Dina da Costa Reis

The materials, technique, conservation treatment and after-care of *Interior de um Convento*

Dissertação apresentada na Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa para a obtenção do grau de Mestre em Conservação e Restauro, especialização em pintura sobre tela

Orientadora: Prof.ª Doutora Leslie Carlyle (FCT-UNL

Co-orientadora: Prof.ª Doutora Maria Filomena Macedo (FCT-UNL)

Presidente:	Profª Doutora Maria João Melo (FCT-UNL)
Arguente:	Doutora Irina Sandu (REQUIMTE FCT-UNL)

Dezembro, 2011

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To André, with whom I share my life.

ABSTRACT

This thesis concerns the study of the materials and techniques of the painting on canvas "Interior de um Convento" belonging to the Portuguese monument Pena National Palace (PNP) and the description of the conservation treatment carried out. The study required the use of several examination and analysis tools such as OM (Optical Microscopy), UV (ultraviolet) and IR (infrared) photography, μ-EDXRF (Energy Dispersive X-ray Fluorescence), μ-Raman (Raman spectroscopy) μ-FTIR (Fourier Transform Infrared Spectroscopy) and SEM-EDX (Electron Scanning Microscopy with Energy Dispersive X-ray Spectroscopy). The conservation treatment focused on minimal intervention with the purpose of maintaining the integrity of a nineteen century painting that has never been restored until the present date. Simultaneously, a project to investigate the best back and front protection system for the PNP's paintings collection was initiated. Relative Humidity (RH) and temperature fluctuations were measured in the Palace and inside the half-closed and fully closed systems used to protect twelve model paintings constructed for the purpose. The objective was to choose the best protection system for dampening RH and temperature fluctuations while preventing the risk of mould occurrence. The preliminary results (4 months of readings) showed that the risk of mould growth requires further study for in a more prolonged period which encompasses seasonal changes.

KEYWORDS

Pena National Palace; Painting on canvas; Conservation and restoration treatment; Back protection project

RESUMO

A presente tese aborda o estudo dos materiais e técnicas da pintura sobre tela "Interior de um Convento" pertencente ao monumento português Palácio Nacional da Pena (PNP), e a descrição do tratamento de conservação e restauro realizado. O estudo requereu a utilização de vários métodos e instrumentos de análise, tais como a Microscopia Óptica (OM), fotografia ultravioleta (UV) e infravermelha (IR), espectrometria de fluorescência de raios X dispersiva de energias (μ-EDXRF), espectrometria de Raman (μ-Raman), espectrometria (FTIR) e microscópio electrónico de varrimento com análise de energia dispersiva de raios X (SEM-EDX). O tratamento de conservação e restauro orientou-se pelo princípio da "Intervenção Mínima" de modo a preservar a integridade de uma pintura pertencente ao século XIX que até à data presente não havia sido restaurada. Simultaneamente, desenvolveu-se um projecto de estudo sobre sistemas de protecção na frente e no reverso de pinturas a tela, especificamente concebido para a colecção do PNP. Mediram-se as flutuações de temperatura e humidade relativa (HR) no ambiente interior e exterior dos sistemas de protecção em doze pinturas modelo construídas para o efeito. O estudo teve por objectivo a escolha do melhor sistema de protecção para estabilizar as flutuações de temperatura e RH e evitar, simultaneamente, o risco de crescimento de microrganismos. Os resultados preliminares (quatro meses de medições) demonstraram que o risco de crescimento de fungos deve ser estudado por um período mais prolongado com mudanças sazonais.

TERMOS-CHAVE

Palácio Nacional da Pena; pintura sobre tela; tratamento de conservação e restauro; protecções de reverso

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INTRODUCTION

The Portuguese monument, Pena National Palace (PNP), constitutes one of the major examples of 19th century Romanticism in the world and is considered by UNESCO a World Heritage Site and one of the Seven Wonders of Portugal. Part of PNP's painting collection, the work on canvas Interior de um Convento provided an excellent opportunity to develop a conservation treatment whilst studying the materials and techniques of a 19th century oil painting. At the same time, the uncontrolled environment in the Palace prompted the need to undertake a project to determine the best back protection system for their paintings which, aside from providing a barrier to dust and debris, would buffer against daily fluctuations in Relative Humidity (RH), held to be a significant factor in the degradation of paintings.

To address the issues raised, this thesis is divided in two parts: I) the materials, technique, conservation treatment and after-care of the painting *Interior de um Convento*; and II) testing different back protection systems against the uncontrolled environmental conditions, referred as the "Back Protection Project". In section I, several scientific examination methods and analytical tools were used to understand more about the painting's construction and condition. Photography with visible, transmitted, and raking light and infra-red (IR) and ultra-violet (UV) light, as well as x-radiography, were used to examine the painting method and its condition. Micro-samples of cross-sections were studied with an optical microscope (OM) and with an Energy Dispersive X-ray Scanning Electron Microscope (SEM-EDX). μ-EDXRF (Energy Dispersive X-ray Fluorescence) analysis of the paint surface combined with μ-Raman (Raman spectroscopy) analysis of cross-sections and μ-FTIR (Fourier Transform Infrared Spectroscopy) analysis of micro-samples were used to characterize some of the paint and the ground, including the pigments and binder. A comprehensive condition report was prepared to assess critical instabilities and to make recommendations for a conservation treatment. The key objectives of the conservation strategy consisted of stabilizing the major structural problems and recovering the aesthetic and cultural value of the painting with minimal intervention.

Section II comprises the "Back Protection Project" the main purpose of which was to find the best protection system for paintings in the particular environment of the PNP.. For this project, 12 model paintings (2 replicas for each of the 6 different back and front protection systems) were constructed. A data-logger placed inside the back of each model painting monitored the RH and temperature immediately behind the painting. The water activity of the model paintings and wall was also measured, as well as the equilibrium moisture content of the wooden strainers. After a four month period, these measurements were studied and compared with the readings taken inside the room where the model paintings were stored.

This Masters thesis is the result of the internship carried out in the Conservation Department at the New University, Faculty of Sciences and Technology, where the research and conservation treatment was carried out, in collaboration with Parques de Sintra – Monte Lua (PSML) which hosted the back protection project and provided the painting for the treatment.

PART I

THE MATERIALS, TECHNIQUE, CONSERVATION TREATMENT AND AFTER-CARE OF *INTERIOR DE UM CONVENTO*

CHAPTER 1 INTRODUCTION AND DESCRIPTION OF THE PAINTING

1.1. Identification of painting

Artist: Unclear (see signature below)
Title: *Interior de um Convento* ("Interior of a convent")
Date: 1855 (19th century) (see signature below)
Signature: Signed "C. Kathan. 55." (??) Letters not clear.
Dimensions (cm): 55,4cm x 45,6cm
Framed: No
Owner: Palácio Nacional da Pena (PNP) - Parques de Sintra, Monte da Lua (PSML)
Inventory No: PNP 584

1.2. Brief description of the image

Fig. 1 - Normal light photograph of front of "Interior de um Convento" before intervention.

The oil painting shows an interior scene probably from a religious convent since a female figure with a nun's habit is depicted in the foreground along with a statue which may represent a bishop since the figure appears to have a mitre shaped hat. The nun wears a long-sleeved beige tunic tied at the waist and a black veil that covers her back. On the left is a sculpture of a Virgin Mary (in a three-quarter view) wearing a red veil over a blue tunic with a golden halo above her head. Her arms are crossed and each hand is holding a sword with a yellow hilt. Above this statue is a representation of Jesus Christ crucified wearing a white loincloth. The hallway on the left ends at an opened door, through which it is possible to see the back of two figures dressed similarly to the nun figure on the foreground. The whole scene is framed by a round black arch secured by a Doric pillar on the left and only by an indiscernible dark rectangular shape on the right. From unseen windows, beams of light shine over the figure of Jesus Christ, most of the floor and over the nun, providing shadows and contrast to her drapes. Since the theme is religious, the artist may have directed the light over the nun in order to imply that she was under divine grace. The dark coloured archway helps enhance the light colours of the interior scene; the few colours that stand out from the dominant ochre/ brown and white paint are the bright reds from the background curtain, the crimson veil of the Virgin and also the intense blue from her tunic.

Part I - The materials, technique, conservation treatment and after-care of *Interior de um Convento*

CHAPTER 2 **CHARACTERIZATION OF THE MATERIALS**[1]

2.1. Textile fibre

Fibres samples (T1) removed from a loose yarn in the left tacking margin of the painting **(Ap. I, Fig.I.1, p.53)** were examined through the Optical Microscope (OM). Transverse sections of the fibres show the hexagonal shape of the cell wall, slightly rounded in outline with a marked rounded lumen (Fig. 2 in text). In longitudinal section the fibres have a tubular shape with dislocations on the cell wall (cross like marks and nodes) and striations (Fig. 3 in text).

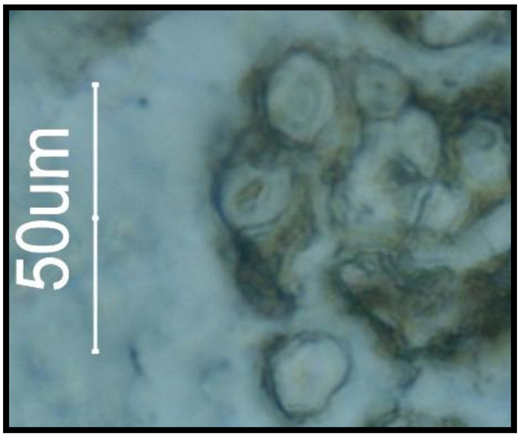

Fig. 2 - Transverse view photograph of the fibres under OM, visible polarized transmitted light, 50x.

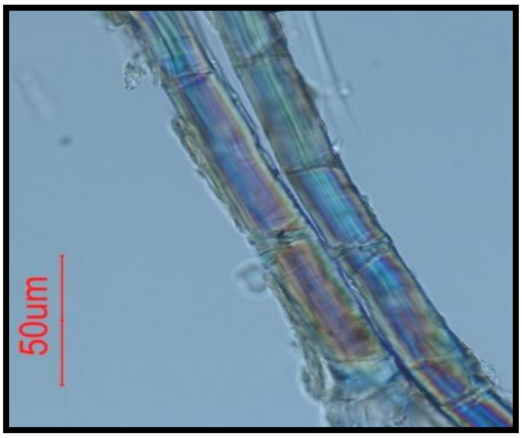

Fig. 3 - Longitudinal view photograph of the fibres under OM, visible polarized transmitted light, 40x.

A common characteristic of most bast fibres, like flax (from the plant *Linum usitatissimum*) or hemp (*Cannabis sativa*) is the presence of X or V shape dislocations of the cell wall, swelling or bulge (node) at the place of dislocation and longitudinal striations (visible in longitudinal sections). Generally it is difficult to distinguish flax from hemp by transverse sections since there are many variations in the shape of the cells of hemp fibres: many are angular and have four, five or six sides whilst others are oval or round. As for flax, fibres present a pentagonal or hexagonal cell outline, usually with a narrow lumen. **[1]**

Therefore, it is only possible to suggest that the fabric is made of flax fibres.

2.2. Size layer

Micro-samples (S1, S2, S3) of ground and fabric was taken from the lower tacking margin **(Ap. I, Fig.I.1, p.53)** and prepared in cross-section to examine under the OM. A protein staining technique (with recourse to a non-covalent UV fluorescent dye) was used in an attempt to identify the presence of a protein based size layer. **[2] (Ap. III, Fig.III.1, p.57)**. Although it had a positive result, it was not possible to ascertain the presence and distribution of proteinaceous size layer because the sample was not representative of a normal stratigraphy of paint composite (due to the broken ground, the fibres were mixed with particles of ground).

[1] See Appendix II – Instruments and Methods of Examination and Analysis, p. 55.

2.3. Ground layer

Paint and ground **(see Ap. III.2, p.58)** cross-sections examined under the OM revealed some features of the ground application. More specifically, the cross-section of black paint **(Ap. III.2, Fig. III.2.3.b, p.58)** allowed for the distinction of three layers of ground: both the 1st and 2nd layer showed big rectangular shaped particles with angular edges scattered over a white opaque matrix. The matrix of the 2nd layer is slightly more opaque than the 1st layer maybe due to the higher concentration of lead, as confirmed by SEM-EDX elemental mapping **(see Ap. III.4, p.60 & 61)**. With this analysis it was possible to observe the distribution of elements on the ground: B, S, O were present on the rectangular shaped particles, confirmed by μ-Raman analysis of the cross-sections as barium sulphate ($BaSO_4$) **(Ap. III.5, Fig.III.5.1, p.62)**; this analysis also confirmed the presence of basic lead white [$2PbCO_3.Pb(OH)$] **(Ap. III.5, Fig.III.5.2, p.62)**. **[3]** The third layer is a beige coloured ground, consisting probably of an *imprimatura* layer which is a layer applied over the ground that modifies the colour, texture or absorbency of the ground. **[4]** SEM-EDX elemental mapping identified lead distributed in this layer **(Ap. III.4, Fig.III.4.2.d, p.61)**.

A μ-FTIR analysis of a ground sample collected from the top tacking margin showed barium sulphate, basic lead white and traces of an aged drying oil **(Ap. III.5, Fig.III.5.3, p.62)**. The FTIR spectrum showed bands characteristic of an aged drying oil: the C-H region at $2920cm^1$ and $2850cm^1$ and the carbonyl region at $1740\ cm^1$. **[5]** The presence of drying oil is probably related to the ground's binder. Characteristic peaks of white lead pigment are present in the hydroxyl region (O-H stretch) at $3539m^{-1}$, the carbonyl region (C=O stretch) at $1741cm^{-1}$, and a strong peak for the carbonate (CO_3) at $683cm^{-1}$. The most intense absorption is due to the carbonates present in the lead white pigment (truncated, 1300-1450 cm^{-1}). **[5] [6]**

Barium sulphate shows typical absorptions at 1176 (medium shoulder), 1120 (strong) and 1085 cm^1 (very strong) of the sulphate (SO_4^{2-}) asymmetrical stretching and at 984 cm^1 for the symmetrical stretching. **[6]** Extensive application in paints of barium sulphate only began in the early 19th century, reportedly used as an adulterant of lead white paint. Barium sulphate was also encountered in paints and colorants known as "lithopone", a white pigment that is a mixture of zinc sulphate and barium sulphide. **[7]** However, this hypothesis was discarded due to the absence of zinc in association with barium in SEM-EDX elemental analysis and because lithopone was produced in 1874 outside the date on the painting. **[7]**

μ-EDXRF analysis of the paint surface shows that B, Ca and Pb are recurrent elements and can be associated with white pigments, like barium white and lead white, possibly found in the matrix of the ground; the presence of calcium can be related to chalk or gypsum – common fillers added to the ground preparation - but there were no conclusive results about these compounds.

2.4. The paint: pigments and binder

μ-EDXRF analysis of the paint surface and μ-Raman of the cross-section CS4 confirmed the presence of vermillion, a red pigment composed of mercury (II) sulfide (αHgS) **(Ap. III.5, Fig.III.5.5, p.63)**. This pigment has a characteristic Raman spectrum with very strong peaks at $42cm^{-1}$ and $253cm^{-1}$, a weak peak at $284cm^{-1}$ and a medium peak at $343cm^{-1}$, as seen in the analysis of red particles found in the beige coloured paint of cross-section CS3 and in the purple colour of cross-section CS4. This purple colour seen through the gaps in the black paint of the nun's veil has a typical orange fluorescence under UV light characteristic of madder lakes **(Ap. III.3, Fig.III.3.1, p.59)**. However, μ-FTIR analysis of the purple coloured paint was inconclusive.

μ-Raman analysis of cross-section CS1, CS2, CS3 and CS6 confirmed the presence of carbon based pigment by the characteristic wavelengths of both lamp and ivory black: ~1325 very strong (broad) : ~1580 very strong (broad) **(Ap. III.5, Fig.III.5.4, p.63)**. μ-EDXRF table of essential elements found can be seen in **Appendices III.5, Fig.III.5.6, p.63.**

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CHAPTER 3 EXAMINATION AND CONDITION REPORT

3.1. Techniques and condition (Ap. IV, Fig.IV.1, p.65)

3.1.1. Auxiliary support: stretcher

The primary support of a canvas painting is a fabric. The fabric is attached to an auxiliary support - strainer or stretcher - that places the painting and fabric under tension. Once a painting is attached to a strainer (a structure with fixed corners) the fabric looses tension by exposure to environmental fluctuations and deterioration of the textile fibres. On the other hand, if it is attached to a stretcher (an expandable structure) the fabric can be re-tensioned by keying out the stretcher's adjustable corners. Keys are small wooden wedges inserted in the corner joints of the stretcher's bar to open those, thus increasing the outer dimensions of the stretcher. **[8]**

The fabric from the painting *Interior de um Convento* is supported by a softwood stretcher formed by four bars (2 vertical bars: 50.2cm x 5.1cm x 1.5cm; 2 horizontal bars: 40.4cm x 5.1cm x 1.5cm) with small bevel on the interior edge. The corner joints are closed (or blind) mortise and tenon, which means that each corner only expands in one direction. This type of stretcher is defined as an adjustable rotary stretcher because it has only four keys, one for each corner to expand in just one direction, similar to a swastika cross **(Ap. IV, Fig.IV.2, p.66)**. Its major disadvantage is that expansion can distort the rectangle into a parallelogram, thereby stressing the paint/canvas system and also distorting the square corner (especially visible in the lower left corner of the front of the painting). Instead of four keys, when it arrived for conservation, there were five keys, (the back bottom right corner has two keys). Since the corner can only expand in one direction, it is thought that this "extra" key was added by someone who did not understand the stretcher's corner construction.

The canvas is attached to the stretcher bars with a total of 37 metal tacks and their distribution can be easily seen in the x-radiograph **(Ap. IV, Fig.IV.3, p.67)**. The surfaces of all tack heads were flaking and powdering most likely due to corrosion, as evidenced by the orange and brown spots mixed with the original black colour found on the tacks **(Ap. IV, Fig.IV.4, p.67)**, the usual corrosion products associated with iron-based artefacts. **[9]** Continuous exposure to high relative humidity (RH) levels facilitates corrosion which leads to the formation of an uneven surface on the tacks heads, thus allowing both water and oxygen to penetrate to the underlying metal surface, where further corrosion occurs. **[9]**

The left corner of the top stretcher bar has a paper label with the printed number "412" and bellow a dark squared shaped stain, most probably from a previous label now detached. There is another label with illegible pencil writing on the right corner of the bottom bar. Pencil inscriptions of numbers can be found near each corner joint (1 to 4), likely used to assemble the stretcher's bars, and on the bottom bar ("12.22"), probably the stretcher's price**.** A small hole on the centre of the top bar may have been caused by a nail used for hanging the picture **(Ap. IV, Fig.IV.5, p.68)**.

In relation to its condition, there is evidence of staining on the lower left and right corners likely due to previous water damage **(Ap. IV, Fig.IV.2, p.66)**. There are also traces of mechanical damage, specifically some abrasion/incision marks over the top and bottom bars **(Ap. IV, Fig.IV.5, p.68)** and "exit-holes" in the wood, evidence of previous insect infestation. Otherwise, the stretcher was in good condition. The circular exit holes are characteristic of xylophagous attack, and their 1.5 to 2mm diameter size are typical of the species *Anobium punctatum*. **[10]** Another sign of insect infestation was the presence of wood dust and frass (mostly larvae fecal pellets). Therefore, it was decided to put the painting in quarantine: it was wrapped and sealed in a transparent sheet of Melinex® and left undisturbed for seven days, after which it was checked for traces of active infestation (wood dust and new exit holes). It was determined that the insects were not currently active.

3.1.2. Support: fabric

The painting's primary support is a moderately tight plain-weave (1:1) canvas made from a single piece of linen fabric with total dimensions of 58cm by 48,5cm (55,4cm by 45,6cm for the image area). The threads are fine and have a "Z" twist. The average thread count is 16 by 20 threads per centimetre, vertically and horizontally, respectively (measured in different spots on the back lower left corner of the painting).

Concerning the fabric's condition, the major concern was that the canvas was not under uniform tension because it was not entirely attached to the stretcher. Four tack holes had become enlarged (likely due to fabric deterioration from rust associated with the tacks[2]) which released the tacking margin along the top edge **(Ap. IV, Fig.IV.6, p.68)**, resulting in a sharp depression in the front of the painting accentuating the top stretcher-bar crease. Despite the oxidation of the fabric, careful observation under the stereoscopic-microscope indicated that, overall, the textile appeared strong and not brittle. Given that the fabric was slack on the stretcher, this resulted in a sharp depression in the front of the painting just below the top stretcher bar which accentuated the top stretcher-bar crease. By raking light observation, it is possible to see creases from all four stretcher's bars as well as cracking associated with the keys at the back of the fabric **(Ap. IV, Fig.IV.7, p.69)**.

Other small deformations in the fabric consisted of bulges along the bottom stretcher-bar due to the presence of debris lodged between the stretcher and canvas, one small dent to the left of the depicted hanging lamp in the hallway, and a small bulge at the upper centre of the painting, perhaps caused by the pressure of another object resting against the back of the canvas. The back of the painting exhibited extensive staining, likely due to water, as well as a substantial layer of incrusted

[2] As noted previously, all metal tacks showed signs of active corrosion which implied that the fabric in contact with the rusted tacks suffered oxidation too. A cellulosic fabric like linen exposed to oxidation reactions can be compromised in its long term stability by continuous chain scission of the polymer (cellulose) backbone, which reduces both molecular weight as well as mechanical strength of the fibres, resulting in a more brittle and rigid fabric. **[11]** Clearly in this case the rusted tacks caused and accelerated the oxidation reactions of the fabric, driven by high RH levels. Oxicellulose, the so called product of cellulose oxidation, was recognized in the fabric's tacking holes by its brown colour, a product of the well-known chromophores, carbonyl groups. **[11]**

dirt. Moisture is the most important factor for spore germination and for successful colonization by fungi, but there are also other key factors like temperature, nutrients and time.

With stereo-microscope observation it was possible to conclude that the dirt was incrusted and could not be removed without mechanical action that could weaken the fabric. The canvas appeared darker in lines which followed the crack pattern of the paint layers; this can be associated with varnish penetrating the fabric through cracks, but it was not clear if that was the case.

3.1.3. Preparation layers: sizing and ground

In *Interior of a Convent*, as with most paintings, the **size** layer was not visible with the naked eye or by magnification because it is in general, a very thin layer and, if applied in a fluid form, it will impregnate the fibres. Using staining tests with the optical microscope, it was possible to determine that a protein was present associated with the canvas, suggesting a water-based animal skin glue. Such glues are very responsive to relative humidity, and in high moisture conditions are susceptible to attack by microorganisms such as mould. The **ground** is light coloured, of average thickness, with an even application and a slight canvas texture associated with a commercially prepared ground. On the right tacking margin, the paint layers end at the edges of the fabric, but on the top and left tacking margin it was possible to distinguish some areas with visible ground. On the bottom tacking margin, only ground was present. Cross-sections of samples of the paint composite (ground plus paint layers and varnish) show that the painting has a first layer of white ground, which appears to involve two application layers of the same formulation followed by a light beige-coloured layer, possibly an *imprimatura* **(Ap. III.2, Fig. III.2.3.b, p.58)**. In the two samples taken from areas where another painting underneath is visible (CS4, CS5), this last beige layer is not evident **(Ap. III.2, Fig.III.2.5 & III.2.6, p.59)**.

With regard to its <u>condition</u>, the four tacking margins had areas of (or in risk of) flaking ground, especially at the turn-over edge of the bottom left corner and along the bottom tacking margin. In these areas, a large section of both ground and paint loss showed sharply lifting edges with near detachment, a sign of poor adhesion to the support **(Ap. IV, Fig.IV.9.a, p.70)**. The location of these severe damages along the bottom and turn-over edge of the painting can be related to the staining on the stretcher bars associated with water exposure. The presence of debris between canvas and stretcher offers a site for moisture retention and associated damages. It is possible to imagine a situation where the painting was hanging with its bottom stretcher bar touching a wet wall, leading to an excess of moisture being absorbed by the wood. This would in turn result in local swelling and shrinking of the fabric near the stretcher bar. During mechanical cleaning, pieces of plaster, likely fallen from the wall to the back of the canvas, were found lodged between the canvas and the bottom stretcher bar, thus explaining some of the deformations, losses and lifting ground/paint.

On the bottom tacking margin, orange and brown stains from tack corrosion were especially noticeable; also an indication that this area had been very moist or wet in the past. The ground along the bottom tacking margin, in particular around the tack holes was loose and flaking **(Ap. IV, Fig.IV.9.b, p.70)**. On the other tacking margins, ground flaking was less extensive and confined to the edges of the most rusted tacks. Examination with raking light indicated encrusted dirt on the upper tacking margin where dust generally builds up in hanging paintings. Little white spots **(Ap. IV, Fig.IV.6, p.68)** were also found both on top of the paint, ground and tacks. These were not identified, and may be associated with fungi colonization or are simply debris/staining from another source.

3.1.4. Underdrawing

Historical sources suggest that either chalk, charcoal, pencil, watercolour paint, diluted oil paint or a combination of theses could be use as sketch materials on paintings. **[12]** Traces of pencil marks are visible on the bottom tacking margin and on some of the other tacking margins as well. The position of the pencil lines may indicate the drawing method used by the painter. These lines can be the remains of a grid used either to draw the one-point perspective of the floor, or to copy a sketch of the scene onto the ground. In the latter case, the sketch is divided into a grid, and the painting (ground) is also divided into a grid with the same number of squares as the sketch. The lines in each square of the sketch are then copied to the correspondent squares in the ground. This method allows the alteration of the drawing scale. **[11]** Infrared (IR) photography **(Ap. IV, Fig.IV.10, p.70)** revealed traces of dark preliminary drawing details. IR is absorbed by carbon based pigments like charcoal, and where the pictorial layers are relatively transparent to IR, these marks can be visible. **[13]**

3.1.5. Paint layers

A first examination of the painting with the naked eye resulted in little information about the painting technique due to the impenetrable layer of dirt which covered the entire image. Apparently, the paint was mostly opaque and thinly applied, since the drawing lines on the floor were visible, and the texture of the painting was smooth with few areas of impasto. After surface cleaning, the paint details and brushstrokes started to appear, especially under the stereomicroscope. Even though the artist subtly used different colour tonalities for the shadows, he seemed to have paid little attention to the figure's features which lack precise brushstrokes and well-defined drawing. Surprisingly, x-radiographic examination **(Ap. IV, Fig.IV.3, p.67)** revealed a previous composition underneath: beneath the nun's figure is what is thought to be an image of a woman, facing a male figure on her left. The man appears to be partially facing away from the spectator and the woman looks as if she wearing a dress with a neckline but this is masked by the nun's habit due to the heavy elements of the white lead paint (the degree of absorption of x-rays by a certain area of the painting depends on the density of electrons of a given element in the paint. Pigments containing heavy elements such mercury or lead will strongly absorb x-rays, appearing as white coloured areas, whereas pigments with lighter elements will appear dark). **[13]** A change in the width and number of stairs steps is also noticeable in the x-radiograph. Some imperceptible shapes covered the main door too. This composition points to a secular theme that was later changed to the current image.

