaux.

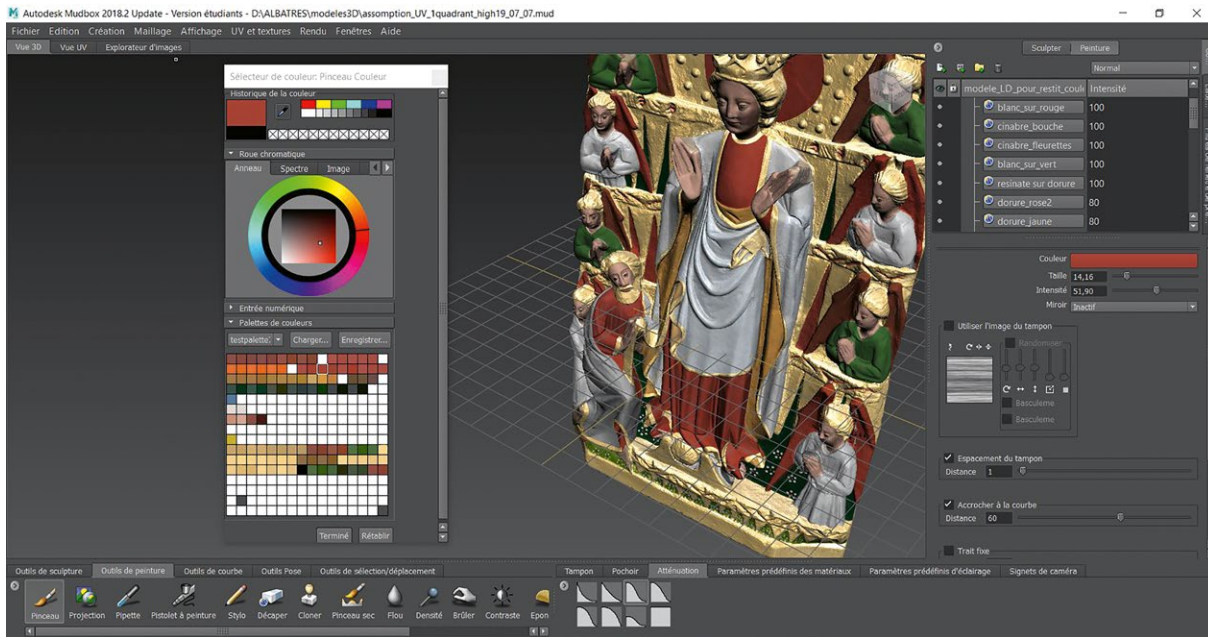
A 3D model of each panel was generated using two techniques, photogrammetry, and laser-scanning. These methods allowed for the digital reconstruction of missing elements, such as filling holes and recreating absent carved elements by analogy with comparable works.

Once the 3D model was created, it needed to be processed using suitable software to apply a coloured overlay. Using the digital palette as described earlier and the digital brushes within the 3D painting software²⁵, the panel underwent a digital painting process. Rather than simply applying uniform colours to selected zones, the colours were meticulously brushed on, mimicking a realistic relief effect by following the contours and incorporating the natural irregularities that arise from manual work. This is why conducting an initial experimental phase was critical and greatly enhanced the quality of the 3D model.

The digital painting process always involved discussion with the programme’s historian to confirm and clarify details as the project progressed.

Various *‘shaders’* were tested to create different surface effects such as matte finishes, shine, and reflections. When it came to gilding, a mask was necessary to selectively apply the gold effect to specific areas.

25 Mudbox (Autodesk) and Blender.



8 Digital painting of the 3D model of the alabaster panel of «The Assumption of the Virgin» (Musée d'Aquitaine, inv. 11775) with the digital palette

Physical Facsimile and 3D Model

The simultaneous production of a physical facsimile and a 3D digital model allowed for the construction of the digital model with precise material references, enabling an assessment of the digital rendering's fidelity to the «original». The physical facsimile served as a visual reference and a validation tool for the digital copy.

During our first tests, noticeable differences primarily concerned the surface properties of materials rather than their colours and shades. Our research highlighted the importance of the alabaster's pristine whiteness – pure, smooth and brilliant – which played a crucial role in the sculptors' choice of this material (and in the buyers' preference for these reliefs). Consequently, the digital simulation of alabaster needed to replicate this unique white quality. The same meticulous attention was given to reproducing