In relation to its condition, the painting was almost unreadable under the incrusted dirt layers. Islands of dirt deposits were deeply imbedded in the texture of the paint strokes (confirmed under the stereomicroscope) **(Ap. IV, Fig.IV.11.a, p.71)**. As cleaning proceeded it was discovered that the paint layers exhibited a surface defect characterized by tiny craters of irregular edges, particularly in the white paint layer of the nun's habit) **(Ap. IV, Fig.IV.11.b, p.71)**. Rica Jones **[14]** describes "micro-cissing", a similar type of paint defect that she believes occurs during oil film formation. She notes that the development of these drying cracks depends on many factors mostly related to the physical construction of the painting. For example, "if a ground is 'fat' (that is, it contains as much or more oil as the paint on top of it), or if it has been polished smooth, or if it is not fully dry, then the paint may shrink into islands or blobs for simple lack of purchase on its surface" (**[14]**, p.50). Regarding *Interior of a Convent*, it is not clear whether this phenomenon can be connected to the underlying paint layers. Cross-sections from the nun's black veil – an area where it also possible to see *micro-cissing,* show a white ground and a build up of multiple layers of paint (which formed the purple colour exposed by paint losses), on top of which was laid a black layer of paint and a upper layer of varnish **(Ap. III, Fig. III.2.5, p.59)**. In the uppermost part of the cross-section, there is a more dense black layer of paint that is broken up with cup shaped sections within which varnish appears. *Micro-cissing* possibly occurred due to the application of the black paint over a still fresh (or partially polymerized) oil paint. Alternatively, a top black layer of paint may have been applied over a not yet fully dry varnish.

Under raking light, the painting's surface exhibited an overall pattern of mechanical cracks (like a cobweb). Under magnification it can be seen that the cracks have sharp edges **(Ap. IV, Fig.IV.8, p.69)**, an instable condition of the paint layers. This type of mechanical cracking is different from drying cracks since they penetrate the entire structure of the painting, from support to the surface, and are generally due to stress release in aged paint or from external impacts. As paint ages and becomes brittle, it can no longer accommodate to the stresses exerted by dimensional changes in the support caused by RH fluctuations. **[15]** The development of these cracks in *Interior of a Convent* clearly appears to be related to the painting underneath as the cracked area corresponds directly to the image below evident in the x-radiograph. Raking light reveals another type of cracking along the stretcher bars, and also associated with buckled cleavage and flaking paint on the right bottom corner) **(Ap. IV, Fig.IV.13, p.71)**, these are due to the physical tensions within the structure of the painting and stretcher (according to Michalski, the high stress in the paint and glue layers at 1ow RH, combined with the small shrinkage of the wood stretcher bars, could explain these type of cracks patterns).

During surface cleaning of the white paint over the figure of Christ, interlaminar cleavage between ground and paint was detected. Under the stereomicroscope, in areas not yet cleaned, small losses of paint alongside of the mechanical cracks were apparent, indicating that that the losses had occurred before the present cleaning **(Ap. IV, Fig.IV.12, p.71)**.

Marks associated with the inside edge of a frame were evident in normal light. Under UV light an area consistent with the frame's rebate appeared as a darker irregular area around the painting. Frame marks were accompanied by traces of gold (likely gold paint). White incrusted lumps were adhered to the paint surface, thought to be from plaster in the rebate of a frame that was placed against the painting when the paint was still fresh **(Ap. IV, Fig.IV.14, p.71)**.

3.1.6. Surface coating: varnish

As noted above, visual evidence of a varnish coating was obscured by an overall dirt layer. The paint surface was covered with stains, including random dirt stains and some white spots located over the dark paint areas on the left and right columns in the image. These greyish spots could represent mould residues from a significant mould infestation. Insect droppings were also found **(Ap. IV, Fig.IV.15, p.71)** as well as abrasion marks. With UV light, some areas of fluorescence associated with a resin (varnish) coating were observed, especially in the upper part of the painting (below the architectural arch). UV light images of paint cross-sections indicate the presence of a natural resin varnish thinly applied **(Ap. III.2, p.58 & 59)**. Further examination of cross-sections concluded that the varnish was very broken and full of accretions which may include dirt and mould residues.

3.3. Condition Summary

When the painting arrived at the FCT-PNT paintings laboratory, significant dirt accretion and mould residue over its surface almost completely obscured the image. The painting was unstable, not only due to active flaking but also because the canvas was detached in places from the stretcher and no longer under uniform stress. As result, there were serious deformations that required treatment.

4.1. Packing for a safe transportation/ Packing design

The best packing system for safe handling and transportation of paintings should, above all, consider the painting's past and present condition but also its construction (materials and technique). The conservator must be able to determine if the painting has enough stability and resilience to tolerate the expected risks of travelling. **[16]** An initial report of the painting's condition was made *in situ* (PNP), prior to travel to the FCT laboratory. As noted in the previous chapter, the painting was actively flaking and had several sharp deformations. These two types of serious damage had to be taken into account during the packing design, in particular, the need to secure the painting horizontally due to the risk of flaking, but also to protect it when it was in a vertical position. In addition was the special obligation of keeping the painting safe against vibrations (a potential severe hazard to a slack canvas). Another issue influencing the case design was the fact that the painting had no frame so it could not be handled without the risk of aggravating flaking. Instead of creating a travelling frame, a system of four independent K-line® corners was made to fit on the corners of the painting in order to safely move it in and out of the box, as described below.

Prior to travel, conservator Diana Conde did a local consolidation on the most vulnerable flaking areas (following the same methodology and materials described in the next section) in order to enable safe handling and transportation of the painting. The packing case design was also determined by the transportation mode and the travelling conditions: the painting was transported by car[3] from the Palace to the Faculty, a forty minute journey (35km). PNP's curator, Bruno Martinho, carried the painting to the transportation van; at the destination, the masters student was responsible for carrying the painting to the laboratory and for unpacking it. Concerning the packing case construction, a polypropylene corrugated plastic (PCP) exterior box was built using Archival quality, double-sided polyester tape on the corner joints and gummed linen tape to reinforce the top lid joints. Since the bottom box had one side with joints which were not taped, the edge could be turned flat and the painting could be taken out of the case just by sliding it with the opposite side K-line® corners **(Ap. V, Fig.V.1.b/c, p.73)**. This system allowed for a controlled unpacking without touching the fragile painting.

Fig. 4 – Scheme of packing case showing different materials used.

[3] Provided by an art transportation company which, along with insurance procedures, were dealt by PNP's administration.

Inside the case, a piece of polyester quilt-batting was cut to the size of the interior space of the stretcher such that it fit inside the back of the painting (allowing for the presence of the keys). This soft and light-weight cushioning material often used in textiles conservation was able to stabilize the sharp depressions in the surface by keeping the canvas in a horizontal position without causing further distortions. In addition, another piece of this material was cut to fit on top of the painting and below the top lid to eliminate any kind movement up or down while the painting was in the box. The painting itself was wrapped with Archival quality unbuffered acid-free tissue paper to minimize the risk of any physical damages (e.g. abrasion) during transportation. The exterior top lid of the box had a large label identifying the work, some basic handling instructions and also specifications about the shipping **(Ap. V, Fig.V.1.a, p.73)**. All of these efforts are considered crucial in reducing accidents, associated with transportation, handling and unpacking. **[17]**

4.3. Local Consolidation

As noted in the Examination and Condition Report (p.5), some top layers of paint and intermediate layers of ground had poor adhesion and were at risk of loss, especially in the tacking margins and bottom turn-over edge, hence requiring a consolidation treatment. A synthetic adhesive, *Lascaux Medium for consolidation*® (Kremer pigments) was used in stock solution. This water based acrylic copolymer adhesive is reported to be resistant to aging (ageing tests performed by the Royal Institute of Technology in Stockholm, Sweden) has excellent penetrating power due to its low viscosity, and dries to a clear and flexible film. **[18]**

A synthetic adhesive was chosen over a natural one, such as sturgeon glue, mainly due to PNP's damp environment which would provides the right conditions for mould growth in a proteinaceous material. During consolidation treatment, the painting was kept in a horizontal position to prevent losses, and the consolidant was applied to the surface with a soft brush (no. 00, *Winsor & Newton*® - England, Series 7) **(Ap. V, Fig.V.2, p.73)**. Excess adhesive was quickly removed with a micro-swab moistened with distilled water prior to its drying. The consolidated areas were lightly heated with a hot spatula at 45ºC-50ºC (previous testing showed the paint to be resistant to the heat required). Where the canvas touched the stretcher (tacking margins and turn-over edge), a silicone coated Melinex® sheet was placed between canvas and stretcher to prevent the canvas from becoming stuck to the wood.

4.4. Mechanical cleaning

Both the canvas and painting surfaces were gently brushed with a soft brush to remove dust particles. A piece of thin blotting paper was gently slid across the inside stretcher bars in order to dislodge the debris stuck between the canvas and the stretcher. With the help of a vacuum cleaner nozzle held above the area of dusting, it was possible to remove all debris **(Ap. V, Fig.V.3, p.73)**.

4.4. Surface cleaning

Depending on its history and environment, a painting can present a thick or a thin layer of surface dirt which may be formed by different substances and particulates, both organic and inorganic in nature. Since most of these components are hygroscopic, dust can create a favourable environment for the growth of mould and the occurrence of chemical reactions (salt corrosion, acidification, etc.) which deteriorate the paint composite **[19]**. The conservator must be able to find a suitable cleaning agent that will remove "unwanted" material without damaging the original. Given the complex composition of dirt, cleaning tests should be carried out using a progressive and controlled method which allows the conservator to have a better understanding of the painting by studying how the painting reacts to an aqueous treatment. Tests also provide information about the nature of the dirt through its chemical dissolution. **[20]**

In this case, the painting had a very thick and encrusted layer of dirt that was obscuring the image and was likely combined with mould. This concreted dirt layer was difficult to wet, and the existence of many sharp cracks with slightly lifted edges created a very sensitive and frail surface which required a diligent and careful approach. Furthermore, as noted by Phenix **[21]**, oil paint films become more polar on aging, so their susceptibility to polar solvents (including water) increases. Such solvents can also penetrate cracks by capillary action and cause damage to the paint composite. Therefore, to evaluate the permeability and sensitivity of the paint layers to water, a small test was made on the ground in an area of loss using a fine brush (W&N nº 00, series 7) with the point very slightly moistened with deionised water. The tiny drop of water was only adsorbed by the surface after a 30 second period with no effect on the ground, which indicated that the ground was not water sensitive and the dirt layer was greasy or contained residues of varnish.

Surface cleaning tests proceeded under the stereo-microscope in a white area in order to assess the response of varnish and paint layers to the cleaning agents. The white paint was assumed to be lead white, which generally forms a tougher relatively "solvent-resistant" paint than in other coloured areas. Three water-based cleaning formulations were tested: deionised water, natural saliva and the chelating agent[4] tri-Ammonium citrate (TAC) dissolved in distilled water. It was found that both deionised water and saliva dissolved part of surface dirt but required prolonged swabbing, consequently removing particles of paint by mechanical action. After testing six percentages of TAC in water (from the least to the greatest concentration) on different colours of the paint (white, blue and red) the most effective system to remove surface dirt without damage to the paint layer was determined to be 2.5% TAC in distilled water **(Ap. V, Fig.V.5, p.73)**. The major advantage of this chelating agent is its low or neutral pH (7 in case of TAC) avoiding the possibility of alkaline hydrolysis of the paint medium (saponification of oil) **[22] [23]**. However, as these substances are not volatile, they need to be removed thoroughly with a swab moistened with distilled water to prevent possible long-term effects on the paint composite. **[20]**

Tests with organic solvents were done as well to remove residues of varnish where present. As there was no significant effect on the surface dirt or paint layer, it was decided to test an area of

[4] "A chelating agent is a material which can form a complex compound with a metal atom." **[22]** (p. 44) Chelating agents will separate and solubilize metallic ions that would otherwise form intractable salts or complexes in the surface of the painting.

suspected build-up of dirt encrusted varnish (thought to be from the frame being varnished with the painting in situ) by using a thick solution of a natural resin with additional solvent (based on the principle that "like dissolves like"). Therefore, a solution of dammar resin dissolved in turpentine (1:1) with the addition of ethanol (10 drops in 1ml of varnish) to enhance the strength of the solution, was applied over the white paint of the nun's habit - a more fragile area where TAC had already been tested with tiny losses of paint particles – but with no effect to the dirt and varnish layer. The same solution with the addition of diacetone-alcohol to delay the evaporation of the solvents was also tested, on what was judged to be a stubborn dirt/resin resin build-up; it was applied through Japanese tissue. The dammar resin plus solvent was left to dry on the surface of the dirt/varnish overnight to encourage dissolution. The following day, removal was attempted with 100% isopropanol which in fact had some effect but it was not considered significant. However, since the incrusted dirt had been softened somewhat with the dammar/solvent solution, it was possible to remove some of it with a scalpel blade seen under the stereo-microscope.

At the completion of the cleaning tests, it was decided that cleaning should progress by stages: the first being the surface dirt removal with 2.5% TAC solution. In this first stage, the cleaning proceed with the painting horizontal facing up, using small cotton swabs moistened with 2.5% TAC solution, rolled very gently over the paint surface, and rinsed with swabs moistened with distilled water **(Ap. V, Fig.V.4, p.73)**. Consolidation of lifting cracks of paint was necessary during cleaning (following the same method described in section 4.3). The next stage will be the removal of tiny dirt islands (incrusted dirt left on the grooves of the textured paint layer) under the stereo-microscope with micro-swabs very slightly moistened with 5% TAC rinsed with distilled water and finally with dry cotton swabs to prevent excess water. The use of micro-swabs under the stereo-microscope can extend the duration of the cleaning for weeks but it was consider the best strategy when dealing with a painting very deteriorated in risk of paint detachment.

4.5. Structural treatment

The objectives of the structural treatment consisted in flattening and re-securing the top tacking margin that was loose and to re-tension the canvas into the original stretcher.

4.5.1. Preparation for treatment: tack removal

It was necessary to remove the tacks from the top tacking margin and the side corners in order to begin the structural treatment (flattening of the edge and strip-lining). To protect the canvas and ground, a thick polyester film (Melinex®) was placed between the tack head and the ground. The tacks heads were first raised with dental spatulas because these instruments have small, thin flat ends which provide good leverage **(Ap. V, Fig.V.7, p.74)** and then pulled out with small pliers. The 11 tacks removed presented severe signs of corrosion, and most had a powdery look and broken points, therefore it was decided to replace them with new ones when the tacking margin was re-attached to the stretcher (see below).

4.5.2. Moisture treatment[5]

The pioneering work of Mecklenburg in the early 1980's provided insight into the mechanical behaviour of the individual components of oil paintings in relation to moisture (RH in the environment). He concluded that above 85% RH, naturally aged oil paint films become slowly flexible, animal glues (in the size layer) enter a completly elastic state (almost a gel) and are unable to bear tensile stress, and the fabric from the canvas, contracts in dimension, shrinking[6] and if already stretched, it becomes stiff. As Hedley explained, "The combination of shrinking canvas, soft and weak size and still rigid and brittle ground is what is catastrophic for the structure". **[25]** Since water is a powerful plasticizer of vegetal fibres by "considerably decreasing their Tg (glass transition temperature) and making them more elastic" **[11]**, conservators are now accustomed to reduce canvas deformations and creases with moisture treatment. However, as noted above, the differential behaviour in the painting's structure demands extreme caution in treatments which involve moisture, such as those planned for the *Interior of a Convent.* In this case, moisture treatments were gradual and controlled. Once it was decided to keep the painting facing up due to the risk of flaking, the whole process was planned and carried out according to the painting's orientation. The moisture treatment was divided in two stages: the first to allow strip-lining on the top tacking margin by unfolding the corners and reducing the crease associated with the turn-over-edge; the second, to remove the major out-of-plane deformations followed by flattening with weights so that the fabric could be uniformly re-tensioned in the stretcher.

To flatten the top tacking margin, the local moisture treatment involved using small pieces of blotter paper very slightly moistened (they had been sprayed with distilled water and kept under Melinex® sheet during the night). These pieces were cut to the width of the tacking margins and slid inside the folded fabric of the corners **(Ap. V, Fig.V.8, p.74)**. The moisture quickly started to make the canvas more flexible and it was possible to gradually unfold the corners by gently opening the moistened blotter strips. A silicon protected bar of wood the same height as the stretcher and canvas was placed near the top tacking margin to serve as a platform where the fabric could be laid after flattening with moistened blotters strips. Once flattened, the area was protected from moisture loss with Melinex® sheet and kept under small weights to keep the fabric from returning to its original shape. For the second stage of the treatment, a template of Melinex® was made to indicate where the moist blotter needed to be positioned underneath the painting. The deformations in the painting were reduced after the repetition of the following steps: 1) application of moistened blotters, 2) feeling the surface within the first minute and leaving the dry/moist blotters in place for usually up to 5 minutes

[5] For further information, see the review article by Paul Ackroyd: "The structural conservation of canvas paintings: changes in attitude and practice since the early 1970s" which provides a comprehensive summary of the research done through the years on the response of canvas paintings to moisture treatments. **[23]**

[6] Water molecules penetrate the capillaries and pores of the cellulosic fibres of the fabric and diffuse into the amorphous regions of the cellulose polymer, forming new hydrogen secondary bonds with the hydroxyl groups of cellulose chains. **[11]** Excess water will make the fibres swell on wetting and as the yarns from the fabric expand, the spaces between threads are reduced thus causing the whole woven fabric to shrink. **[25]**

until the paint composite felt significantly flexible, 3) replacing the moistened blotters by dry ones, 4) applying a system of weights on the area to flattened it **(Ap. V, Fig.V.9, p.75)**.

To feel the level of moisture, the surface of the painting was touch by hand. Generally, if the surface was cold, this meant it already up took a lot of moisture, leading to the fast removal of the blotter and its replacement by a dry one. Being able to "feel" for the moisture in the surface of the paintings comes with a certain experience on these kinds of treatments and also requires an organized action with fast steps, otherwise, whether the painting ends up swelling or the moisture evaporates during the evaluation of the paints condition. The system for weighting the surface involved having a flat seamless platform beneath the painting for support (to ensure that the plasticized paint composite is not deformed by the presence of any sharp edges or undulations in the support and surface), then immediately on top of the paint surface, a sheet of thin Melinex® followed by another K-line board with its sharp edges removed. Evenly distributed lead weights and lead-shot bags were then placed on top of the K-line board. Since the top tacking margin had been reinforced with strip-lining (see next sub-chapter 4.5.3.), it was possible to keep the canvas under tension by securing the excess polyester lining fabric with push-pins to a bar of wood. Throughout the series of local moisture and weight treatments, the polyester fabric was gently re-tensioned with push-pins to gradually effect a complete return to plane. Once flattened, the painting remained secured in this position until it was ready to be re-attached to the stretcher.

4.5.3. Partial strip-lining

Strip-lining was made only on the weaker areas of the tacking margins, namely, the top tacking margin and on the left lower corner of the painting. After looking at several different fabrics, it was decided to use a synthetic fabric – polyester restoration fabric, not only because it was a similar density to the original canvas, but due to its strength, long-term durability and resistance to moisture and tearing. After testing different combinations of BEVA® 371 gel and BEVA® 371film to adhere the polyester fabric to a sample of linen fabric in order to evaluate the peel strength of the adhesives, BEVA-film was first adhered to the polyester fabric with high temperature (around 70ºC) and then this was adhered to the original canvas with a lower temperature (around 60ºC) using a heat spatula. This not only resulted in good adhesion (high peel strength) but also kept the adhesive from impregnating the canvas fibres which guarantees the reversibility of the treatment and any possible side effects caused by aging of the adhesive.

To do the strip-lining, the painting was turned face down on a flat seamless surface covered with silicone coated Melinex®. BEVA® 371film was cut to the exact profile and size of the tacking margin, adhered to the polyester fabric and then adhered to the back of the tacking margin (0,5 cm inside the painting image area, slightly under the stretcher bar) with a heat spatula at 63º-65ºC **(Ap. V, Fig.V.10.a, p.75)**. To carry out strip-lining along a small section of the lower edge of the left tacking margin, the fabric had to be placed between the stretcher and the canvas (with the adhesive facing the canvas) and then heated with the spatula. Loose canvas threads along the edges of the canvas were glued in place using BEVA® 371 gel (60:40 gel to white-spirit) applied with a brush **(Ap. V, Fig.V.10.b, p.75)**.

4.5.4. Re-tensioning

After the flattening treatment and the reinforcement of the tacking margins with strip-lining, the canvas needed to be reattached to the stretcher. In order to hammer fresh tacks in place, a platform was built to secure the painting and to provide support to the wooden bars on hammering. When hammering the tacks into the left and right edges of the top tacking margin, the stretcher bars running along the sides of the painting were able to distribute the force along the stretcher which was held in place with a wooden bar across the bottom edge. As for the centre of the top tacking margin, a shallow wooden bar fixed (with nails) to the platform served the same purpose, supporting the central part of the stretcher bar[7] **(Ap. V, Fig.V.11, p.76)**. Once the painting was in place, the painting could slightly pre-stretched under raking light, using the excess polyester strip-lining fabric held under tension with push-pins attached to a wooden bar **(Ap. V, Fig.V.12, p.76)**. With raking light it was possible to see the effects of the re-tensioning and to adjust and pull the canvas uniformly in the upper region of the painting, securing it in place along the wooden bar.

The next step was to tack the original tacking margin to the original stretcher while the polyester fabric was under tension, thus holding the tacking margin securely in place **(Ap. V, Fig.V.13.a, p.76)**. The tacks chosen were very similar to the original ones and were hammered very gently into the stretcher wherever an original tack had been, using the same tack-holes in the stretcher from before. As the need for other points of attachment arose during the process (the original tacks were not always placed at regular intervals), it was decided to add very small nails between tacks on the areas that needed to be secured (primarily to even out the tension along the top tacking margin) **(Ap. V, Fig.V.14, p.76)**. Because the polyester strip-lining fabric was very closely woven, the small tacks held it in place, without interfering with the original appearance of the tacking margins. Care was taken not to drive these small nails through the ground, introducing new holes, but to placed them in pre-existing ground losses along the tacking margin. Their positions are recorded in the detailed photograph of the tacking margin. After re-attaching the canvas to the stretcher, the excess polyester fabric was cut off with a scalpel blade using a chamfered piece of matt-board between the fabric and stretcher to protect the wood **(Ap. V, Fig.V.13.b, p.76)**.

4.6. Further treatment

Due to time restrictions, it was not possible to finish the treatment before completing the thesis. However, it is expected that the treatment will continue as follows:

a) Completion of surface cleaning: By the removal of encrusted surface dirt using 5% TAC in distilled water and with mechanical removal (under the stereo-microscope).

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[7] With thanks to Dr. Isabel Cardoso for her suggestion to use the small brace-bar on the platform.

b) Reintegration of image: Exposed canvas in paint losses will be infilled with an appropriate archival quality fill material, textured to match the paint surface, then inpainted with Gamblin® Conservation colours (see below). A range of infill materials generally used in conservation field were tested on a canvas sample stretched to a wooden board using different combinations. It is very important to test the infill materials (also known as putties) because they will have an impact, not only on the structure of the canvas painting, but on the surface appearance as well since they can change its colour and luminosity. In this case, the priority is given to an infill material that will be flexible enough to accompany the contraction and expansion on the canvas during RH cycles without cracking or flaking. Since the exact chemical composition of the tested commercial putties (Ecostucco® and Flügger®) is unknown, they are not considered appropriate in this case. The most flexible putties tested were the wax-resin filler (4 parts Beewax to 1 part ketone resin) and the synthetic BEVA® 371 gel with chalk, neither of which showed signs of cracking after drying. Both are applied with heat and can form layers of different thicknesses. They are reversible, easy to apply, reasonably flexible, have good adhesion and cohesion and although BEVA® 371 is a commercial formulation, its formula is published and it is considered an acceptable conservation quality material. **[24]** As for the inpainting materials, Gamblin® colours are pre-mixed paints that were especially developed for conservators and are considered to be stable and reversible **[25]** and suitable to use in diverse painting styles and techniques by achieving an "optical gamut from transparent to opaque colours". **[26]**

c) Varnishing: Prior to inpainting, the painting will be varnished with a synthetic varnish such as Laropal® A81 (same resin used as binder for Gamblin® colours) soluble in hydrocarbon solvents that are 25% aromatic (with solvents such as isopropanol, ethanol and acetone). **[25]** This solution will be applied in spray with a spray gun and compressor to give a uniform distribution of the varnish and to ensure that the varnish does not penetrate the paint and cracks to saturate the back of the canvas (a risk in brush-varnishing).

d) Stretcher treatment: The planned treatment for the tack corrosion is to consider converting the corrosion products by chemical action. Previous to this step, mechanical removal of corrosion products with glass-bristle brushes will be carried out locally on the heads of the tacks. Chemical conversion will consist of placing a solution of tannic acid at 2.5% and phosphoric acid at 5% (2:1) on the heads of the tacks (while ensuring that the surrounding ground on the tacking margins is fully protected and isolated). The tannin (tannic acid) will react with the iron oxides, converting them to iron tannates, a stable blue/black corrosion product. After drying, mechanical cleaning is repeated, and the solution reapplied. These steps continue until the tack surface exhibits a black color. A protective coating against moisture will be applied with 5% or 10% Paraloid B72® solution in an appropriate solvent. Whether it will be possible or advisable to carry out this treatment is still under consideration at the time of the writing.

CHAPTER 5 AFTER-CARE

5.1. Framing and glazing

There are two options for the frame: either a new frame is reconstructed in the appropriate historic style (19^{th} century), or an old frame is adapted to the painting. The last option is the most interesting given that an old frame has esthetical and historic value which will enrich the painting. Inside the frame, the painting should rest on synthetic velvet tape or on archival quality foam tape applied to the frame's rebate, since the wood from the frame can cause abrasion where it is in contact with the paint surface. Special inert (acid-free) plastic spacers (e.g. Econospace®) will be used to separate the painting from the glazing.

Care must be taken to ensure that the glass in the frame is held at least 0.5cm away from the surface of the paint. Condensation, mould and paint/varnish sticking to the glass are hazards of glazings which are too close to the paint surface. The most affordable option is a non-glare glass, however from the properties of glazing materials recommended in the literature **[28]**, the best option is an anti-reflective laminated glass that provides good clarity, breakage and shatter resistance as well as a degree of UV filtration (given by the resin adhesive layer in laminated glass). Recently, a material that combines the advantages of both acrylic and glass has become available (Optium™ by Viratec in the USA and by TruVue® in the UK). It is an abrasion-resistant acrylic with a titanium-based low reflective coating, good UV filtration, a high level of clarity and light transmission and "it also exhibits lower than usual static charge". **[28]**

5.2. Back Protection System

Even though the results of the Back Protection Project are preliminary (see chapter 8, p.), it clearly demonstrates the value of glazing and sealing the back of paintings in order to stabilize RH inside the micro-environment created around them. However in the Palace's particular environment, with very high RH levels sustained over significant periods of time, this ideal option may not be advisable for the Palace's paintings collection due to the risk of mould growth being exacerbated in such a closed system.

PART II

THE BACK PROTECTION PROJECT

CHAPTER 1 **INTRODUCTION**

The conservation world is currently enjoying a relatively dramatic civil war over the issue of what is a safe climate for our rarities and how quickly it may be allowed to change without causing distress to either object or conservator.

Tim Padfield, 2003 (http://www.conservationphysics.org/index.php)

1.1. Objectives

The particular environment in the historic Palace with its high RH (reaching up to 95% RH) throughout the whole year, offers an excellent opportunity to evaluate the effectiveness of a number of back protection options for reducing the impact of RH fluctuations, while establishing whether a dangerous micro-climate is created in a relatively closed system. It is anticipated that the back protection project will help conservators identify the best option for back protection in similar uncontrolled conditions, and will specifically lead to a recommendation for the protection of the paintings collection at the Palace.

1.2. Some basic concepts

The complex structure of canvas paintings is characterized by the variety of materials used in the construction of its multiples layers. These materials are generally hygroscopic (such as textile fibres from the canvas or animal glue from size layer), and will react dimensionally to changes in temperature and relative humidity (RH). **[30]** Mecklenburg considers that high moisture levels are the greatest cause of damage to paintings both on wood and canvas. **[31]**

To comprehend this statement, the reader needs to understand some basic concepts, in particular, relative humidity (RH) and temperature (T), equilibrium moisture content (EMC) and water activity **(a_w)**. Expressed in percentage, **RH** is the measure of the quantity of moisture in the air by calculating the ratio of the water vapour concentration present to the maximum possible (saturation) water vapour concentration at the same **temperature**. **[32]** Therefore the RH of air changes according to absolute humidity (AH), temperature and pressure. The interdependence of temperature and RH is expressed by the **dew point:** this specifies the temperature to which the air must be cooled to reach condensation (100%RH). **[33]** Hygroscopic materials will "adsorb moisture when the RH in the surrounding air increases and desorb moisture when it decreases. Increasing the temperature of the material drives off moisture, while moisture is adsorbed when the temperature decreases". **[30]** When a hygroscopic material is no longer taking up (adsorbing) or releasing (desorbing) water vapour at a given temperature, RH, and atmospheric pressure, it is said to reach its equilibrium moisture content (**EMC)**. A diagram representing the relation between EMC and RH at a constant temperature **-** the sorption curve, (known as an **isotherm) -** helps to estimate the EMC changes that accompany RH fluctuations, offering an indicator of the dimensional stability of hygroscopic materials. Temperature also plays a role in EMC: the moisture content of a material will be reduced by an increase in temperature at a constant RH, and vice versa. **[17] [30]**

At a constant RH and temperature, materials with a high EMC will have enough moisture to support fungal activity, the major cause of biodeterioration of works of art. However, it is important to note that fungal growth depends not only on EMC but also on **water activity (a_w)**, defined as the ratio of vapour pressure of water in a material by the vapour pressure of pure water at the same temperature and RH. The water activity will be influenced by chemicals and bond strengths within the material. Chemicals such as glycerol or certain salts can increase the EMC of organic materials without making them vulnerable to fungal attack, because a_w can be lowered to a level where water is no longer chemically available for fungi. Variations in a_w are the main reason that some materials kept at a constant RH and temperature are more prone to fungal attack than others. **[35]**

1.3. Literature Review

Nowadays, installing or upgrading equipment necessary to maintain an appropriate environment in an exhibition space is a common measure for the protection of works of art but may give a false sense of security. Recent studies show that pernicious micro-climates can be generated between paintings and interior surfaces of the walls upon which they are hung. For example, when the surface of a building's exterior wall gets fairly cold, the interior surface can reach dew point, even with moderate indoor RH levels (such as 50%). **[31]**

For decades, conservators have been looking at new ways to create, stable and controlled micro-climates within which paintings are able to safely travel and remain during exhibition and storage. A good example is Sozzoni's work, published in 1993, which shows a simple and economical design for using a picture's frame as the showcase body. By putting an airtight glazing at the front of the painting and an airtight back board attached to the reverse of the frame, a completely sealed microclimate is created. **[36]** Although not the first (see literature review by Wadum **[37]**) Sozzoni helped create a standard way of enclosing paintings by adapting an original frame or creating a new one fit for this purpose.

Small museums and galleries often struggle to find financial support to monitor and control the most important works from their collections whilst trying to study and preserve the remaining. As an historic building that holds a vast artistic and cultural heritage, Palácio da Pena is also facing the same problem but with the additional issue of being located on top of a hill that has its own micro-climate with rapid and severe daily changes in RH and temperature. Due to the large palace's interiors serving as showrooms for a diversity of collections, including ceramics, metals, paintings, textiles, etc., and having hundreds of visitors per day, it is not only impractical to create a stable environment in all rooms by the installation of air conditioning equipment; the building´s structure itself must also be considered (see below). A survey of the palace' paintings collection conducted in February 2011, by Master's student Diana Conde, showed that 31% of the works were classified as very unstable (risk of flaking, poor adhesion between layers, cracks, etc.) and 18% had possible active wood infestation. In the absence of complete climate control, therefore, one strategy to maximise the preservation of the paintings collection at PNP, would be to dampen the effects of rapid environmental changes by protecting each individual painting at the back and at the front.

Several studies have been carried out to evaluate the impact of full back protection systems on paintings. It is generally accepted that back protection is a useful way to avoid accidents caused by mechanical impacts, to prevent dust and debris from falling between stretcher and canvas, to reduce vibration of the canvas in transit, and to discourage the practice of writing on or attaching labels to the back of the canvas. **[38]** However, there is still an ongoing debate over the efficacy and possible consequences of back protection materials for the stabilization of RH fluctuations.

Sandner, Schramm, & Schaft **[39]** conducted an investigation where they tried to find a basic model for all types of canvas paintings that could act as a climatic buffer by bringing the climatic conditions of the back of the canvas closer to those of the face of the painting, as well as acting as a shock absorber, and which could be generally used, easily mounted and removed. They calculated different degrees and velocities of water vapour diffusion and the permeability of original canvasses with various paint surfaces (test models and originals). They also studied various back protection materials (hardboard, museum cardboard and polyurethane foam sheets), and tested models with silica-gel between the backing boards and the canvas including a model where the painting is also glazed. They put the model paintings in compartments with variable RH and with sensors located inside the closed interior space of the stretcher. Since variations in RH inside the back of the paintings were significant, except for the model with glazing and back protection, they assumed that the major air leakage comes from the face of the painting as well as from general leakage of the system. They also concluded that leakages of the stretcher system are the decisive factors for the exchange of humidity. However, their article lacks clear results and well-founded conclusions, as these last two points were based on their assumptions.

On other hand, Ligterink & Di Pietro **[40]** tried to quantify the stabilization effect on RH fluctuations caused by back protection systems using model paintings. More specifically, they intended to predict the effect of different backing materials and different stretchers, on the RH response of back-protected paintings with respect to the particular climatic situation of the exhibition/storage room. With model paintings experiments they concluded that a back protection material should be impermeable to prevent water vapour leaving the system through the back of the painting. They also recommended that backing materials should be hygroscopic to provide a reservoir of moisture, and to be able to release moisture over a short time to counteract the considerable flow of moisture through the canvas. Even though the results are very important to the study of back protections systems, their mathematical models involve significant simplifications and limitations which make it difficult to extrapolate to real objects.

In another article **[41],** the same authors tried to develop a physical model that takes into account the complicated moisture desorption of the wooden stretcher in order to predict the RH response of a painting to external RH fluctuations. Measurements of the RH for the enclosed air volume inside model paintings, allowed them to conclude that the RH response of canvas paintings with a backboard is the combined result of three different moisture transport processes: 1) the release of moisture through the painting that is determined by the canvas's permeability; 2) a fast exchange of moisture between the enclosed air and the surface of the wooden stretcher and the canvas; 3) a slow diffusion of moisture from the internal part of the wooden stretcher to the enclosed air. These conclusions show the importance of the wood stretcher in the back protection system and demonstrate the complex moisture exchange occurring between wood and canvas, thorough the paint surface and through the back board (where permeable).

Padfield & Robinson **[42]** analyzed a situation very similar to the uncontrolled environment at PNP, focusing on the microclimate behind two paintings from the Chapel of Ledreborg, in Denmark. While a damaged painting was in intensive care in the National Museum's workshop, they put in the vacant niche of the chapel two paintings, one designed to imitate the original without back protection and the other with a polyester foil stretched over the back of the frame in order to exclude water vapour coming from the direction of the wall. Temperature and RH sensors were placed in front of these pictures and in the air space between the canvas and the wall. The outside climate was also measured. Prior to being placed in the chapel, both the protected and the unprotected paintings had been stored for weeks in a room at 40%RH. The unprotected canvas came rapidly to equilibrium close to the average of the RH in the chapel, while the protected canvas came slowly to equilibrium. At the end of the measuring period, the RH behind both canvases was more stable to fluctuations than in the room. The authors felt that the wall was actively stabilizing the RH behind the unprotected painting, and that the canvas in the protected picture was stabilizing the RH of the air trapped behind it.

Padfield et al. **[43]** studied the physical principles governing water and vapour distribution in small spaces subjected to a temperature gradient. Although primarily focused on framed prints, there were several relevant points: the 1st is that a small gap (minimum 20mm for small sized pictures) between the painting and the wall will increase the indoor air flow enough to reduce temperature gradients and, consequently, the risk of condensation. The 2nd point is that if paintings are to be kept in a sealed enclosure, a careful choice of back protection and sealing materials must be made in order to ensure that harmful pollutants are not released inside. And finally, insulation materials should not be used when a painting will be exposed to direct light, because the enclosure could heat up and condensation could occur on the glass which is the coolest part of the assembly.

More recently, Michalski **[44]** recognizes the importance of protecting the back of paintings on canvas as a conservation measure to reduce risk from punctures and tears from behind, as well as the risk of linen weakening caused by air pollution (if the materials are impermeable), and the risk of cracking caused by even small drops in RH during transit, or by daily RH fluctuations in uncontrolled buildings. However he warns of the risk of mould growth when a stable high RH is achieved at the back of protected paintings (see chapter 3, p.39). Therefore, for climates which presents dry days but damp nights, he advises the use of ventilation holes at the back to avoid fungal growth. But for environments with damp days and nights sustained throughout the whole year, he predicts that mould growth is inevitable, especially for paintings lined with glue and paste linings.

This literature review revealed that the importance and value of back protection systems was fully recognized by practicable real cases and test models. It was possible to learn that water vapour exchanges occur between both canvas and paint layers and the back protection system, either by the material itself or through air leakage. Temperature gradients are a very important factor to consider as well because this will influence RH fluctuations and can reduce or increase the risk of condensation. It appears from the work carried out and described above, that the best protective system is the one which will enclose the painting from front and back to reduce rapid daily RH fluctuations, and contains a hygroscopic or buffering material. It was also evident that paintings be separated from the wall by at least 2cm to allow air circulation and thereby decrease the risk of condensation within the enclosure.

Finally, the best strategy will not overlook the environment in which the painting is exposed and what RH and temperature conditions prevail in the area immediately behind the paintings (e.g. governed by the wall itself). How the best strategy relates to the particular conditions at Palácio da Pena and the performances of the model paintings in situ will be discussed in chapter 8.

CHAPTER 2 **EXPERIMENTAL DESIGN**

2.1. Project design (Ap. VI, Fig. VI.1/2, p. 77 & 78)

Six back protection options (Sets) were selected for the study, each with one replica, for a total of twelve model paintings. The six different options were chosen according to their current use in the conservation field, but also in relation to the damp environment at PNP in which certain materials may suffer condensation inside the sealed back. All model paintings were separated from the wall by 2cm using cork spacers, as recommended in the literature (see Literature Review above).

Set 1 – Polypropylene corrugated plastic (PCP) board with silica-gel and glazing: presents a system which offers both back and front protection: on the back by the use of a non hygroscopic material (PCP board sealed with a gasket of Archival quality rebate foam tape) with the addition of a buffering material (silica-gel, *Art-Sorb*®) attached to the interior surface of the PCP board; and on the front by glazing the painting. It is expected that the back board and glazing will buffer the painting against short-term environmental changes. **[38]**

Set 2 – PCP board with silica-gel: is the same as Set 1 but without glazing. Solely a back protection, it offers the opportunity to study the level of leakage through the front of the painting and its significance in maintaining stable RH and T values. **[39]**

Set 3 – PCP boards: uses a PCP board alone sealed with gasket. Essentially, it will be useful to determine if a low moisture diffusion material like PCP can risk condensation occurrence.

Set 4 – PCP board with fabric: presents a hygroscopic material, in this case a cotton fabric, attached to a PCP board with no gasket (assuming that the fabric is a sealing agent for itself). It is expected that a hygroscopic material will have a different response to RH fluctuations than non-hygroscopic materials, but there is no certainty about the stabilizing effect of this combination, hence the importance of the experiment.

Set 5 – Non Woven Fabric (*Reemay*®): utilises a non-woven polyester fabric (*Reemay*®), attached directly to the stretcher with staples. This synthetic material offers a degree of dust protection, but primarily, it prevents debris from falling into the back of the canvas. Since it is permeable to moisture, it was considered to be the least effective back protection system in relation to RH and Temperature fluctuation inhibition, but was included as an option should the moisture impermeable designs result in mould growth.

Set 6 – Control: does not receive any form of protection, to study the differences that occur between a painting with and without a back protection system or full enclosure (see Fig.5 in text).

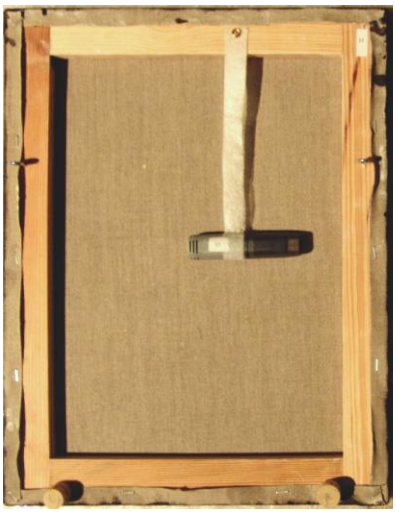


Fig. 5. Control set with data-logger

2.2. Model paintings construction (see Appendix VII, p. 79)

The selection of materials and techniques used for the model paintings construction was carefully planned. For a better understanding of the results, and in order to recreate the experiment should the need arise, all details were fully documented throughout the whole project and are thoroughly described in Appendix X, p.56. Briefly, two pieces of linen fabric were washed, re-stretched 3 times on a loom and then cut and stapled to the wooden strainers. The size layer consisted of rabbit skin glue (RSG) *Zecchi*® 7% in water applied in gel form. Two layers of ground (chalk in 7%RSG) were also applied followed by the resin coating consisting of 31% wt/vol Dammar resin dissolved in distilled turpentine and coloured with powdered pigment in order to create an paint and varnish-like surface in imitation of an oil painting on canvas. The same varnish without the pigments (uncoloured) was used as the final coating.

2.2.1. Back protection materials

a) Polypropylene corrugated plastic boards – Consisting of a chemically stable copolymer of polypropylene and polyethylene, it is a durable, heat and chemically resistant material that is also lightweight, moderately strong and rigid, and with minimal moisture diffusion. **[38]** A gasket consisting of a strip of foam self-adhesive tape, (Volara®), was attached to the interior edges of the polypropylene boards **(Ap. VIII, Fig. VIII.1, p. 85)** in set 1, 2 and 3 to provide an efficient seal and reduce air circulation. All boards were secured to the painting using a system of six metal "spring clips" attached to the strainer with wood screws **(Ap. VIII, Fig. VIII.2, p. 85)**. Due to an insufficient supply of spring clips, there were not enough to secure the backing boards using only these clips, therefore, four wood screws with cup washers were driven through the board and strainer in each corner. For a real painting, the protection board should ideally be attached to the frame and not to the strainer/ stretcher primarily to ensure that the wood's movement is not limited by the backing board.

b) Art-Sorb® – Made by impregnating particles of synthetic amorphous silica ($Si0_2$) and lithium chloride (LiCl) into a non-woven, polyethylene/polypropylene fibre sheet, Art-Sorb® is a buffering material widely used in the Conservation field to regulate RH within display cases. This material functions by slowly giving off or taking in moisture from the surrounding air. According to the supplier information **[45]** it has a uniquely high adsorption/desorption capability throughout the entire range of RH values. Besides, it does not off-gas and will absorb a small amount of organic volatiles. However, Art-Sorb® sheets give off a fine dust of potentially corrosive LiCl and therefore, cannot be used in direct contact with art objects, in this case the back of a canvas painting. The supplier recommends that the Art-sorb® sheets should be sealed with permeable but dustproof materials such as Tyvek® fabric (not used for this experiment). Used in Sets 01 and 02, Art-sorb® sheets were already preconditioned to 50% RH and were cut into four rectangular pieces leaving an empty square of exposed back-board to accommodate the RH & T data-logger **(Ap. VIII, Fig. VIII.3, p. 85).** The Art-sorb® sheets were attached to the PCP board using Archival quality, double-sided tape**.**

c) Cotton canvas – The cotton canvas chosen (cotton duck) is a heavy, plain woven cotton fabric. It is a hygroscopic material which means it absorbs and desorbs moisture. Used in Sets 07 and 08, the fabric was cut to a size 2-3cm bigger than the PCP board in order to be folded around it and attached with Archival quality tape on the outside of the board. The coated board (fabric facing the back of the canvas) was attached to the stretcher with the same devices used in the PCP boards.

d) Reemay® - Acid-free, 100% polyester, Reemay® is a nonwoven fabric, which, according to the product literature, is moisture permeable, but has only 0.5% moisture pickup at 98% RH. It retains its physical properties when wet and is dimensionally stable during humidity changes. Used in Set 05, Reemay® fabric was cut into a rectangular piece so it could cover the interior space of the painting and was folded on the edges to create a margin for fixing to the strainer. Strips of mat-board was placed on top of the fabric margin and stapled through the wood to facilitate staple removal when access is needed to the data-loggers for data-collection. By regulating the force of the staple application (adjustable on the electric staple gun), staples were put in to only half of their depth along the top and part-way down the right side for easier removal/access **(Ap. VIII, Fig. VIII.4, p. 85).**

2.2.2. Framing and glazing

In Set 1, the model paintings were framed, glazed in the front and protected in the back by a PCP board coated on the inside with Artsorb®. The frame consisted of a wooden structure designed to keep the glass well above the painting's surface (as required when framing actual paintings). For the glazing normal glass was used to create the sealed environment, whereas non-glare glass would be recommended for actual paintings (see chapter 5, p.17) **(Ap. VIII, Fig. VIII.5, p. 85)**.

2.2.3. Spacers and hanging hardware

To separate the model paintings from direct contact with the wall, two cork spacers 2cm long were nailed on the bottom corners at the back of each wooden strainer. For hanging the model paintings, it was decided to use traditional picture wire or hanging wire with eye hooks. Hanging hooks with a system of three nails in a triangular disposition were hammered onto the wall after marking by pencil an equal distance between the twelve model paintings. The paintings were installed 15cm away from each other.

2.2.4. Installation

The location (the room adjacent to King Manuel II's chambers) for the backing board project at PNP was chosen based on the availability of an outdoor wall, to ensure maximum RH and T changes. The wall was made of plaster and showed

Fig. 6. Room at the PNP

signs of extensive mould growth **(Ap. VIII, Fig. VIII.6, p. 85).** Evidence of high levels of moisture present in the walls was gained by observing that any small scrape to the wall resulted in an immediate water mark in the wall's coloured surface. Another advantage is that the model paintings would not be disturbed as the room was being used as a temporary storage room closed to public.

3.3. Measurements/ Equipment

3.3.1. Relative Humidity and Temperature (RH & T)

Data-loggers capable of measuring RH and temperature at regular intervals over long periods were selected and programmed to do readings each 30minutes. After ruling out several options, it was decided to hang the data-loggers in the centre of the interior space created between the back protection and the canvas. Each data-logger (*EL-USB-2*) was suspended on a strip of Reemay® fabric from the top strainer bar, hanging in the centre of the back of the model painting. The Reemay® was sewn around each logger to hold it secure and the data-logger was fastened to the strainer by a wood screw in a cupwasher **(see 'control set', Ap. VI, Fig. VI.2, p. 78)**. Being a synthetic fabric with only 0.5% moisture pickup, Reemay® was chosen over natural fabrics to avoid using a hygroscopic material that could influence the RH results. There was one data-logger (*EL-USB-2-LCD+*) in the room that was collecting RH and T readings as well.

3.3.2. Equilibrium Moisture Content (EMC)

Readings taken of the equilibrium moisture content of the strainers were carried out using a BES Bollmann® Easy Contact instrument. It was applied to the bottom right corner at the back of each wooden strainer every fifteen days. The EMC scale is 1 to 30.

3.3.3. Water Activity (a_w)

The water activity of the back protections boards, the front of the model paintings, the canvas and the wall was measured using a HygroPalm AW1 Rotronic® instrument. The a_w was measured on the back of all model paintings except the ones with Reemay® (numbers 9 and 10) and on the front of all except those which were glazed (numbers 1 and 2).

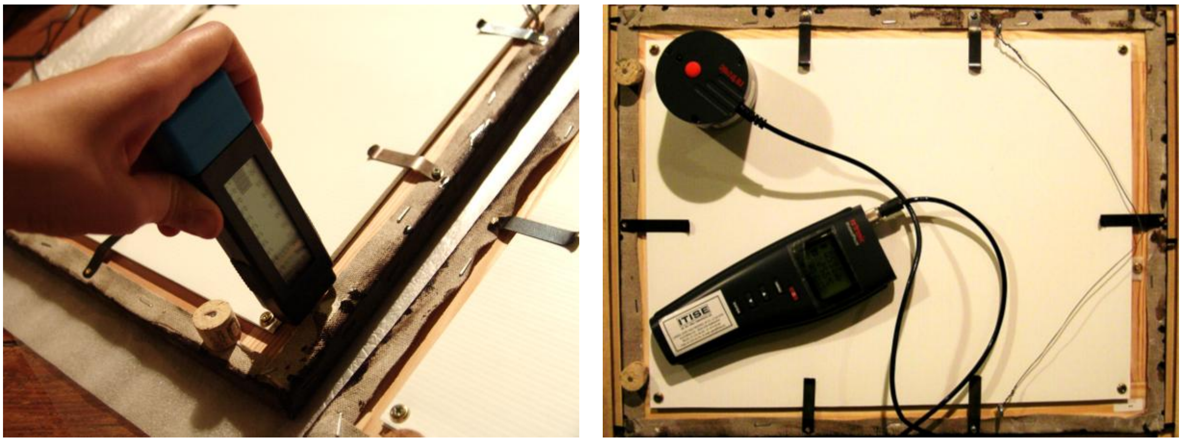


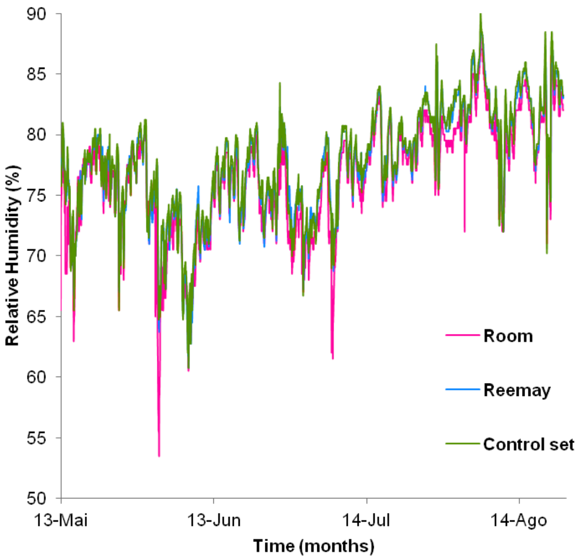
Fig. 7. (left) Measuring the EMC of the back of the stretcher from one of the model paintings; (right) Measuring the a_w of the back of one of the model paintings.

CHAPTER 3 **DISCUSSION FOR PRELIMINARY RESULTS**

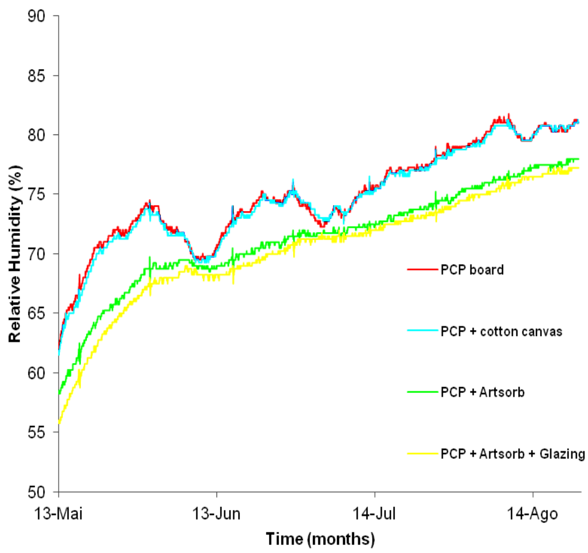
3.1. Relative Humidity and Temperature

The RH and T in the room and inside the back protection systems were measured during a 103 day period, from 13 of May to 23 of August (the data-loggers were rapidly placed again inside the model paintings after downloading the data to the computer). Since the differences between the two model paintings (replicas) from the same set were insignificant, an average of the two was made to represent each set (**Ap. IX, Graphs IX.1, p. 87**).

The climate measurements of the room were summarized in a graph (**Ap. IX, Graphs IX.4, p. 90)** showing that RH is cycling up and down with minimum values that coincide with maximum values of temperature (generally, if T rises, RH drops and vice-versa). Daily cycle fluctuations of RH ranged between differences of 1 to 16% and the temperature varied between 1 to 4ºC (minimal and maximum variations per day). Notice, however, that in the month of June, RH varied from 53.5 to 80.5%, an almost 30% RH variation in 30 days. The temperature did not diverge much (ranged between 17.5ºC and 23ºC).