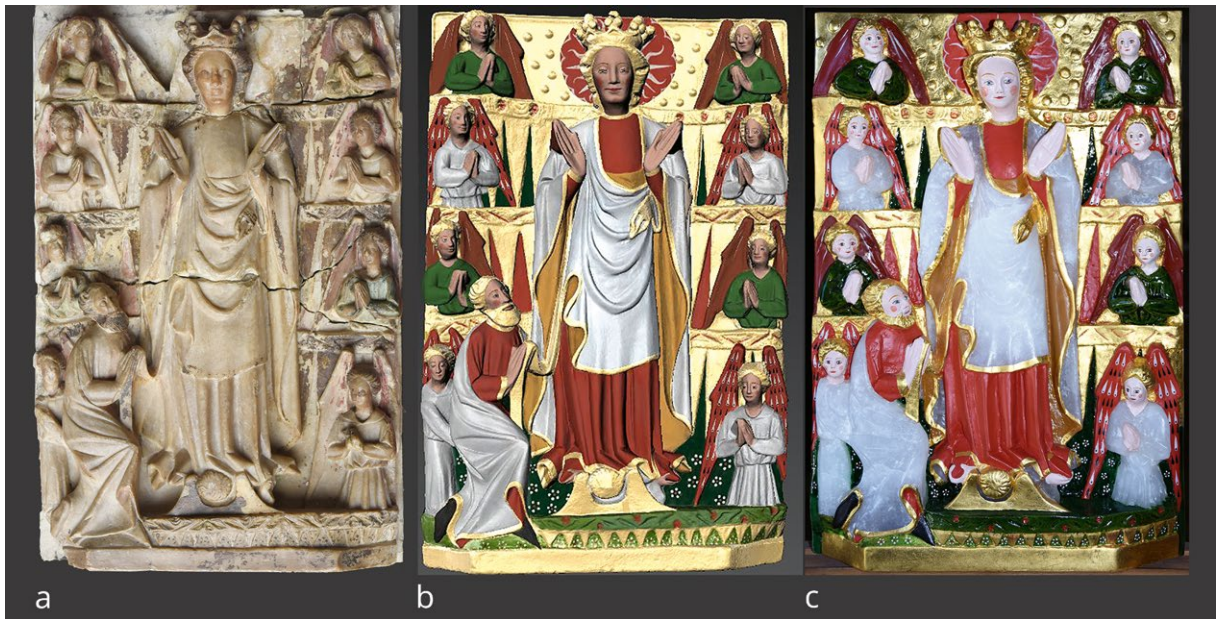
the brilliance and translucence of gold and copper resinate, highly valued by medieval viewers.

Although the computer graphics software, Mudbox, initially chosen did not consistently deliver satisfactory outcomes and demanded significant adjustments²⁶, we eventually switched to Blender (Fig. 8–10). The facsimile production prompted a detailed examination of the materiality and visual characteristics of both the support and the paints, contributing to the enhancement of the digital model and its visual qualities. While digital models are more accessible and cost-effective to create compared to physical copies, expanding our sample collection is crucial for assessing the standardization of painters' decorative techniques or determining the representativeness of the physical facsimile in reflecting the pictorial practices of medieval England.

²⁶ In the case of the «Assumption» panel, the outcomes appeared satisfactory, possibly due to the fewer white areas compared to the Libourne and St. Michel panels.



9 a, b) Digital reconstruction of «The Saved Entering Paradise» (Libourne inv. 02.1.45) with a variation in the light; c) Digital reconstruction of «The Coronation of the Virgin» (Saint-Michel de Bordeaux)



10 a) «The Assumption of the Virgin» (Musée d'Aquitaine, Bordeaux, inv. 11775; second half of the 14th cent. A.D.); b) 3D model, coloured and textured with Mudbox; c) Facsimile, painted and gilded

Conclusion

The originality of the ALBÂTRES programme is rooted in its broadly and concretely multidisciplinary approach, where complementary facets necessitated continual feedback among team members. The regular exchanges proved especially fruitful and essential in a context where the terminologies across dis-

ciplines differed, prompting numerous adjustments to achieve consensus. Each stage served as a vital link in a chain, progressively deepening our understanding of the artworks and aiming to restore their original appearance as accurately as possible.

The process commenced with initial observations, then moved from analyses to physical recreations and colour/material measurements, prompting both physical and digital reconstructions, and culminated in a virtual reproduction. This systematic approach yielded unprecedented results while the potential for comparison between physical and digital methods of reconstruction was particularly valuable in terms of production processes and outcomes. Making a physical copy that was identical in terms of materials required considerable time and a substantial budget, whereas digital modelling proved cost-effective and efficient. However, the physical copy provided unique insights into production that the digital approach could not offer. In terms of rendering, the material effects obtained digitally were not satisfactory at first, and it took a good deal of trial and error and finally a change of software to obtain the desired

appearance of the materials. This was itself made possible by having the material reference at hand.

The experimental part represented an essential stage of the project, providing essential data for digitally reconstructing materials identified during the analyses. The measurement of chromatic coordinates and data characterizing the surface appearances enabled the composition of a digital palette and the application of shaders for surface rendering. Experimentation with model samples or complete copies deepened our comprehension of the artwork and medieval practices.

Our collective effort significantly advanced the interpretation and overall study of these panels. Colour, an integral element of these works, directly influenced their perception, comprehension, interpretation. Finally, it is worth noting that the methods employed in this project can be adapted to other works and contexts, with the potential to greatly enrich the understanding of colour within the realm of medieval art.

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Fig. 4 Aurélie Mounier

Fig. 5 Maud Mulliez

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