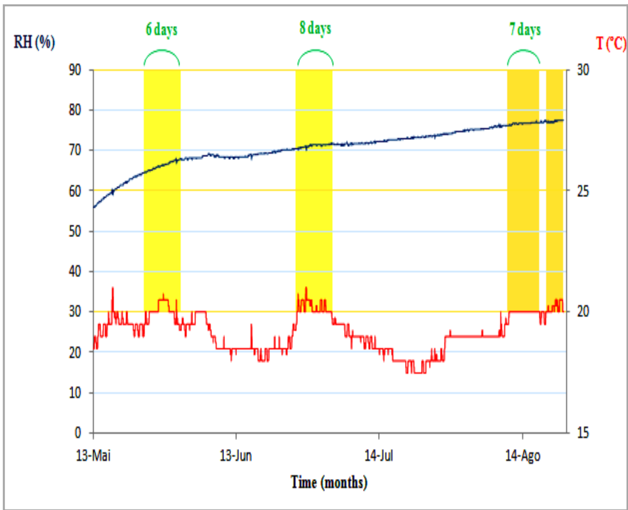


Graph 1 – RH of room, set 5 (Reemay®) and 6 (control)

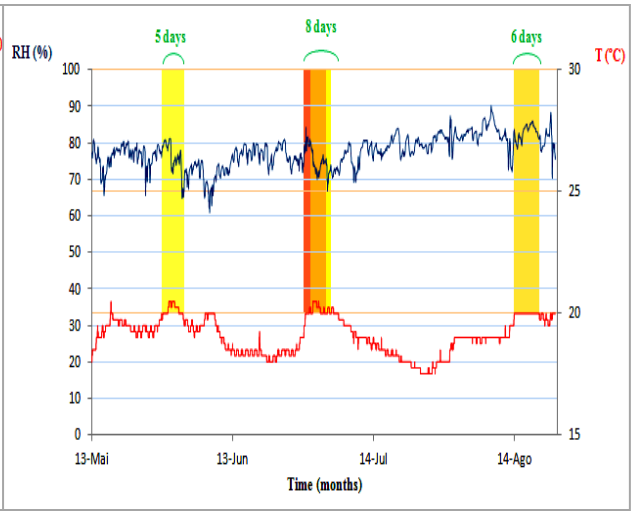


Graph 2 – RH of set 1 (PCP board +Artsorb®+ glazing), 2 (PCP +Artsorb®), 3 (PCP alone) 4 (PCP with cotton canvas.

When comparing the room conditions to the readings inside the back protected model paintings (**Ap. IX, Graphs IX.2/3, p. 88/89)**, it was possible to find obvious differences between set 1, 2 and the others (Graph 2 in text). Sets 1 (PCP board with Art-sorb® and glazing) and 2 (PCP board with Art-sorb®) present much more stable RH cycles which means that they are effectively buffering the RH conditions of the room. Their temperature did not differ much from the room's temperature, except in some periods where it was slightly higher (~0.5ºC) in set 2; however, this temperature gradient is not relevant for the study. Set 2 exhibits the same RH pattern of set 1 but with slightly higher RH values (around 2%) which can be due to the absence of glazing. RH cycling of sets 3 (PCP board) and 4 (PCP board with cotton canvas) showed almost the exact same line, but more variable T than RH values. Temperature from set 3 appears to be higher than set 4 and the room, but with no effect to the RH that remains equal to set 4. Set 5 (Reemay) has a RH and T pattern very similar to set 6 (control) and the room (Graph 1 in text). By studying the RH and T graphs, it was possible to assess that set 1 and 2 offer the best dampening effect on the RH fluctuations in the room.



Graph 3 – RH and T of set 1. Yellow bars point out time periods in which the temperature was above 20ºC and RH above 65%: conditions favorable of mould growth.

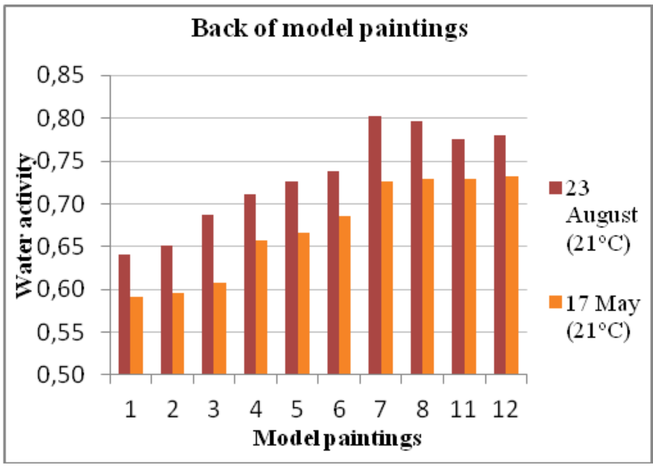


Graph 4 – RH and T of room. Even though RH exceeds 80%, it is not sustained long enough for mould growth.

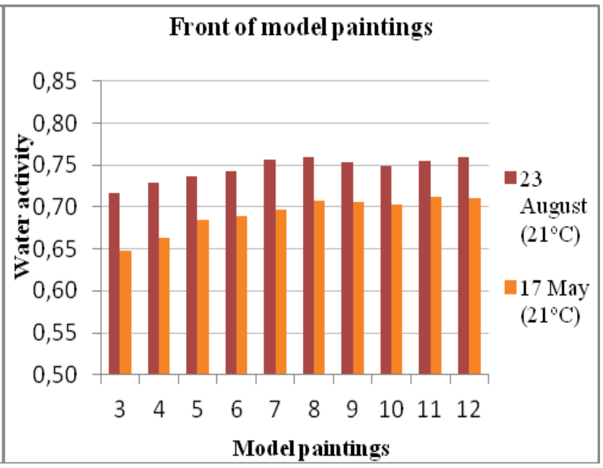
However there are still some questions which need to be addressed namely, which set has the higher risk of mould growth? Michalski emphasizes the fact that a stable RH condition is not necessary a good thing from the perspective of mould growth. Organic materials with a surface rich in protein (e.g. leather, skin,; starched, sized, or dirty textiles and paper) can grow mould over a period of 100 days at 70%RH, 10 days at 80%RH and only 2 days at 90% to 100%RH. **[43]** A conservation limit of mould growth for any kind of material - organic or inorganic, clean or not - would be **below 60% RH and 20ºC**. **[45]** However, time for germination of mould is the most important issue to consider in conservation of works of art since "the three factors required for growth – **nutrients, temperature and humidity** – must exist simultaneously for a certain period of time" **[46]**. Interpreting the graphs 3 and 4 in text, one can see the severe risk of prolonged high RH conditions on mould growth, especially in unventilated space like the interior space created between canvas and back protection in set 1 (PCP board with Artsorb® and glazing). The risk of mould growth can be more proper was analyzed by studying the water activity results from the wall and front and back of the model paintings.

8.2. Water activity (a_w)

Water activity measurements of the wall from 13 of May to 23 of August showed that the wall had an increase from 0.6 a_w to 0.86. According to the literature, fungi need a range between a_w **0.70 and 0.98**. Growth cannot occur at a_w 1.0, which would be pure water without nutrients, and it rarely occurs below a_w 0.70 because enzymes and proteins are altered. **[33]** Fungi growth is also dependent on temperature: above 20ºC, some species of fungi (e.g. *Penicillium* and *Aspergillus*) have optimum conditions for growth if water activity is also favorable (>0.78 for that species). **[33]**



Graph 5 – a_w values of the back of the model paintings (1 to 12) from day 17th May (temp. rounded 21ºC) and 23rd August (temperature rounded 21ºC)



Graph 6 – a_w values of the front of the model paintings (1 to 12) from day 17th May (temp. rounded 21ºC) and 23rd August (temperature rounded 21º

Therefore, although the wall had increased its water activity to a level which favored mould growth, around 9th August this situation may have been interrupted due to the low temperatures (18 to 19ºC).Water activity measurements made to the back of the model paintings revealed that it had an increase from 17 May to 23 of August of around 0.05 (Graph 5 in text). Set 4 (PCP board with cotton canvas) had the highest values maybe because the a_w measurement equipment was reading the fabric as well (that was folded over the back of the PCP board). Looking at the front of the model paintings (Graph 6 in text), the highest values measured also belonged to set 4 (and to set 6 - control). In August, all sets measured (except 1 and 2 that had glazing) had exceed a_w 0.70, which means that the surface of the paintings were reaching suitable conditions for mould growth. Below 20ºC, mould growth slows down but is not stopped (if RH/ water activity is high enough to sustain fungal activity. Of course it is important not to overlook the source of nutrients and the RH and T conditions: It is expected that the paint surface - primarily in unglazed paintings - will develop a dirt layer which may promote fungi activity in case of prolonged high RH conditions and temperatures below 20ºC.

8.3. Equilibrium moisture content (EMC)

EMC measurements made to the strainers of all twelve model paintings show that from May to August there is an average increase of 2 units (in a scale of 1 to 30) in a range between 14 and 16 **(Ap. IX, Graphs IX.5, p. 90)**. Except for model painting number 11 (one of the control set), the results are very similar. The small variations between two model paintings (11 and 12) can be due to differences in the wood (the strainers were made mainly of pine, but they may vary in density or even wood species). From studying the isotherm **(Ap. IX, Graphs IX.6, p. 90)** it is possible to conclude that EMC changes accompany RH fluctuations as it seems to be happening with the strainers, since the increased EMC followed the RH rise. **[29]**

CHAPTER 9 CONCLUSIONS

These preliminary results indicate that the best system for dampening the RH fluctuations of the room is Set 1, which offered full protection at the back and front and included silica gel. By comparing sets 1 and 2 (with and without glazing), the results have confirmed the theory that water vapor also exchanges through the paint layer **[39]** and that silica-gel is really making a difference in buffering RH fluctuations. Nowadays it is well known that changes in RH produce changes in the dimensions and mechanical properties of organic materials and can lead to severe damage. However, the damp environment (above 75% RH) at PNP also promotes several types of deterioration such as mould, rapid metal corrosion, which lead to extreme forms of biological and mechanical damage.

The main objective of this project was to study the effects of each protective system and discuss their advantages and disadvantages. Results from RH/T monitoring in the model painting controls suggest that the risk of mould is smaller (for this period of time), since the RH can drop below the 60%RH level, whereas the fully protected and buffered model painting (Set 1) maintains a high stable RH which is most conducive to mould activity. Hygroscopic materials like the cotton canvas added to the back of Set 4 may turn out to provide a suitable substrate for microorganisms to grow, but these possibilities can only be studied in a more prolonged period with seasonal changes (a higher RH is expected in Winter).

For further research, there is also the possibility of deliberately putting a fungi growth medium inside the back protected model paintings to test the mould germination risk and degree of mould growth for each protection system. Michalski believes that the lower risk alternative for paintings in damp environments is to seal them in an air-tight enclosure pre-conditioned at 50%. **[43]** Although a reasonable (but expensive) alternative, it does not take into account the potential for the build-up of unacceptable levels of pollutants due to off-gassing of materials within the case and from the painting itself. If none of the back protection options studied are effective in solving the dual problem of dampening RH fluctuations while discouraging greater mould growth, perhaps the best strategy would be to improve the climate inside the Palace by reducing air leakage and increasing heat flow in order to secure the stability of the paintings collection at PNP.

FINAL CONCLUSIONS

It is unusual to find a painting, such as *Interior de um Convento*, of this age (mid-19th century) that has never been treated and is in its original state. Thirty years ago, at the hands of a traditional restorer, most certainly it would have been subjected to lining, a treatment which conservators now know to have many potential problems including: weave emphasis, moating, excessive flattening, darkening of tonalities, and all problems associated with the behaviour and ageing of adhesives impregnated into the canvas. **[48]** Alternative methods have been introduced since, based on a deeper knowledge of the materials used both in the construction of works of art as well as in their restoration. Therefore, in order to preserve the integrity of the work of art, every effort was made to develop a treatment that involves minimal intervention and that focuses on preventive conservation. The major conservation challenge in this case was to proceed with the structural treatment of the support without taking the painting off of its stretcher since re-stretching is a process which exposes all the component layers of a painting to additional stresses and strains. **[49]** Instead, the alternative chosen, was to strip-line the loose top tacking-margin of the painting in order to reinforce it and enable re-tensioning once the painting had been restored to plane by a series of local moisture treatments.

Details of this intervention will be incorporated in an exposition of the painting at the PNP, to raise awareness to the conservation challenges in minimal intervention. At the same time, it is expected that the “Back Protection Project” will be continued out for six more months and will give rise to new conclusions that will hopefully lead to a new understanding of the conservation strategy needed for PNP’s painting collection.

REFERENCES

[1] Catling, D. M., and Grayson, J. E., *Identification of vegetable fibres*, Archetype Publications, London (1998).

[2] Schäefer, S. 'Microscopic Fluorescence Staining techniques for the Identification of Proteinaceous Binding Media Within Paint Cross Sections', Unpunlished doctoral research, Faculty of Sciences and Technologies, New University of Lisbon, Lisbon.

[3] Burgio, L and Clark, R.J.H. **'**Library of FT-Raman spectra of pigments, minerals, pigment media and varnishes, and supplement to existing library of Raman spectra of pigments with visible excitation'. *Spectrichimica Acta Part A 57* (2001) 1491–1521.

[4] Kirsh, A., Levenson, R., *Seeing Through Paintings: Physical Examination in Art Historical Studies (Materials & Meaning in the Fine Arts),* Yale University Press, New Haven (2000).

[5] Weer, J., Loon, A., and Boon, J. J., 'FTIR Studies of the effects of pigments on the aging of oil', *Studies in Conservation* **50** (2005) 3-22.

[6] Campos, M., *The study of lead white oil paints: a molecular approach to the whites of Amadeo de Souza-Cardoso*, Master's thesis, Faculty of Sciences and Technologies, New University of Lisbon, Lisbon (2010).

[7] Feller, R., 'Barium Sulfate' in *Artists' Pigments: Volume 1: A Handbook of their History and Characteristics*, R. Feller (ed.), Cambridge University Press, Cambridge (1986).

[8] Gettens, R. J., Forbes, E. W., & Stout, G. L.. *Painting Materials*. Dover Publications, New York (1966).

[9] Logan, J., 'Care and cleaning of iron" in *CCI Notes no. 9/6,* Canadian Conservation Institute, Ottawa (1987).

[10] Pinniger, D., *Pest Management in Museums, Archives and Historic Houses*, Archetype, London (2001).

[11] Eastop, D., and Tímár-Balázsy, A., *Chemical Principles of Textile Conservation (Butterworth-Heinemann Series in Conservation and Museology),* Butterworth-Heinemann, Oxford (1998).

[12] Carlyle, L., *The Artist's assistant: oil painting instruction manuals and handbooks in Britain 1800–1900 with reference to selected eighteenth-century sources*, Archetype Publications, London (2001).

[13] Taft, W. S., and Mayer, J. W., *The Science of Paintings*, Springer-Verlag, New York (2000).

[14] Jones, R., ‘Drying Crackle in early and mid eighteenth century British painting’, in *Appearance, Opinion, Change: Evaluating the Look of Paintings*, ed. V. Todd, United Kingdom Institute for Conservation, London (1990) 50-52.

[15] Keck, S., ‘Mechanical Alteration of the Paint Film’, *Studies in Conservation* **14**(1) (1969) 9-30.

[16] Richard, M., Mecklenburg, M., and Merrill, R., *Art in Transit - Handbook for Packing and Transporting Paintings*, National Gallery of Art, Washington (1991).

[17] Stolow, N., *Conservation and Exhibitions: Packing, Transport, Storage, and Environmental Considerations,* Butterworth-Heinemann, London (1987).

[18] Hedlund, H.P., Johansson, M., ‘Prototypes of Lascaux’s Medium for consolidation: Development of a new custom made polymer dispersion for use in conservation’, *Restauro* **6/2005** (2005) 432-439.

[19] Moncrieff, A., and Weaver, G., *Science for Conservators, Vol. 2: Cleaning (Conservation Science Teaching Series),* The Conservation Unit of Museums & Galleries, Routledge (1987).

[20] Phenix, A., ‘Solvent Abuse: some observations on the safe use of solvents in the cleaning of painted and decorated surfaces’, in *The Building Conservation Directory,* 1997, <http://www.buildingconservation.com/articles/solvent/solvent.htm> (accessed 7 February 2011).

[21] Phenix, A., ‘The swelling of artists' paints in organic solvents. Part 2, Comparative swelling powers of selected organic solvents and solvent mixtures’, *Journal of the American Institute for Conservation* **41** (1) (2002) 61-90.

[22] Perry, R., ‘Problems of dirt accumulation and its removal from unvarnished paintings: A practical review’, in *Dirt and Pictures Separated,* United Kingdom Institute for Conservation, London (1990) 3-6.

[23] Carlyle, L., Townsend, J.H., and Hackney, S ‘Triammonium citrate: an investigation into its application for surface cleaning’ in *Dirt and Pictures Separated*, ed. Hackney, S., Townsend, J., and Eastaugh, N. London: United Kingdom Institute for Conservation (1990) 44-48.

[24] Ackroyd, P., ‘The structural conservation of canvas paintings: changes in attitude and practice since the early 1970s’, *Reviews in Conservation* **3** (2002) 3-14.

[25] Hedley, G., ‘The practicalities of the interaction of moisture with oil paintings on canvas’ in *Measured Opinions,* ed. C. Villers, United Kingdom Institute for Conservation, London (1993) 112-22.

[26] Fuster-López, L., Agustí, M. C., Blay, V. G., *El estuco en la restauración de pintura sobre lienzo : criterios, materiales y procesos.* Universidad Politécnica, Valencia (2004).

[27] Leonard, M., Whitten, J., Gamblin, R., and René, E., ‘Development of a new material for retouching’ in *Tradition and Innovation: Advances in Conservation (Contributions to the Melbourne*

Congress, 10-14 October 2000), eds. A. Roy and P. Smith, International Institute for Conservation of Historic and Artistic Works, London (2000) 111-113.

[28] Dunkerton, J., 'Retouching with Gamblin Conservation Colors', in *Mixing and Matching, Approaches to Retouching Paintings,* eds. R. Ellison, P. Smithen, R. Turnbull, Archetype Publications, London (2010) 92-100.

[29] Freemantle, R., 'Glazing Over: A Review of Glazing Options for Works of Art on Paper', *Tate Papers*, Issue 3 (2005).

[30] Richard, M., 'Control of temperature and relative humidity in packing cases', in *Art in transit: Studies in the transport of paintings*, eds. M. Richard, M. Mecklenburg, R. Merril, National Gallery of Art, Washington (1991) 279–97.

[31] Mecklenburg, M. F., 'Micro climates and moisture induced damage to paintings' in *Museum Microclimates. Contributions to the conference in Copenhagen 19-23 November,* eds. T. Padfield and K. Borchersen, National Museum of Denmark (2007) 19-25.

[32] Padfield, T., *The role of absorbent building materials in moderating changes of relative humidity*, PhD dissertation, Department of Structural Engineering and Materials, Technical University of Denmark (1999).

[33] Michalski, S., 'Incorrect Relative Humidity', in *Ten Agents of Deterioration,* Canadian Conservation Institute, Ottawa (2009).

[34] Grattan, D., and Michalski, S., 'Environmental Guidelines for Museums - Temperature and Relative Humidity (RH)', in *Conservation Information Database*, Canadian Conservation Institute, Ottawa (2010).

[35] Florian, M. E., *Fungal facts: Solving fungal problems in heritage collection*, Archetype Publications, London (2002).

[36] Sozzoni, L., 'An economical design for a microclimate vitrine for paintings using the picture frames as the primary housing', *Journal of the American Institute for Conservation* **36** (2) (1997) 95-107.

[37] Wadum, J., 'Microclimate Boxes for Panel Paintings', in *The Structural Conservation of Panel Paintings*, eds. K. Dardes, A. Rothe, The Getty Conservation Institute, Los Angeles (1998) 497-524.

[38] Hartin, D., 'Backing boards for paintings on canvas', in *CCI Notes no. 10/10,* Canadian Conservation Institute, Ottawa (1993).

[39] Sandner, I., Schramm, H. and Schaft, A., 'Reverse side protection of paintings – test results and suggestions for a model' in *ICOM Committee for Conservation, 10th triennial meeting: Washington, DC, 22-27 August 1993: Preprints,* ed. J. Bridgland, James & James, London (1993) Vol. I 157-163.

[40] Di Pietro, G. and Ligterink, F., ‘Prediction of the relative humidity response of backboard-protected canvas paintings´, *Studies in conservation* **44** (1998) 269-277.

[41] Di Pietro, G. and Ligterink, F., ‘The effect of the wooden stretcher on the HR response of backboard protected canvas painting’ in *ICOM Committee for Conservation, 12th Triennial meeting, Lyon, 29 August-3 September 1999: Preprints*, ed. J. Bridgland, James & James, London (1999) Vol. I 70-76.

[42] Padfield, T. and Robinson, A., ‘The climate behind pictures mounted against the outer walls of the chapel of Ledreborg, Denmark’ in *ICOM Committee for Conservation, 11th triennial meeting, Edinburgh, Scotland, 1-6 September 1996: Preprints*, ed. J. Bridgland, James & James, London (1996) Vol. I 72-75.

[43] Padfield, T., Berg, H., DahlstrØm N., and Rischel, A., ‘How to protect glazed pictures from climate insult’ in *ICOM Committee for Conservation, 13th Triennial Meeting, Rio De Janeiro, 22-27 September 2002: Preprints*, ed. R. Vontobel, James & James, London (2002) Vol. I 80-85.

[44] Michalski, S., ‘Risk Analysis of Backing Boards for Paintings - Damp Climates vs Cold Climates’ in *Colour and Conservation - Materials and Methods in the Conservation of Polychrome Art Works. Minimal Intervention on the Structural Conservation of Paintings. Proceedings of the CESMAR7 Conference, Thiene, 29-30 October 2004*, Il Prato, Padua (2005) 21-27.

[45] Waller, C., ‘ART-SOB’, <http://www.cwaller.de> (accessed 10 February 2011).

[46] Michalski, S., ‘Relative Humidity: A Discussion of Correct/Incorrect Values’ in *ICOM Committee for Conservation, 10th Triennial meeting, Washington, D.C., 22-27 August 1993: Preprints*, ed. J. Bridgland , James & James, London (1993), Vol. II. 624-629.

[47] Krus, M., Kilian, R. and Sedlbauer, K.,”Mould growth prediction by computational simulation on historic buildings’ in *Museum Microclimates. Contributions to the conference in Copenhagen 19-23 November*, eds. T. Padfield and K. Borchersen, National Museum of Denmark (2007), 185-190.

[48] Hackney, S., ‘Reline, Line, Deline’, in *Alternatives to Lining: Structural Treatment of Paintings on Canvas without Lining*, eds. M. Bustin, and T. Caley, United Kingdom Institute of Conservation, London (2003) 5–8.

[49] Hedley, G., ‘Some empirical determinations of the strain distribution of stretched canvases’, in *Measured Opinions*, ed. C. Villers, United Kingdom Institute for Conservation, London (1993) 21-26.

APPENDICES

Fig. I.1. Overall Normal Light Map of sampling:

- Yellow dots: cross-sections of paint composite (ground + paint layers + varnish)
- White dots: µ-FTIR (**F1** – ground from tacking margin; **F2** & **F3** – varnish; **F6** – purple paint).

CS.G1 & **CS.G2** – Cross-sections of ground taken from the tacking margin.

S1, S2 & S3 – Cross-sections for staining (fiber + ground)

T1 – Cross-section of fiber (transverse view) + fiber shredded in microscopic slide (longitudinal view)

The strategy adopted to examine and analyse the painting materials began with a photographic record, followed by the radiography of the painting. μ-EDXRF analysis of the main areas of colour (four or five points analysed for each colour) provided an overview of the elements present. Details of the methods and instruments are described below.

a) Photographs: An extensive photographic record of the painting was done at the Photography laboratory (FCT-DCR) with the cameras *SONY DSC-F828* and *NIKON D200*. The painting was photographed under visible reflected light (with right and left lights away from the painting in a 45º angle), raking light (a right or left light almost parallel to the painting), Ultraviolet fluorescence (UV filter) and Infrared (IR filter).

b) X-ray Radiography: High resolution digital radiography of the painting was made at the Radiographic room (FCT-DCR) with the ArtXray System. The system used is composed of an X-ray generator Y.MBS/160-01 with a directional beam. The radiographic image was obtained with a digital camera, sensitive to gamma radiation of 10-160kV, pixel size of 83 μm and resolution of 12 pixels/mm, at a voltage of X-rays of 55 kV, current X-ray of 1,2 mA.

c) Stereo-microscope: Photographic records of the paint surface were made using an Olympus stereo-microscope SZX12, coupled with an extensive arm SZ-STU2 and a digital camera DP-12 with an idependent light source HighLight 3100 (in Metal's laboratory, FCT-DCR).

d) Micro Energy Dispersive X-Ray Fluorescence (μ-EDXRF): μ-EDXRF analyses of the painting were done in the FCT-DCR scientific laboratory. The equipment used to analyze the painting was an ArTax transportable spectrometer, Intax GmbH model, equipped with a X-ray Molybdenum (Mo) ampoule. The identification was made by exciting with a primary beam of 0,3 mm diameter and a xFlash detector refrigerated with the Peltier (Sidrift) effect with a resolution below 170 eV. The analytic conditions were: 40kV of difference of potency, 600μA and 150seconds for acquisition.

All **cross-sections** were embedded in a UV light curing resin based on methacrylate (Technovit 2000 LC®) (41). Each Cross-section was hand polished with 7 successively finer grades of cushioned abrasive sheets *Micro Mesh*® (300, 600, 800, 1200, 3600, 8000,12000 grits). Micro-sampling for μ-FTIR was carried out under a stereo-microscope (FCT-PNT lab) using a micro chisel from Ted Pella micro tools. All cross-sections of the painting were examined under OM (section belloq), and followed by μ-Raman, SEM-EDX and μ-FTIR analyses of cross-sections and micro-samples, respectively. A total of fourteen samples were taken from areas of pre-existing losses or other areas of damage to use in the following examination and analysis techniques (except μ-EDXRF):

e) Optical Microscopy (OM): Examination of cross-sections was carried out at the Paintings laboratory (FCT-DCR) with an optical Zeiss Zxiopla Z Imaging microscope with a Nikon digital camera DMX 1200F and a mercury lamp HBO100 and a halogen lamp HAL100. The Ultraviolet fluorescence source is ebq100 isolated Kübler codIX. The samples were observed under visible transmitted and reflected light, in dark (f2) and bright field (f1), interferential contrast (f3), polarized light (f4), as well as under different types of fluorescence filters: BP 395-440, FT 460, LP 470 (f5), BP450-490, FT510, LP515 (f6) and BP300-400, FT395, LP420 (f8). Five magnifications were applied: 5x (500μm), 10x (100μm), 20x (100μm), 40x (50μm) and 50x (50μm). For the capture and treatment of images the software DP-Soft 3.2 and Nikon ACT-1 were used.

f) Micro Fourier Transformed Infrared Spectroscopy (μ-FTIR): μ-FTIR analyses were performed on a Nicolet Nexus spectrophometer interfaced with a Continuum microscope with MCT-A detector cooled by liquid nitrogen in the Scientific laboratory (FCT-DCR). The spectra were collected in transmission mode, with spatial resolution of 50-100μm, an optical resolution of 4 cm^{-1} and 128 scans, by using a Thermo diamond anvil compression cell. The spectra are shown as acquired, without corrections or any further manipulations, except for the occasional removal of the CO_2 absorbance curve at approx. 2300-2400 cm-1.

g) μ-Raman: The μ-Raman analyse were carried out using a Labram 300 Jobin Yvon spectrometer, equipped with a HeNe laser 17 mW operating at 632,8 nm in the Scientific laboratory. The selection of the excitation wavelength was chosen according to the colour of the samples, to optimize the results, avoiding fluorescence phenomena. The spectrum were obtained with 50x and 100x Olympus objective lens that result in a resolution of respectively 4 and 2 μm diameter. The potency in the samples was controlled through the application of a 0.1 mW (for laser 633 nm) and 3.75 for laser 532. The spectra were obtained at an interval of 50-2200cm^{-1}. Using exposure times of 1-20 s and 3-15 accumulations. The laser beam was focused either with 50 x or 100x objectives. The laser power at the surface of the samples was varied with the aid of neutral density filters (optical density 2).

h) Scanning Electron Microscopy Energy Dispersive X-ray Detection (SEM-EDX): Scanning Electron Microscope (SEM) with image processing and quantitative analysis and elemental chemical analysis by EDX was conducted in the Laboratory of Structural Materials in (FCT - CENIMAT/I3N) The electron beam high voltage was 10 KeV and the magnification varied between 50x to 500x, with a resolution of 3.5 nm. The samples required a carbon coating through an evaporator.

III.1) Protein Staining of fibre sample

For the identification of any size layer (location and penetration), a protein staining technique was used. A non-covalent UV fluorescent dye ("Sypro Ruby") was applied in form of drops to the top of the cross-sections and in about 15s started to react, showing an orange fluorescence under UV light. All samples collected (S1, S2, S3) had fibres with a dispersed broken ground, thus the results were inconclusive regarding the exact location of the protein within the paint composite and canvas. Results from S2 are shown bellow.

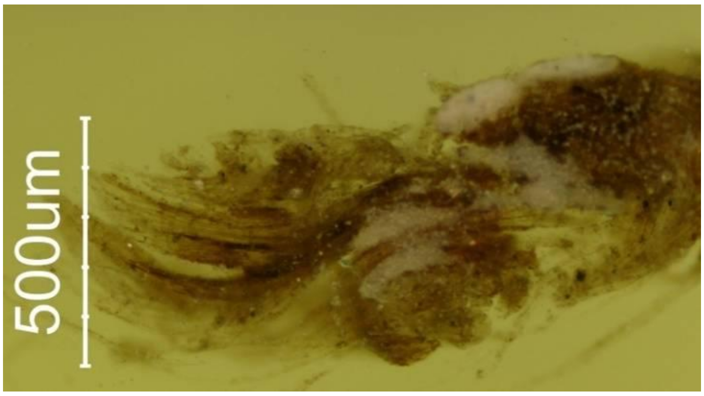


Fig. III.1. a) Sample S2 under OM, reflected light, dark field (f2), 5x, before staining.

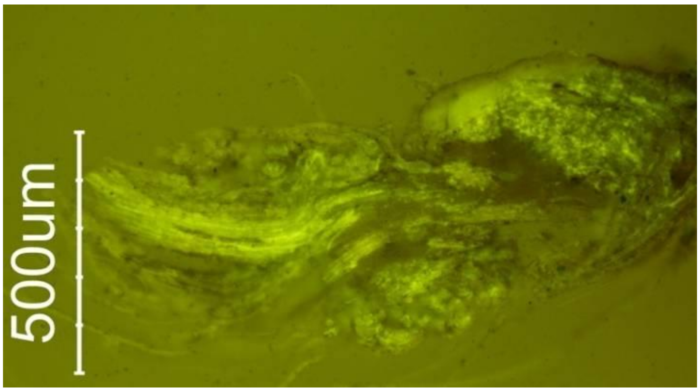


Fig. III.1. b) Sample S2 under OM, fluorescence (f6), 5x, before staining.

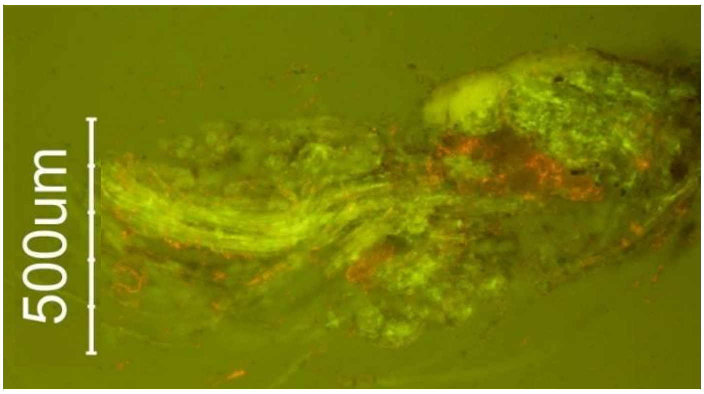


Fig. III.1. c) Sample S2 under OM, fluorescence (f6), 5x, after staining.

III.2) Cross-sections

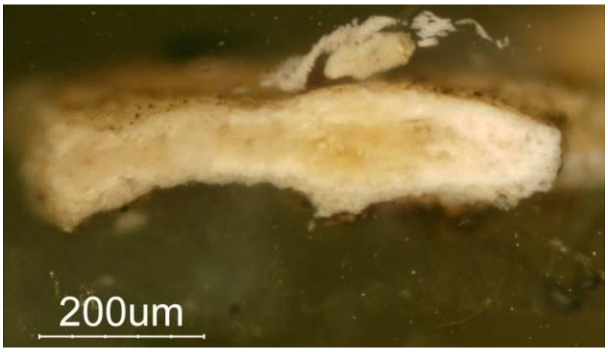


Fig. III.2.1. a) CS.G1 (ground layer) under OM, reflected light (f2), 10x.

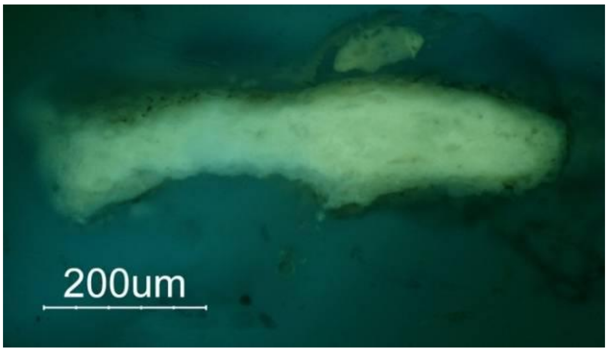


Fig. III.2.1. b) CS.G1 under OM, fluorescence (f5), 10x.

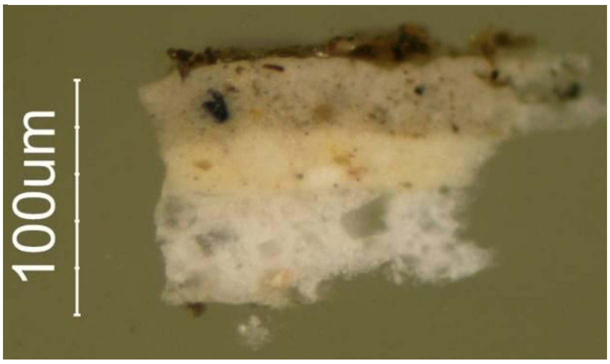


Fig. III.2.2. a) CS1 (ochre paint composite) under OM, reflected light (f2), 20x.

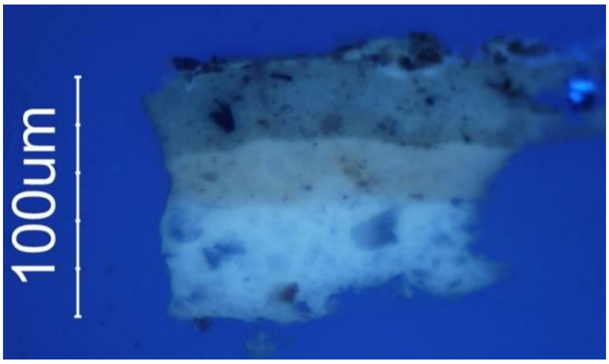


Fig. III.2.2. b) CS1 under OM, fluorescence (f8), 20x.

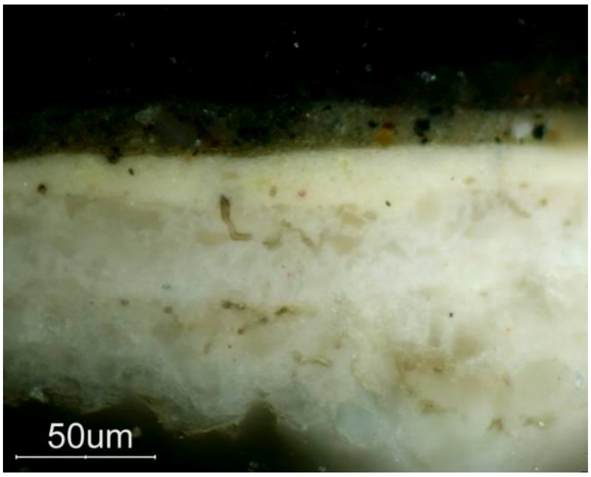


Fig. III.2.3. a) CS2 (black paint composite) under OM, reflected light (f3), 40x.

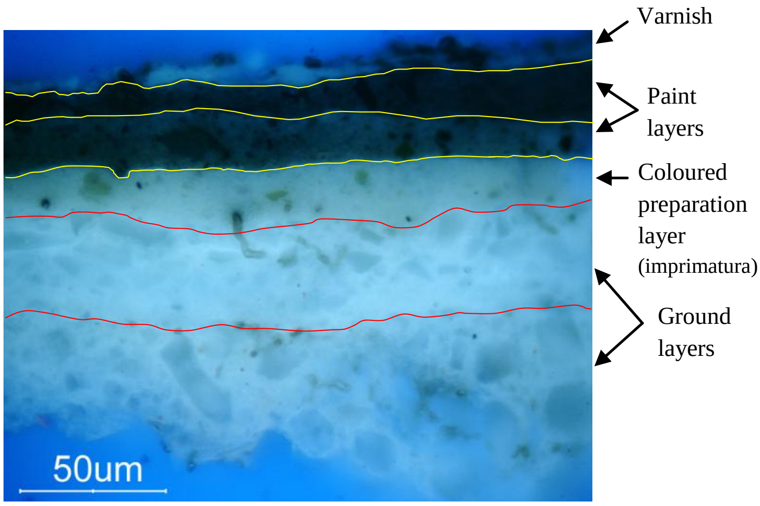


Fig. III.2.3. b) CS2 under OM, fluorescence (f8), 40x. Shows lines separating the layers of ground and paint.

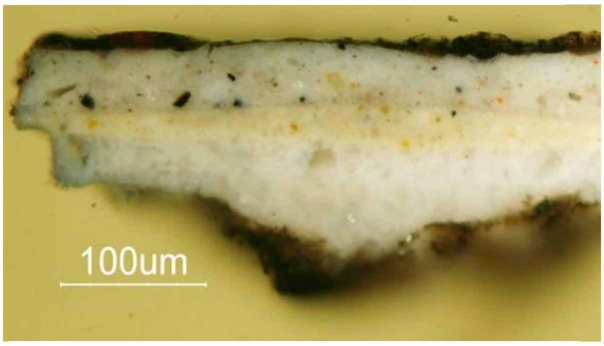


Fig. III.2.4. a) CS3 (white paint composite) under OM, reflected light (f3), 20x.

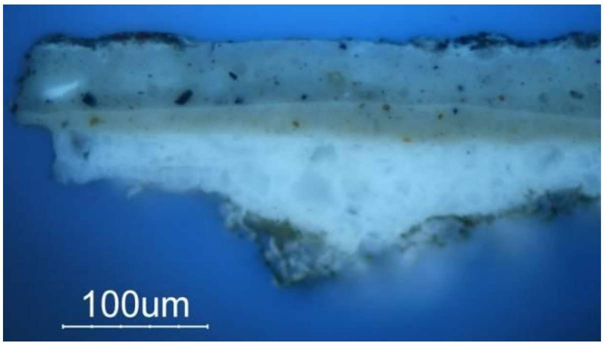


Fig. III.2.4. b) CS3 under OM, fluorescence (f8),

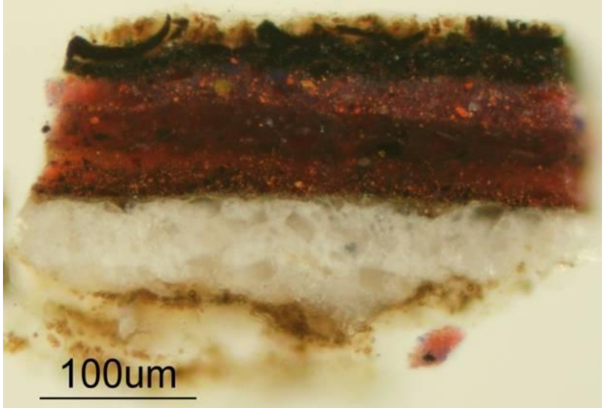


Fig. III.2.5. a) CS4 (black and purple paint composite) under OM, reflected light (f2), 20x.

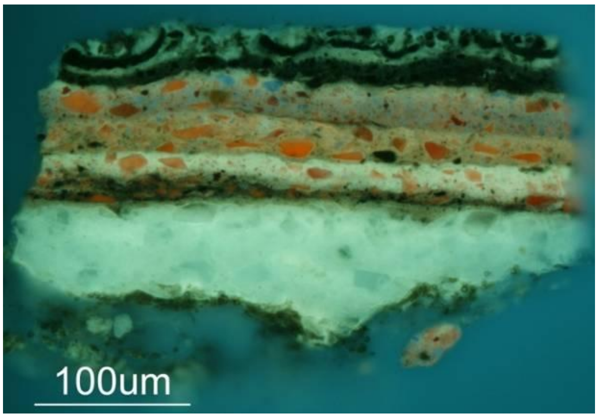


Fig. III.2.5. b) CS4 under OM, fluorescence (f5), 20x.

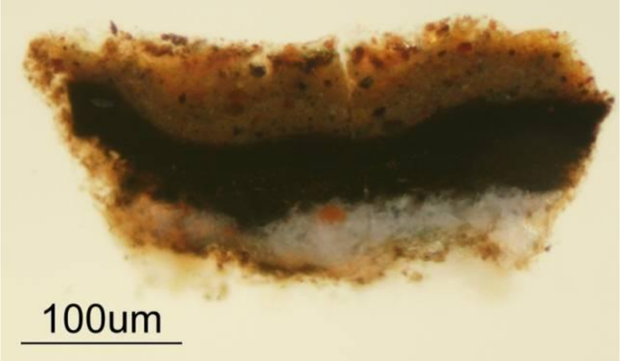


Fig. III.2.6. a) CS5 (brown and black paint composite) under OM, reflected light (f3), 20x.

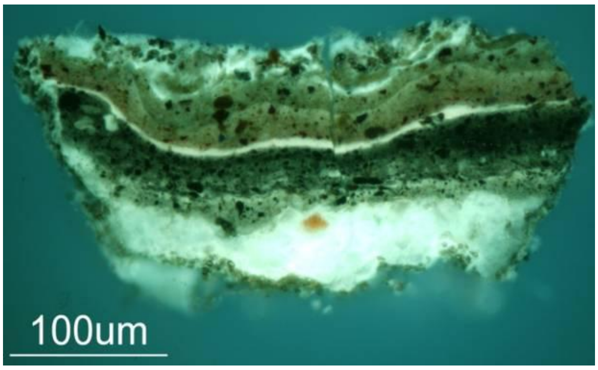


Fig. III.2.6. b) CS5 under OM, fluorescence (f5), 20x.

III.3) Ultraviolet light photography

Fig.III.3.1. UV photographic detail of orange fluorescence on area of paint losses where it has another painting underneath (white circle).

III.4) SEM-EDX

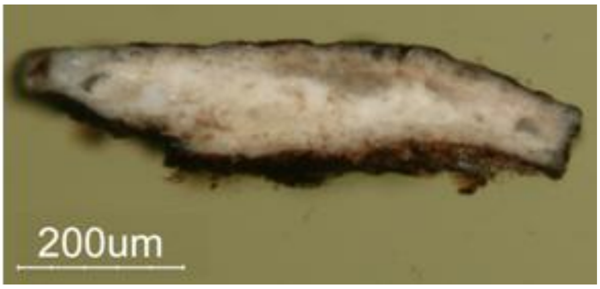


Fig. III.4.1. a) CS.G2 (ground layers) under OM, visible light (f3), 40x.

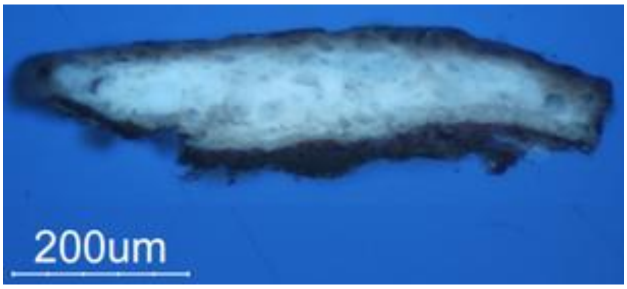


Fig. III.4.1. b) CS.G2 under OM, fluorescence (f8), 40x.

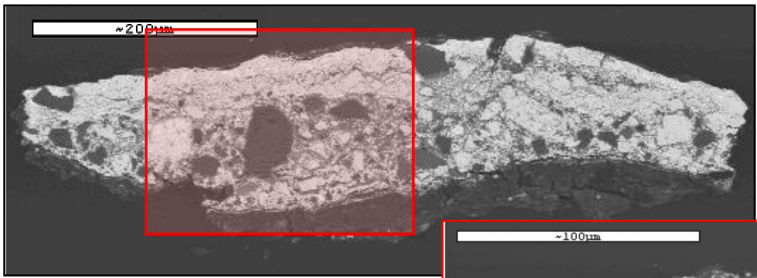


Fig. III.4.1. c) CS.G2 - Backscattering electron image by SEM-EDX.

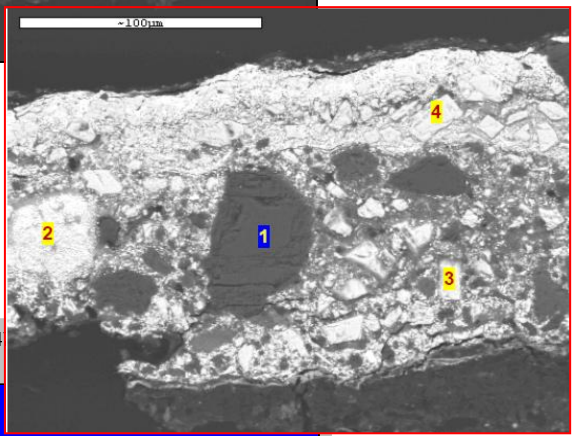


Fig. III.4.1. d) CS.G2 –Backscattering electron image by SEM-EDX, 100µm, showing points analyzed.

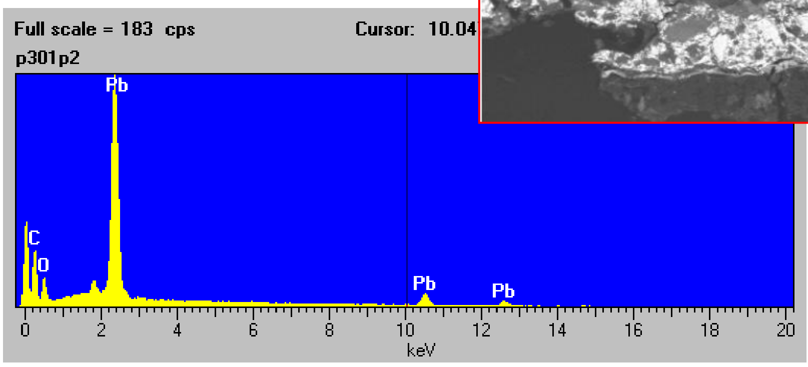


Fig. III.4.1. e) EDX spectrum of point 2 (fig. 8. b) showing elements present: lead, carbon and oxygen.

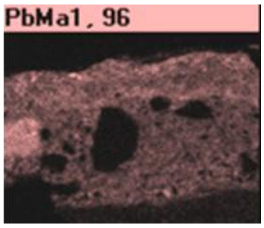


Fig. III.4.1. g) Elemental mapping of detail (b) showing distribution of lead.

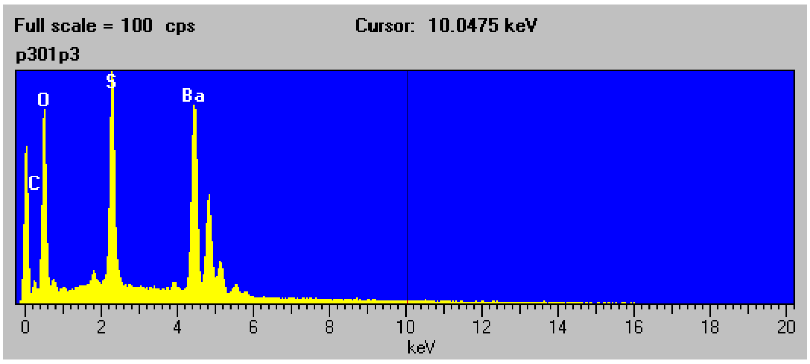


Fig. III.4.1. f) EDX spectrum of point 3 showing elements present: barium, sulfur, carbon and oxygen.

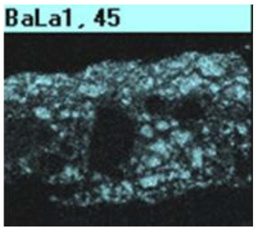


Fig. III.4.1.h) Elemental mapping of detail (b) showing distribution of barium.

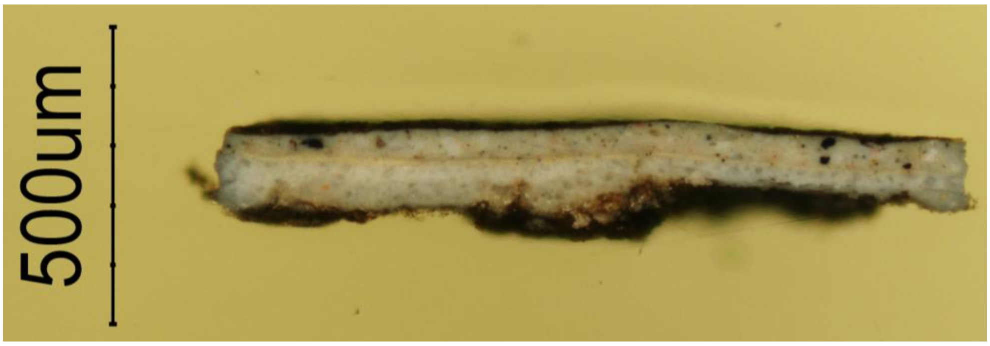


Fig. III.4.2. a) CS3 (white paint composite) under OM, reflected light (f3), 5x.

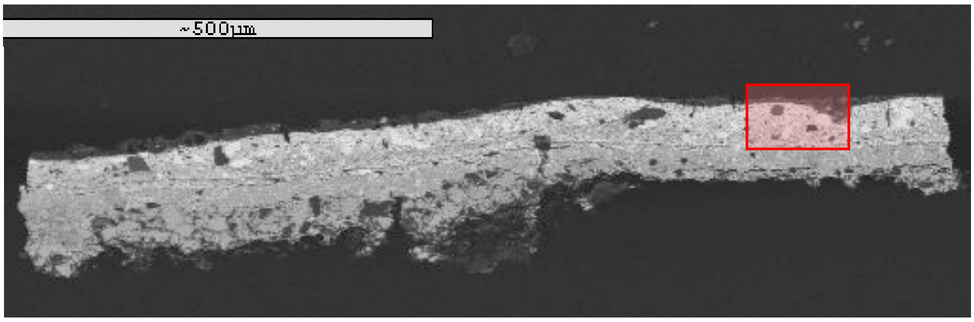
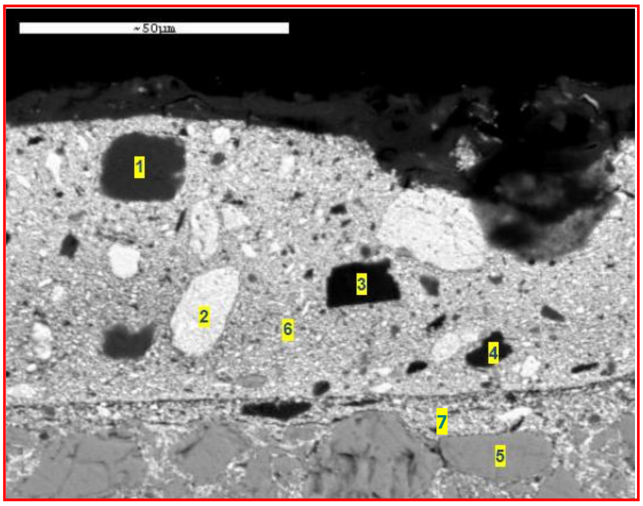


Fig. III.4.2. b) CS3 - Backscattering electron image by SEM-EDX.



P1 – Ca+, P, C, Pb, O

P2 - Pb+, C, O

P3 - Ca+, Mg, C, O

P4 - Ca+, C, O, Mg

P5 – S+, Ba, C, O, Si, Ca

P6 - Pb+, C, O

P7 - Pb+, C, O

Fig. III.4.2. c) Detail of fig.9 (b) showing points of EDX analyses. The elements found are indicated on the left of the image (symbol plus indicates the element with the highest intensity).

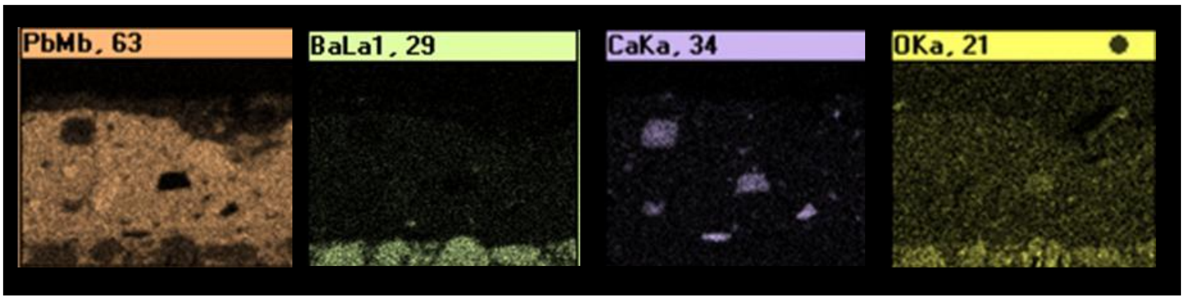


Fig. III.4.2. d) Elemental mapping of detail (b) showing distribution of lead, barium, calcium and oxygen. It is possible to assume that the first layer of ground is mostly composed by barium sulphate (presence confirmed by µ-Raman and µ-FTIR analyses).

III.5) µ-Raman, µ-FTIR and µ-EDXRF

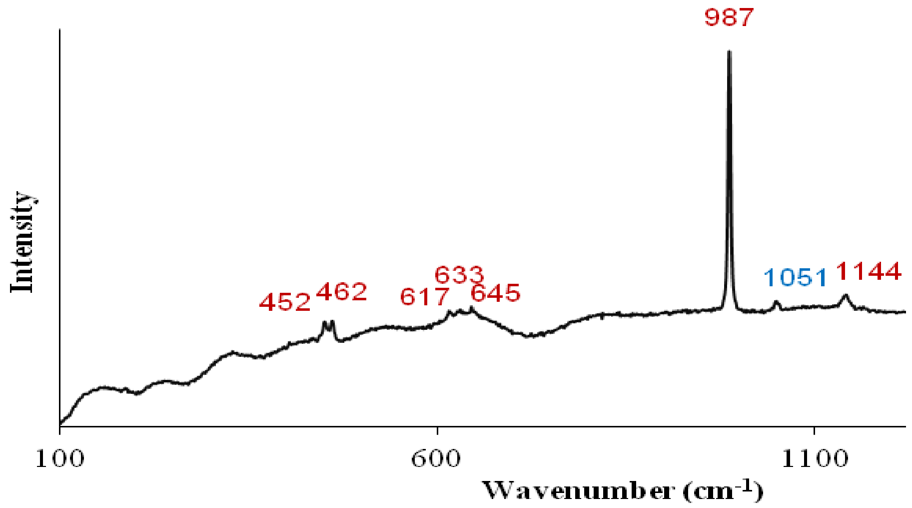


Fig.III.5.1. µ-Raman spectrum of first layer of ground (cross-section CS3) showing characteristic peaks of barium sulphate (in red) and lead white (blue).

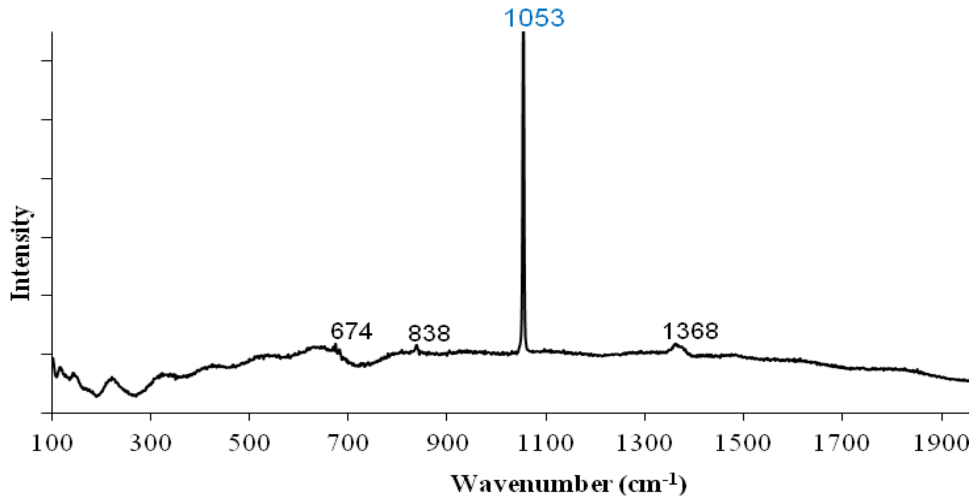


Fig. III.5.2. µ-Raman spectrum of beige paint layer (cross-section CS1) showing characteristic peaks of lead white (in blue)

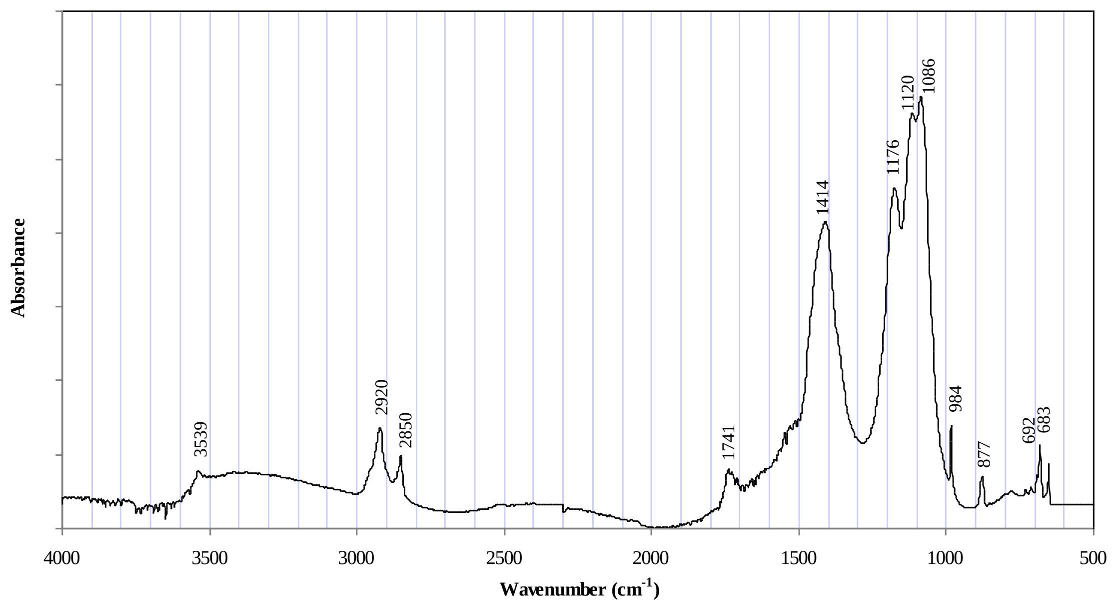


Fig. III.5.3. µ-FTIR spectrum of ground from tacking margin (sample F1).

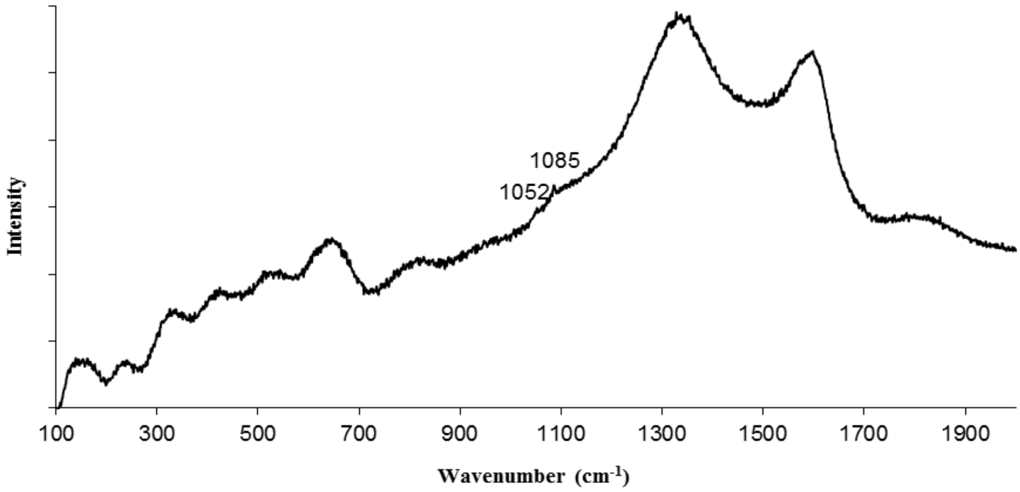


Fig. III.5.4. μ-Raman spectrum of black paint layer (cross-section CS2) showing characteristic wavelengths of ivory or lamp black: ~1325cm^{-1} very strong (broad): ~1580cm^{-1} very strong (broad). The peak at 1052cm^{-1} corresponds to white lead and the peak at 1085cm^{-1} may correspond to chalk.

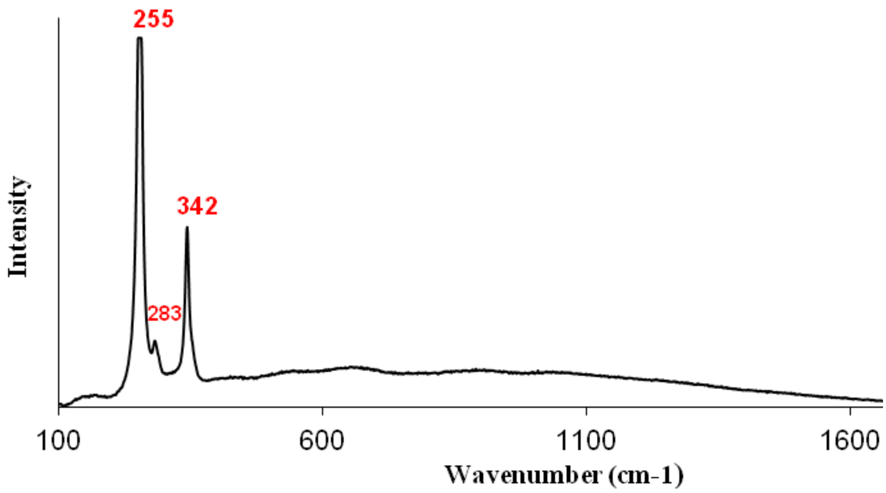
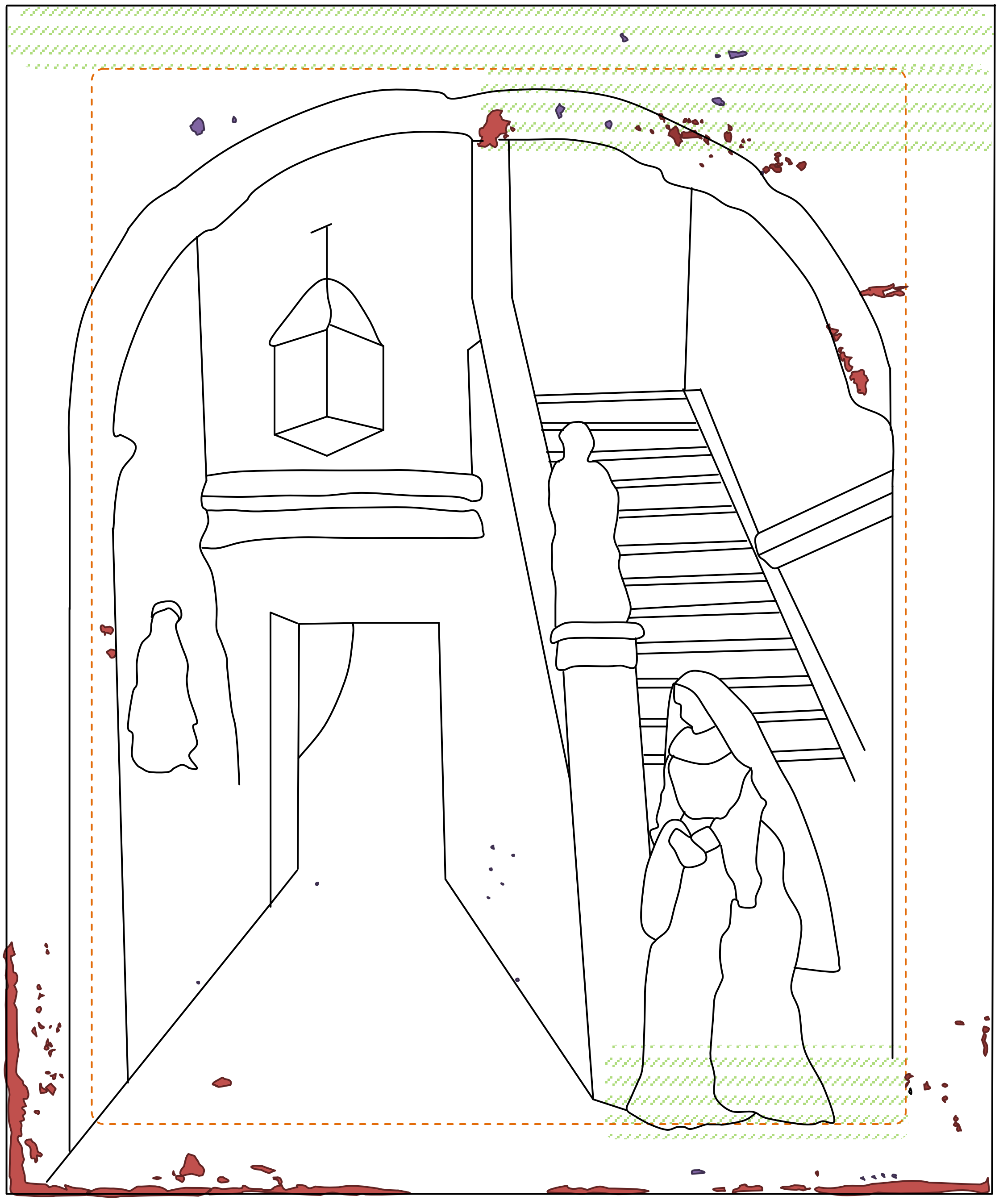


Fig. III.5.5. μ-Raman spectrum of red particles in purple paint under black paint (cross-section CS4) associated with previous image beneath nun's figure, showing characteristic peaks of vermillion (in red).

Colours	Area	Detected elements	Possible pigments identified
Brown	Statue	Pb+, Fe, Ca, Ba, Mn (Cu, Zn)	Burnt Umber/ Raw umber
Red	Virgin Mary's veil	Pb+, Fe, Hg, Ca (Ba, Cu)	Vermillion (confirmed by μ-Raman)
Blue	Virgin Mary's robe	Pb+, Co, Fe (Cr)	Cobalt blue
Flesh tone	Hand of Virgin Mary	Pb+, Fe, Hg, Ca, Co (Cr)	Lead white with vermillion
Yellow	Wall above crucifix	Pb+, Ba, Fe (Ca)	Yellow Ochre
White	Loincloth of Christ in crucifix	Pb+, Fe (Ca)	Lead white (confirmed by μ-Raman)
Black	Background	Pb, Fe, Ca, Ba (Cu, Mn - Zn)	Lamp or carbon black (confirmed by μ-Raman)

Fig. III.5.6. μ-EDXRF table with detected elements (symbol plus for most intense peak emission lines and parentheses for less intense peak emission lines) from different coloured areas of the painting associated with possible pigments.



Losses exposing canvas

Losses exposing ground layers

Stretcher mark

Main deformations of fabric

Fig.IV.1. Schematic drawing of painting with coloured areas representing different condition problems.

Fig.IV.2. Normal light photograph of the back of the painting with arrows which indicate the one direction of movement for each of the corner joints. This type of rotary stretcher creates a parallelogram (dashed lines).

Fig.IV.3. Digital radiographic image of the painting showing the tack distribution and the underpainting (nun's area, staircase and at the end of the hallway).

Fig.IV.4. Normal light photographic detail of rusted tack at the top of the right tacking margin of the painting.

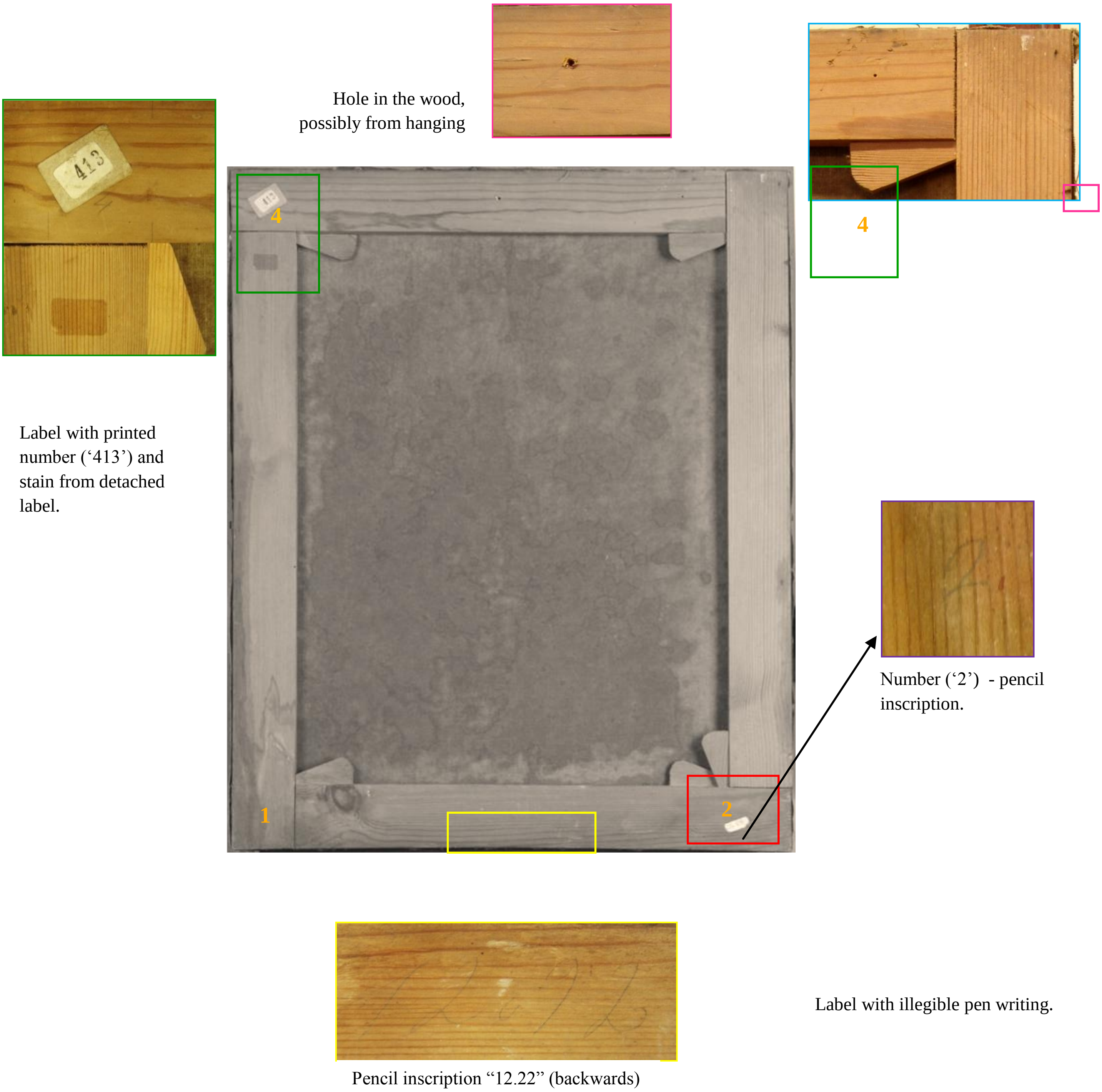


Fig.IV.5. Modified normal light photograph of the back of the painting with mapping of details (coloured squares) that indicates from where each detail was photographed. Numbers in yellow indicate the local of the pencil inscriptions (numbers 1 to 4) possibly associated with the assemblage of the stretcher’s bars.

Fig.IV.6. Normal light photographic detail of top tacking margin showing fabric loose from the stretcher.

Fig.IV.7. Left raking light photograph of front of the painting showing all creases and sharp deformations of the fabric and the sharp crack pattern of the paint layers. Arrows, circles and square points to different types of deformation and causes.

Fig.IV.8. Right raking light photographic detail of front of the painting showing crack pattern of the front of the painting around the figure of the nun.

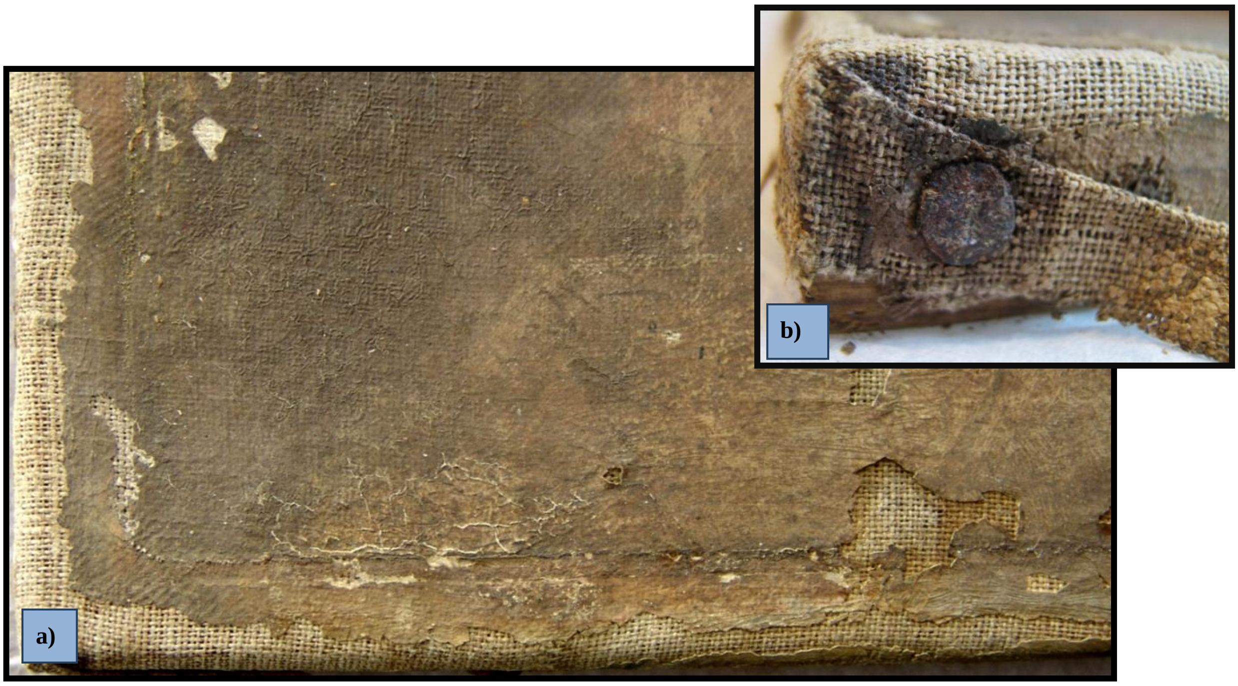
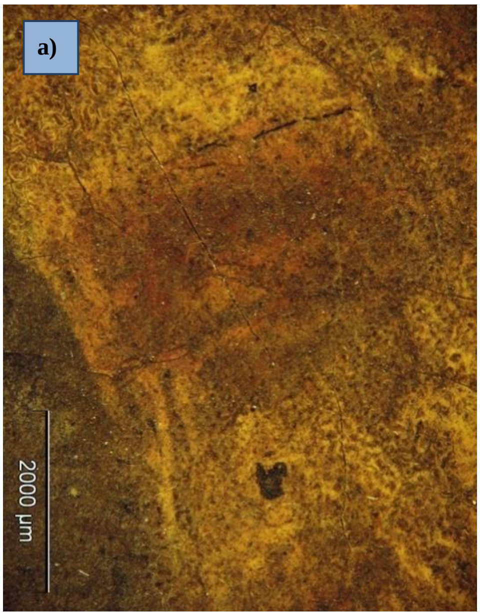


Fig.IV.9. a) Normal light photographic detail of corner in the front of the painting demonstrating area of paint losses, flaking paint and ground layers, especially evident in the turn-over edge. b) Normal light detail of the corner of the bottom tacking margin showing flaking ground and rusted tack.

Fig.IV.10. a) Infrared (IR) photographic detail of front of the painting showing drawing lines in the floor; b) Infrared photographic detail of nun's face. Note that more detail of the image is visible using IR light than normal light due to extensive dirt/ mould incrustation on surface before treatment.



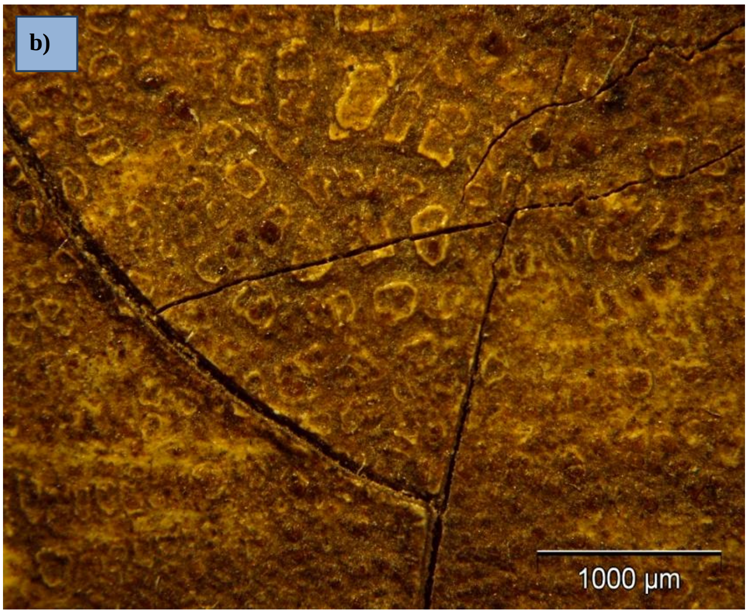


Fig.IV.11. a) Photographic detail under stereo-microscope, 7x, showing incrusted dirt in the nun's face; b) Photographic detail under stereo-microscope, 63x, showing "micro-cissing".

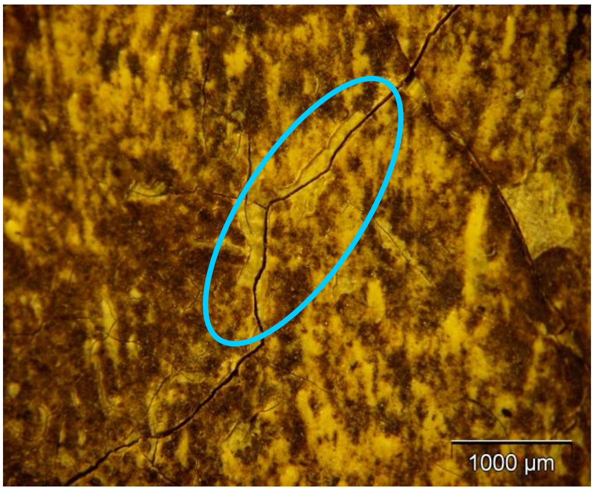


Fig.IV.12. Photographic detail under stereo-microscope, 25x, showing interlaminar cleavage in the white paint of nun's habbit.

Fig.IV.13. Normal light photographic detail of stretcher bar crack pattern.

Fig.IV.14. Normal light photographic detail showing traces of gold paint, probably from a past frame, and lumps of plaster stuck to the paint.

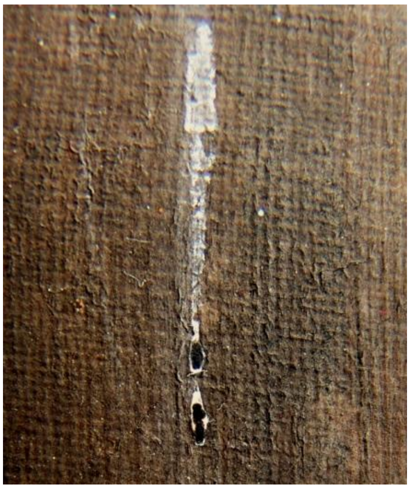


Fig.IV.15. Normal light photographic detail showing insect speck over the surface of the painting.

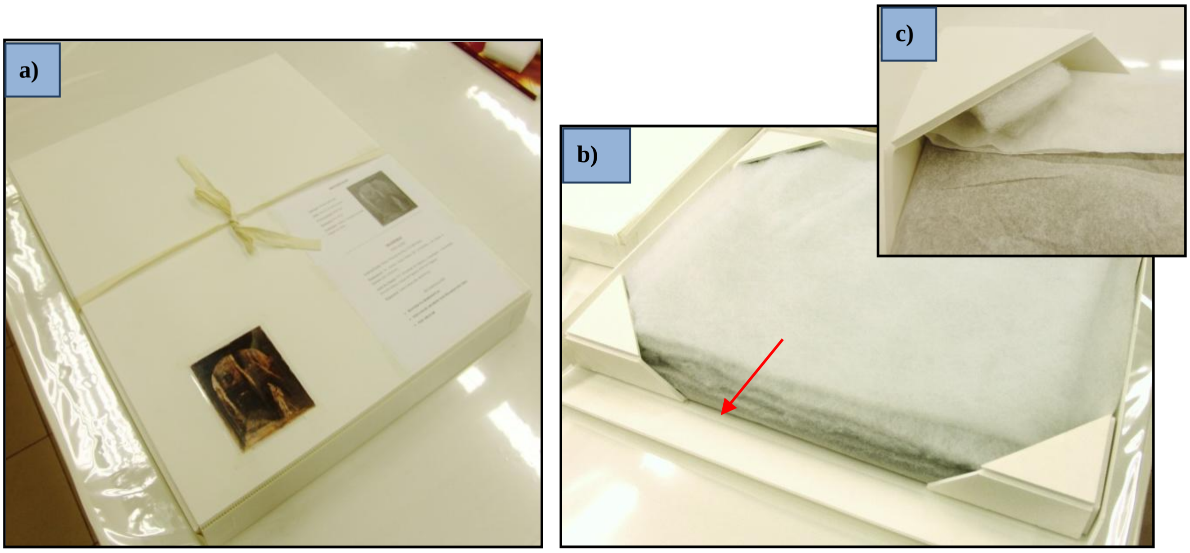


Fig. V.1. a) Normal light photograph of packing case; b) Opened box with painting inside (red arrow indicates the possibility of sliding it out from the box); c) detail of K-line corners with piece of quilt-batting holding it.

Fig. V.2. Normal light photographic detail of consolidation treatment

Fig. V.3. Normal light photographic detail of mechanical cleaning

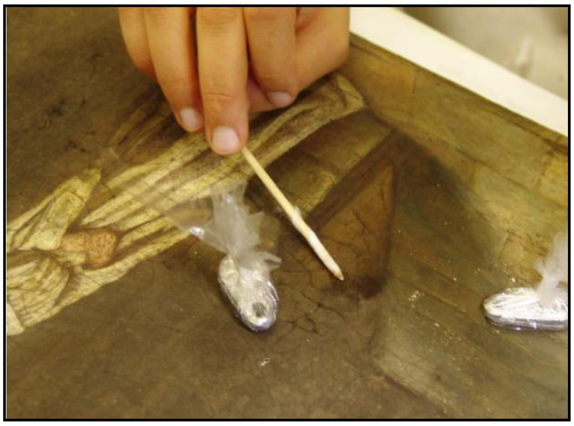


Fig. V.4. Normal light photografic detail of surface cleaning with micro-swab

Fig. V.5. Normal light photographic detail of cleaning area in white paint (nun's habit).

Fig. V.6. Normal light photograph of front of the painting after 1st stage of surface cleaning

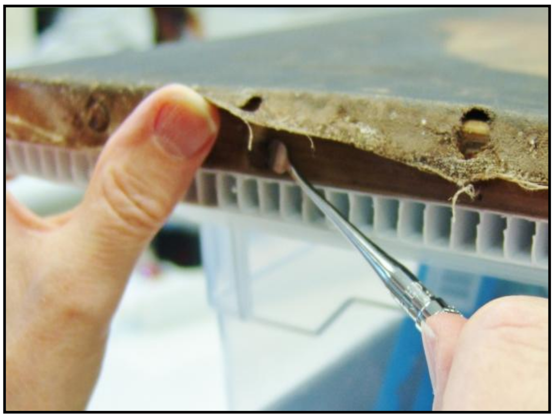


Fig. V.7. Normal light photographic detail of tack removal with metal spatula.

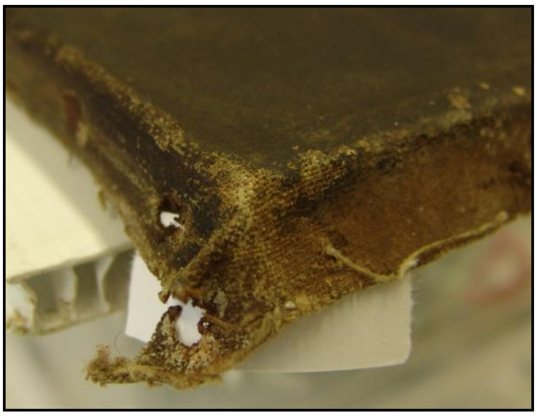


Fig. V.8. Normal light photographic detail of moisture treatment on corners of the top tacking margin using slightly moistened blotter strips.

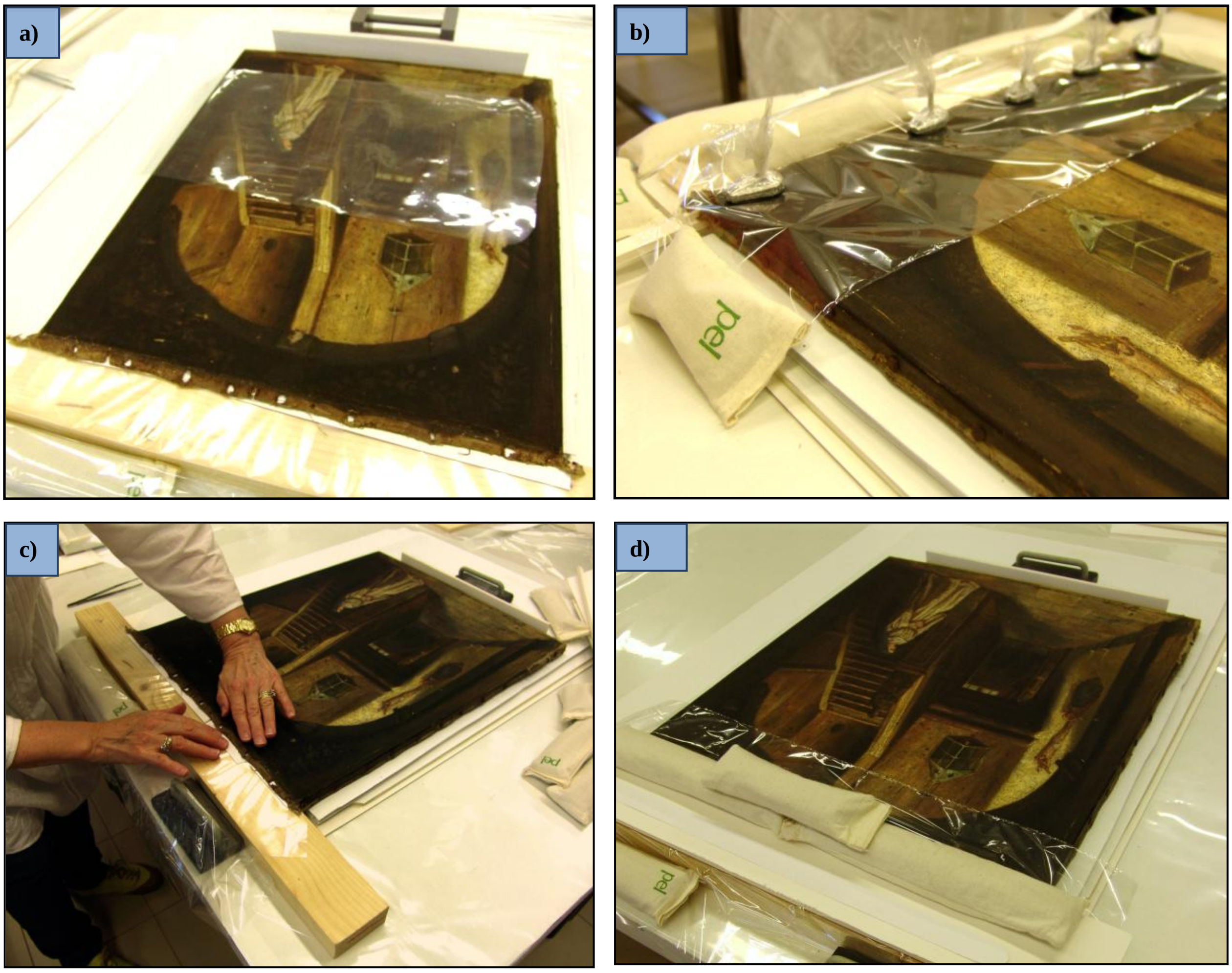


Fig. V.9. a) Normal light photographic detail of top tacking margin being prepared for moisture treatment: a moistened blotter strip was slide down the canvas; b) detail of small weights on top of the tacking margin during moisture treatment; c) detail of surface of the painting being touch by hand to feel the level of moisture; d) painting after replacing the moistened blotter by a dry one and being covered with Melinex® and weighted with sand weights.

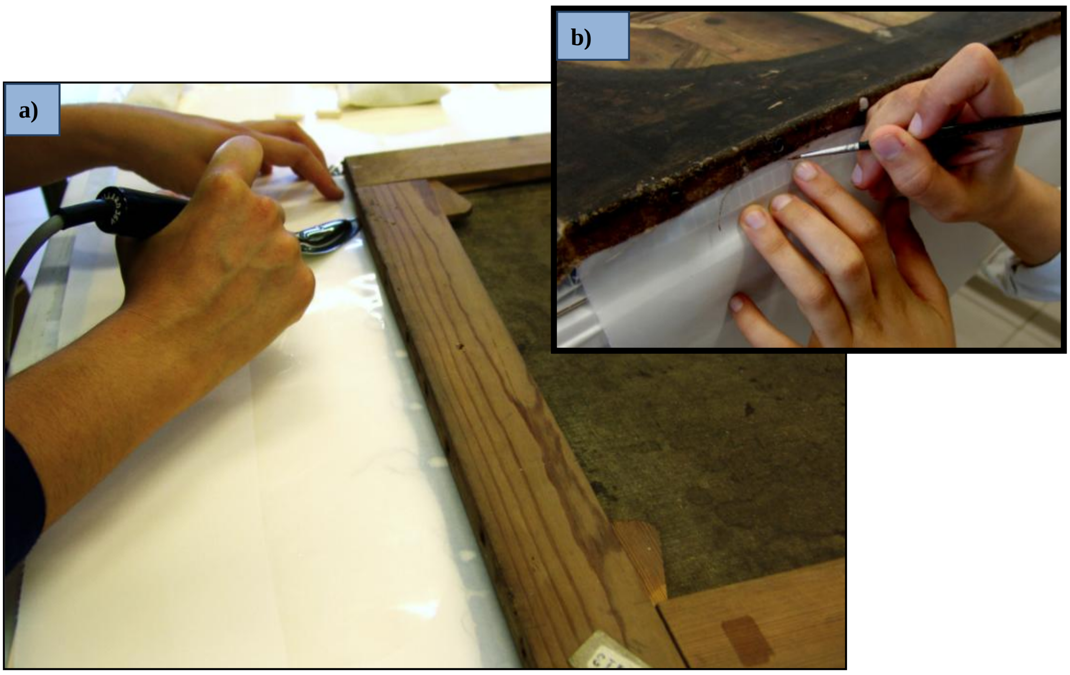


Fig. V.10. a) Normal light photographic detail of heating the polyester fabric with BEVA-film to adhere it to the canvas on the top tacking margin; b) detail of loose canvas threads being glued in place with a brush using BEVA® 371 gel in white-spirit.

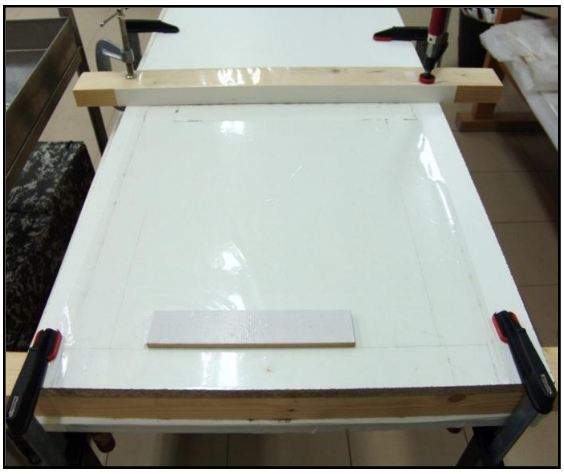


Fig. V.11. Normal light photographic detail of painting being pre-stretch under raking light with push-pins attached to the wooden bar. Demarked a rose is the detail for the tacks and the small nails added.

Fig. V.12. Normal light photographic detail of applying BEVA 371 gel with a fine brush to adhere loose threads of the canvas in place.

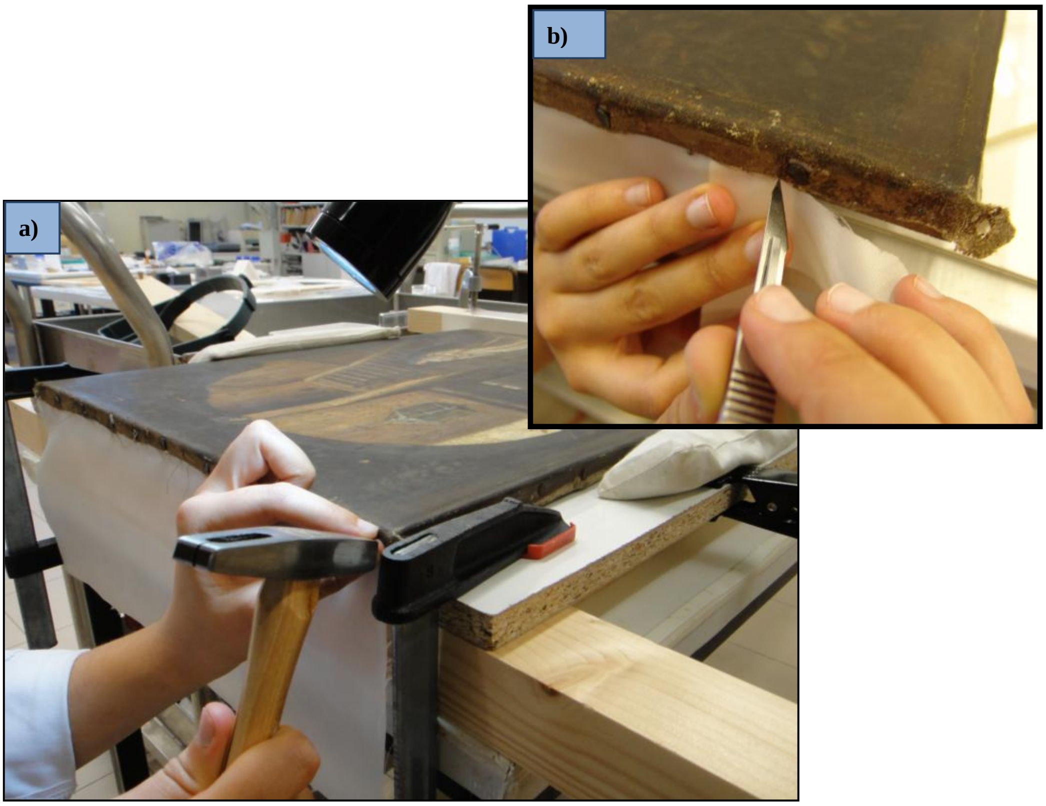


Fig. V.13. a) Normal light photographic detail of hammering new tacks in place (top tacking margin); b)detail of excess polyester fabric being cut with a scalpel blade with a piece of matt-board between the fabric and stretcher to protect the wood.

Fig. V.14. Normal light photographic detail of new tacks and small nails (demarked in blue circles) added to previous holes on the original fabric and wood.

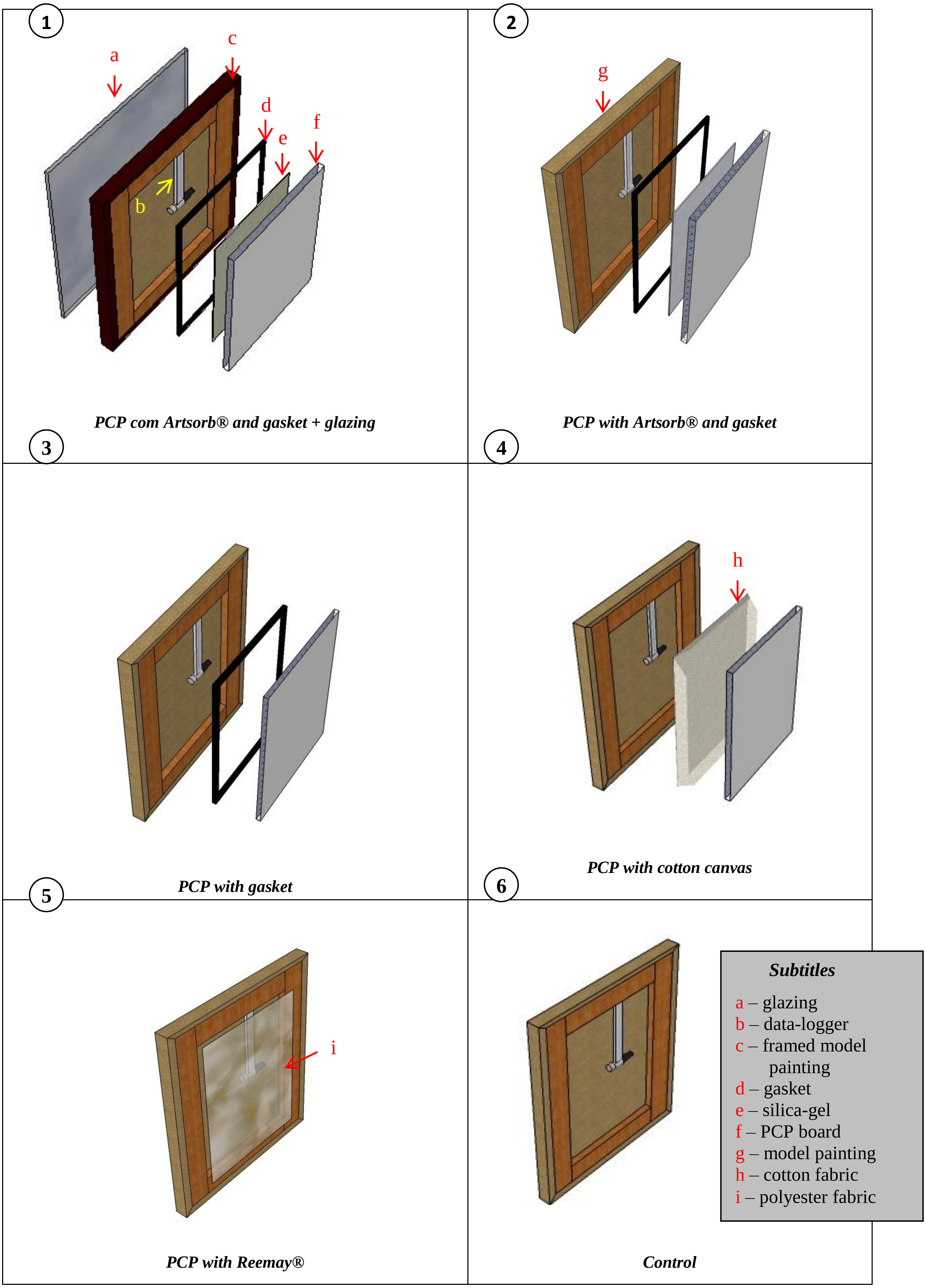
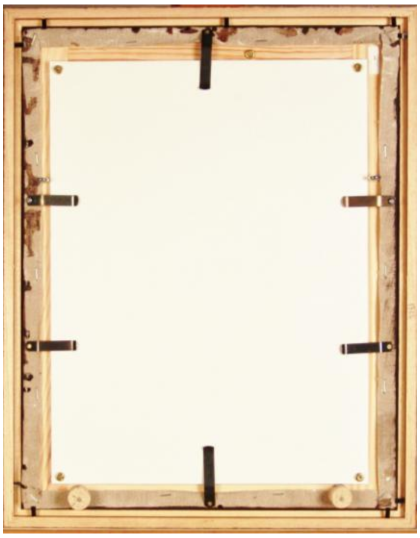


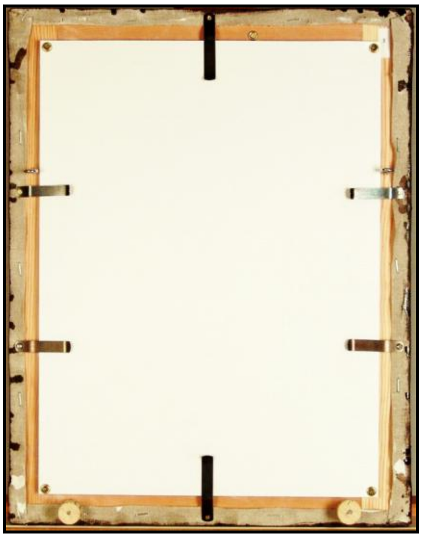
Fig. VI.1. Schematic drawings of the six back protection systems

1



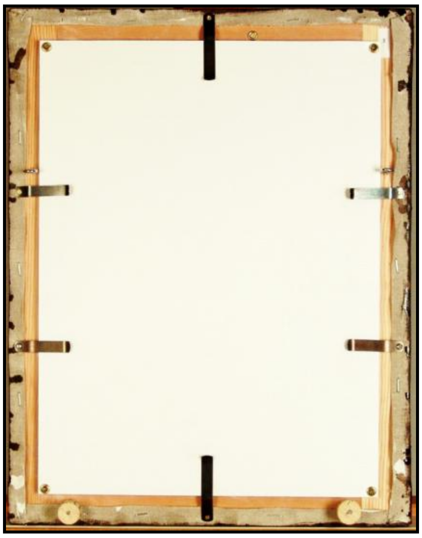
PCP with Artsorb® and gasket + glazing

2



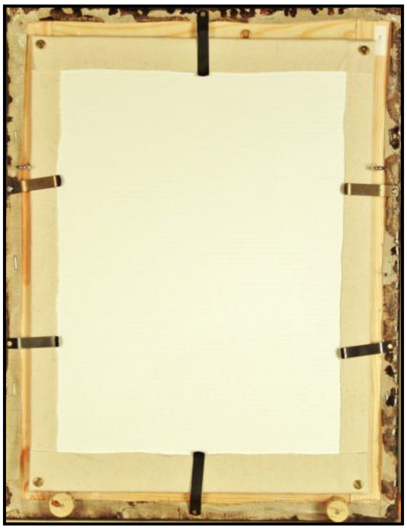
PCP with Artsorb® and gasket

3



PCP with gasket

4

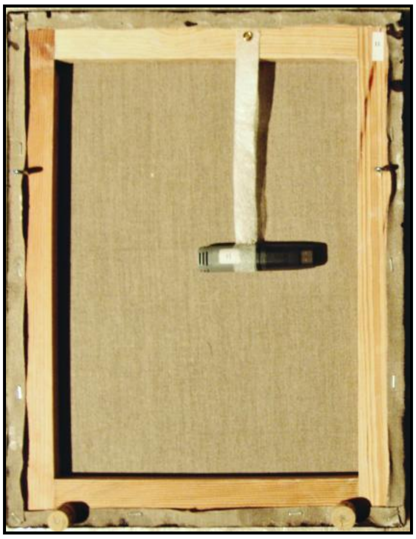


PCP with cotton canvas

5

PCP with Reemay®

6



Control

Fig. VI.2. Normal light photographs of the six back protection systems

Description[1]

1) Strainer: Twelve strainers were ordered with the same proportions as the oil painting *Interior de um Convento*, 4.5cm for the width of the strainer bars, 1.8cm for depth, 35 cm for the total width plus 45cm for the total length of the strainer –. All strainers were handmade by a local carpenter using pine wood and polyvinyl acetate glue for the square corners. Before ordering the strainer, a debate surrounding the possibility of using the same wooden bar depth as the data-logger (2.6cm) arose. As a hygroscopic material, the wood from the strainer will slow down the RH response of the enclosed air inside the back protection system. **[1]** According to the literature review, an important relation can be found between the wood and canvas interior surface area to the air volume of the enclosed space. After calculating the ratio of hygroscopic material (canvas interior surface area + wood interior surface area) to interior air volume of several strainers/stretchers, it was decided to order a strainer with a depth more consistent with standard dimensions, rather than an unusually deep dimension to accommodate the dataloggers. This meant that the data-logger lightly pressed against the canvas creating a bump in front of the painting. On the other hand, using a strainer different from those found in real paintings would create a false scenario with unreliable findings/results.

2) Fabric: Considering the painting collection at PNP, it was decided to use a linen fabric since it's the most common painting support fabric before the 1900. **[2]** The medium weight linen fabric chosen was placed in a sink with running tap water to remove any factory sizing or other residues like gums, synthetic coatings, etc. It is known that natural fibre fabrics are frequently sized at least on the warp threads during weaving. **[2]** The fabric was cut in two pieces that were stretched on large wooden looms while still wet. To stretch the fabric evenly, two middle threads from the warp and weft direction were marked in pencil. With the help of these pencil guide lines, the loom was laid on top of the fabric and the stretching begun by pulling the middle of the margins using canvas pliers and then stapling the middle points with an electric staple gun *Black & Decker® KX418E*. When the fabric dried completely, it became very slack and was re-stretched on the loom then re-wet with a water-soaked sponge. The

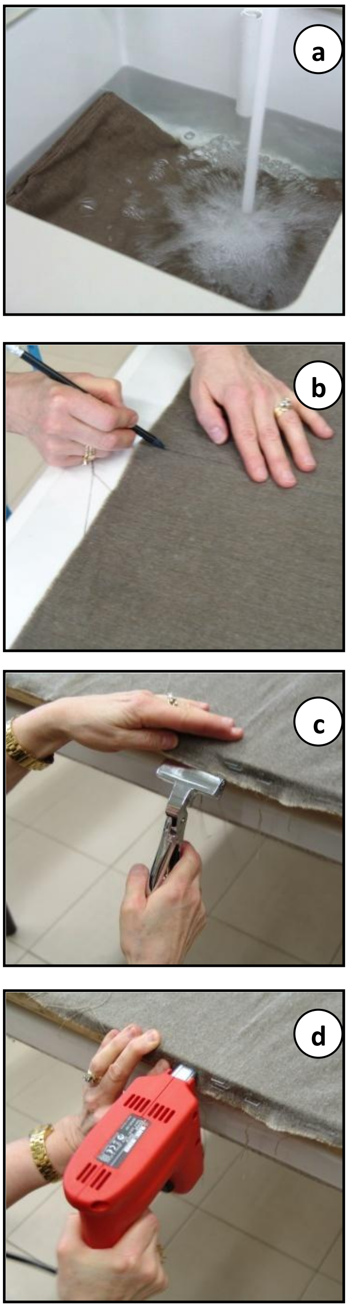


Fig. VII.1. a) Washing the fabric; b) Marking the fabric with pencil guide lines; c) Using canvas pliers to stretch the wet fabric; c)Stapling the fabric into the strainer.

[1] See references for this section in page 83.

wetting and re-stretching process is important to reduce fabric crimp (a deformation of the threads that occurs during manufacture when yarns pass over and under one another). **[3]** After stretching and rewetting a total of three times, all the fabric slubs (irregular threads) were removed with a scalpel blade and the fabric surface smoothed with a sanding block.

3) Size layer: In a broad sense, size means any material that is used to seal a porous surface. **[4]** In the case of easel paintings, the size acts as a barrier between the fabric and ground, preventing the latter from sinking into the former, which allows the artists to save more ground material. **[5]** Aside from this economic reason, sizing a canvas can prevent the occurrence of chemical reactions caused by the migration of oil and ground substances into the threads. Furthermore, it keeps the fabric taught on the stretcher during ground application and also creates a smooth and even surface for the ground layer. **[6]** The most traditional size layer is made from animal glue, a water based glue that is very hygroscopic and susceptible to microorganism and insect attack. Studies suggest that the size layer "has the most significant effect on the overall properties" of the painting because it is "very responsive to water, determining the stress states of the composite" **[3] (**p. 217).

Since the purpose of the project was to evaluate whether a sealed enclosure at the back would exacerbate mould growth, for preparing the model paintings, all animal glues available in the FCT-UNL laboratory were tested for the presence of preservatives and fungicides. The tests were performed by putting eight samples of different brands and types of animal glue (including rabbit skin glue and gelatin glue) into a sealed box with distilled water along a period of five days. Only two animal glues did not show signs of mould growth; of the remainder, it was decided to use rabbit skin glue (RSG) *Zecchi®* 7% in distilled water (weight/volume), prepared in a *bain marie* at 60ºC. The glue was then cooled and refrigerated until it gained the consistency of a gel. Gelled size application was chosen over fluid size application because, according to Heldley, it develops full shrinkage potential when exposed to moisture, increasing the risk of ground detachment. **[7]** The size was applied with a large metal spatula, following the warp and weft direction, while the fabric was stretched in the loom. The fabric became instantly taut as the glue penetrated into the threads. After the size was dry (3 days), the fabric from both looms was marked with a pencil and cut into rectangular pieces of approximately 41cm x 51cm (including 3cm for each tacking margin). All pieces were stretched onto individual wooden strainers and attached using a staple gun, leaving a 2cm space between each staple along the tacking margins.

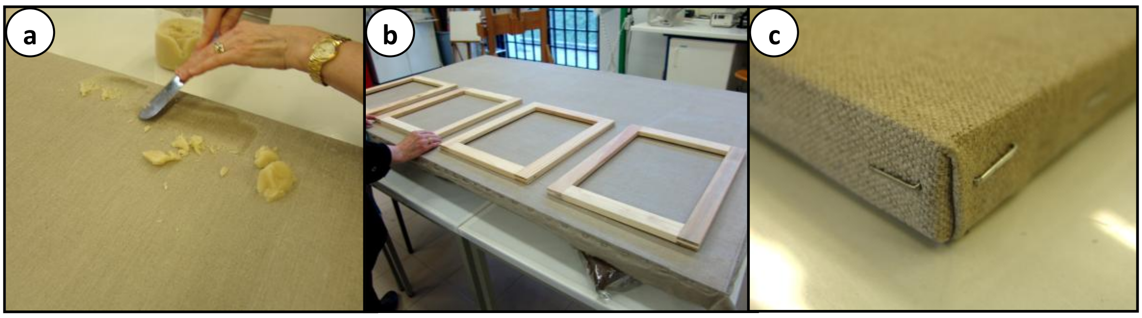


Fig. VII.2. a) Applying the size layer with spatula; b) marking the fabric to cut into rectangular pieces; c) detail of staples in the strainer's corner.

4) Ground: One of the most significant purposes of the ground was the production of a surface suitable to be painted on. As well, a ground layer can have an aesthetic function. For example, to provide a specific texture or colour that would give different visual effects. In the case of a coloured ground, it can influence the overall tonality of the finished painting or even be used in combination with a painting as a background colour. **[8] [9]**

A chalk-based gesso with a 7% RSG binder was applied as the first layer of ground. It was chosen primarily as it would dry quickly and the glue binder may offer a further site for mould growth. For its preparation, 245g of Champagne chalk from *Kremer*® was added to a glass with 300ml of 7% RSG while it was being heated at 60ºC. The chalk was added little by little, slowly sinking in as it was absorbed by the glue. When the chalk started to show at the surface of the glue, it was gently stirred with a glass rod to avoid creating bubbles. After it reached a mayonnaise consistency, the gesso was applied by brush with vertical and horizontal strokes until the surface was homogeneous. Prior to application, tests were made on a piece of canvas to evaluate the chalk-based gesso's workability, (as had also been done for the RSG size layer. The coloured varnish was also tested: when applied directly over the ground layer, it appeared matt because it sank into the gesso, but when a 2nd layer of clear varnish was applied, it gained gloss. Once the ground dried, all model paintings were sanded with abrasive sheets of *Micro Mesh*® (1800 grit) using a *Kapaline*® board placed under the canvas to avoid strainer bar creases. A 2nd layer of chalk-based gesso was applied, filling the pinholes that had remained and creating a more even surface once sanded.

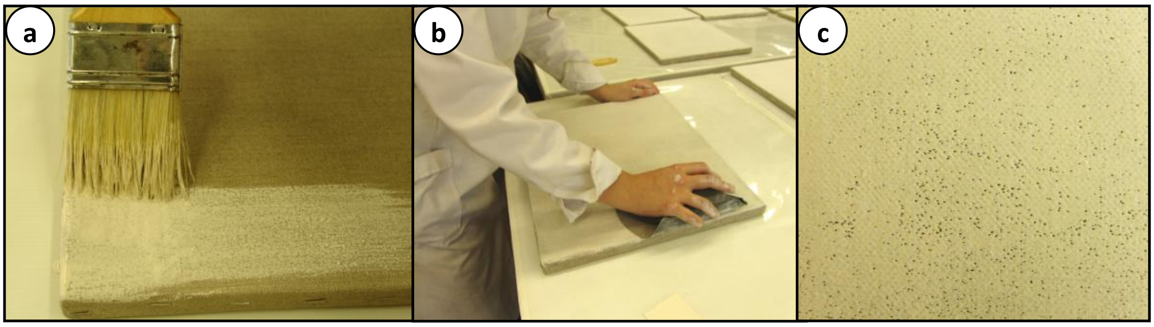


Fig. VII.3. a) Applying the gesso by brush; b) using abrasive sheets to sand between coats of gesso; c) detail of pinholes.

5) Surface coating: Because of time restrictions, it was not possible to use oil paint, as it is a slow-drying material. Therefore, in order to create a paint and varnish-like surface in imitation of an oil painting on canvas, it was decided to apply a resin coating consisting of 31% wt/vol Dammar resin (FCT-UNL supplies) dissolved in distilled turpentine (*Winsor and Newton*™) and coloured with powdered pigment. Like oil varnishes (varnishes prepared using oil as a major component with a resin such as Copal or Amber), spirit varnishes (varnishes prepared using solvents such as turpentine or alcohol) were used as additions to oil paint, as intermediate layers during paintings and as final varnishes. For this project, the choice of a spirit varnish relied on its relatively fast and easy preparation without the need of heat treatment. **[8]**

Dammar gum was weighted (200g) and wrapped in gauze (silk-like polyester fabric) tied with a string to make a bag. The bag was suspended inside a closed glass jar in direct contact with the distilled turpentine (460ml). During a three day period, the jar was swirled one or two times a day to help dissolve the resin and the lid remained closed to prevent the evaporation of solvent. The bag was then removed, since it had only been used to filter the residues: debris, bark and a wax-like component of the resin that turpentine does not dissolve. The resulting solution of dammar resin had a yellow and clear appearance. To colour the varnish, a mixture of dry pigments were added: Raw Umber *Cornelissen*® (30g), Alizarin Crimson *Cornelissen*® (2g), Blue pigment (unidentified, FCT-UNL stock) (3.5g), Black pigment (unidentified, FCT-UNL stock) (3g).

Fig. VII.4. Dammar gum wrapped in gauze.

The coloured varnish was applied by brush with vertical and horizontal strokes until it formed an even surface. During application, pin-holes created by air bubbles started to appear at the surface of the varnish but eventually disappeared once it had dried. All tacking margins showed signs of varnish dripping over the edges since the varnish was applied with the model paintings in the horizontal position.

Fig. VII.5. a) Applying coloured varnish with brush; b) detail of 1st application of varnish drying on model paintings; c) detail of varnish dripping.

Since the 1st layer of varnish was very translucent, another mixture of dry pigments in the same proportions was added to the remaining coloured varnish for the 2nd layer. After a short 24hours drying period, the 2nd layer of coloured varnish was applied by brush creating a darker and even surface. For the final coating, the initial solution (dammar dissolved in turpentine) was used without the addition of solvent in order to make a thick layer of varnish. This was applied by brush following the same procedure as the coloured varnish only one day after the application of the 2nd coating of coloured varnish. Because of the very short interval between coats, the top coat of varnish started to dissolve the coloured varnish below, first producing an orange-peel effect, and then gradually creating white islands of exposed ground at the turn-over-edges.

References

[1] Di Pietro, G. and Ligterink, F., 'The effect of the wooden stretcher on the HR response of backboard protected canvas painting' in *ICOM Committee for Conservation, 12th Triennial meeting, Lyon, 29 August-3 September 1999: Preprints,* ed. J. Bridgland, James & James, London (1999) Vol. I 70-76.

[2] Hedley, G., Villers, C., and V. R., Mehra, 'Artists' canvases: Their history and future' in *Measured Opinions,* ed. C. Villers, United Kingdom Institute for Conservation, London (1993) 50–56.

[3] Young, C., *Measurement of the Biaxial Tensile Properties of Paintings on Canvas*, PhD dissertation, Imperial College, University of London (1996).

[4] Richard, M., Mecklenburg, M., and Merrill, R., *Art in Transit - Handbook for Packing and Transporting Paintings*, National Gallery of Art, Washington (1991).

[5] Van Hout, N., 'Meaning and development of the ground layer in seventeenth century painting', in *Looking Through Paintings, the Study of Painting Techniques and Materials in Support of Art Historical Research,* ed. E. Hermens, Leids Kunsthistorisch Jaarboek, Archetype Publications, London (1998) 199-225.

[6] Carlyle, L., and Hendriks, E., 'Visiting Claessens, Artists' Canvas Manufacturers', *News in Conservation No. 11,* April 2009.

[7] Hedley, G., and Odlyha, M., 'The Moisture softening of paint films and its implications for the treatment of fabric supported paintings' in *Measured Opinions,* ed. C. Villers, United Kingdom Institute for Conservation, London (1993) 99-102.

[8] Carlyle, L., *The Artist's assistant: oil painting instruction manuals and handbooks in Britain 1800–1900 with reference to selected eighteenth-century sources,* Archetype Publications, London (2001).

[9] Kirsh, A., Levenson, R., *Seeing Through Paintings: Physical Examination in Art Historical Studies (Materials & Meaning in the Fine Arts),* Yale University Press, New Haven (2000).

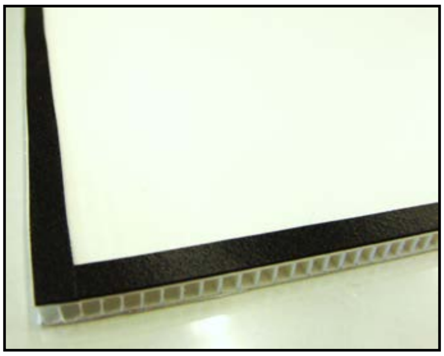


Fig. VIII.1. Detail of the gasket

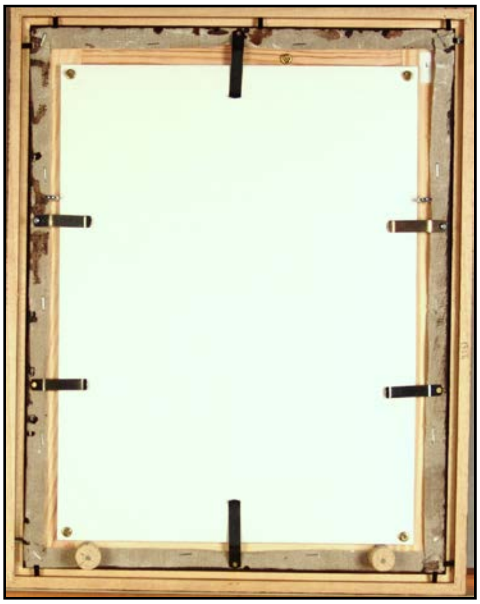


Fig. VIII.2. System of six metal "spring clips" in 01 Set

Fig. VIII.3. ArtSorb® sheet with an empty square to accommodate data-logger

Fig. VIII.4. Detail of the staple application in the Reemay® set

Fig. VIII.5. Detail of the installation wall with extensive signs of mould growth

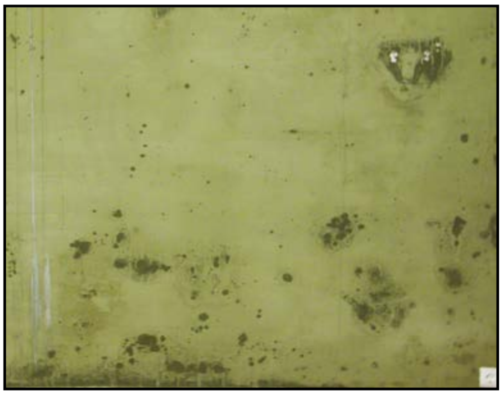
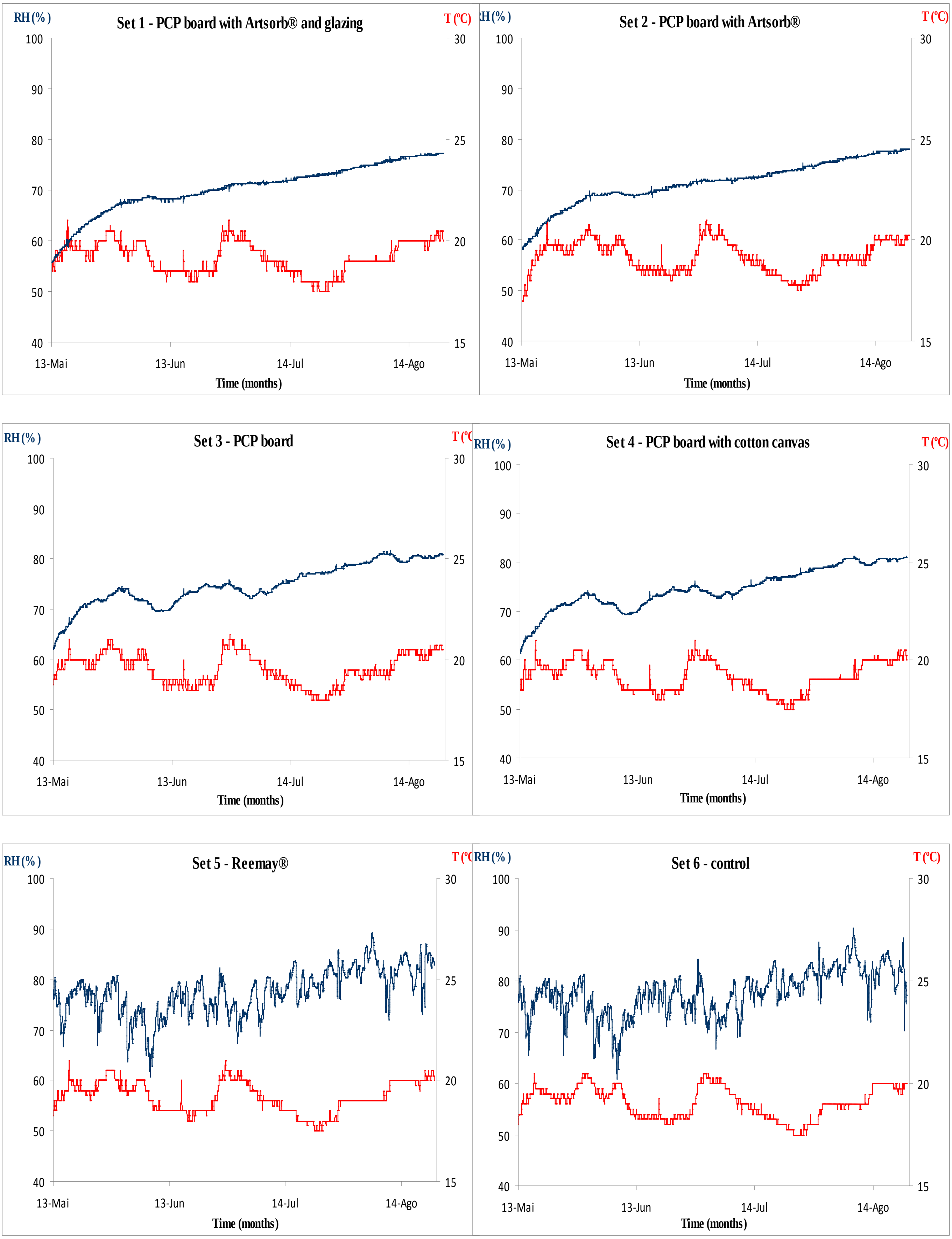
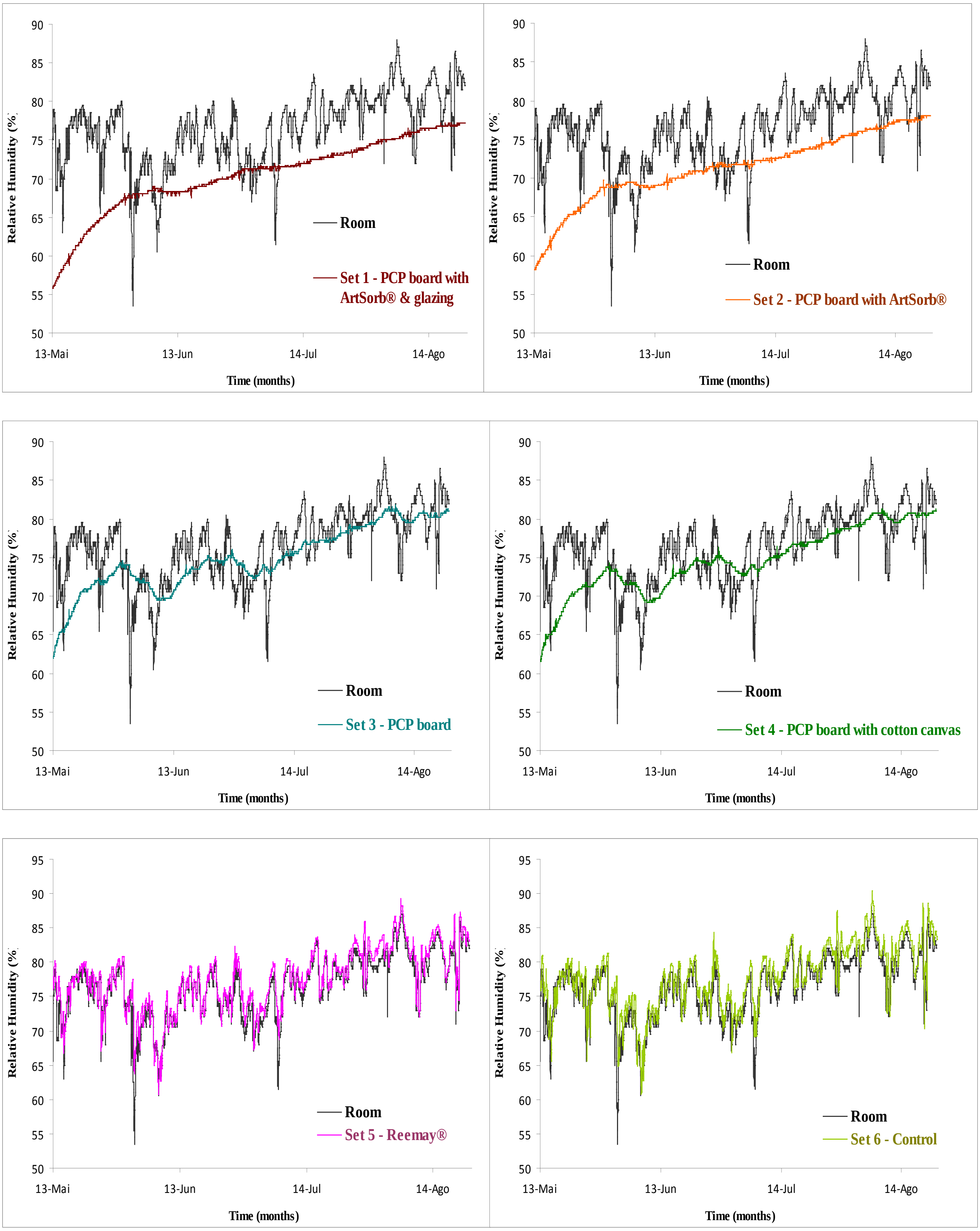


Fig. VIII.6. Front of framed and glaze model.



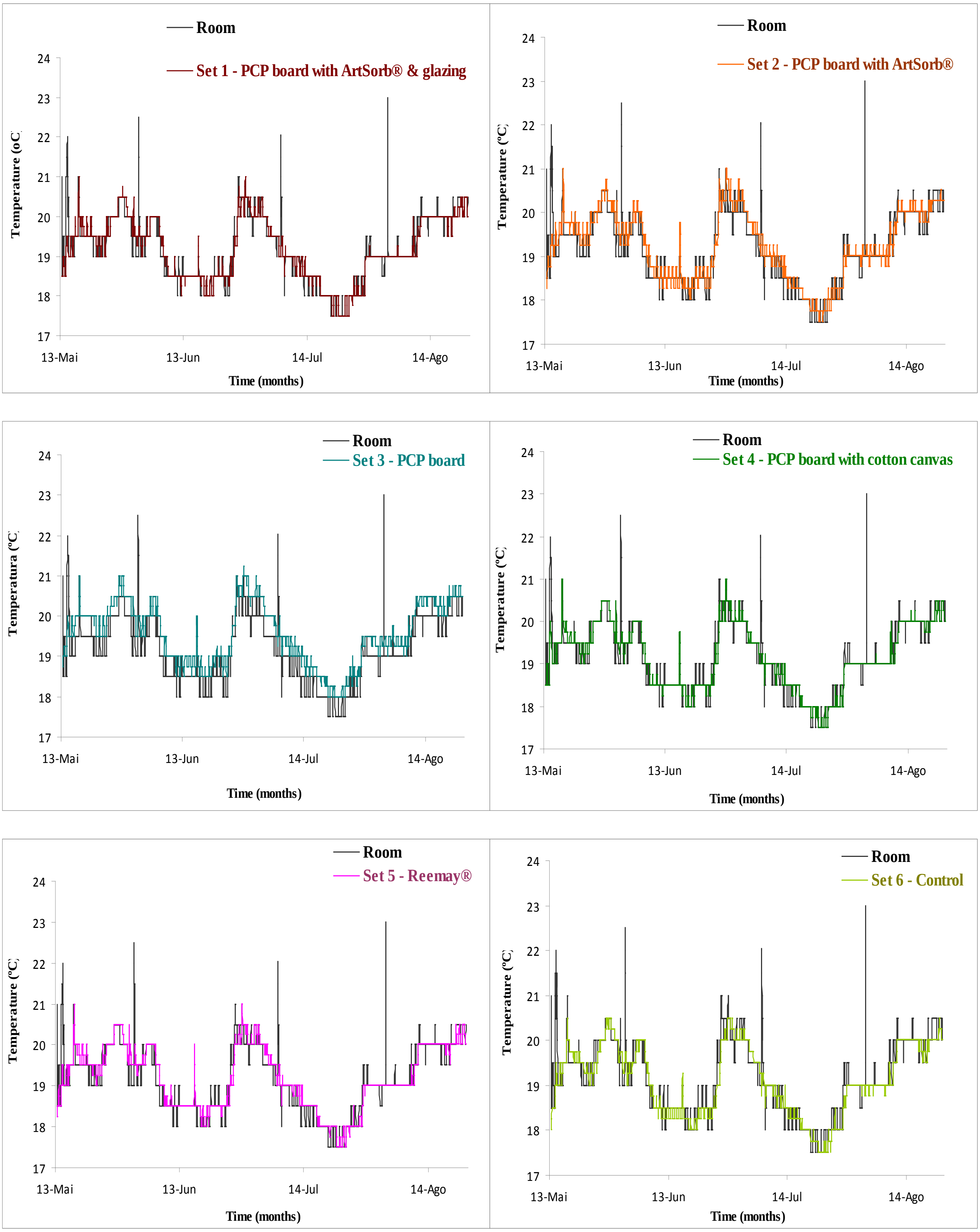
Graphs IX.1. Four month period of temperature (T – red line) and Relative Humidity (RH – blue line) readings for all six

Relative Humidity: room versus sets

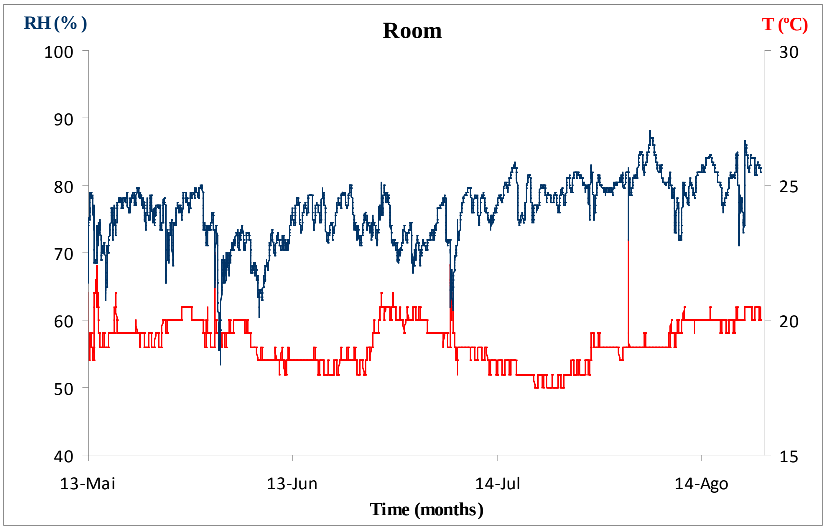


Graphs IX.2. Four month period of RH readings for Room (black line) and the six different Sets (coloured lines)

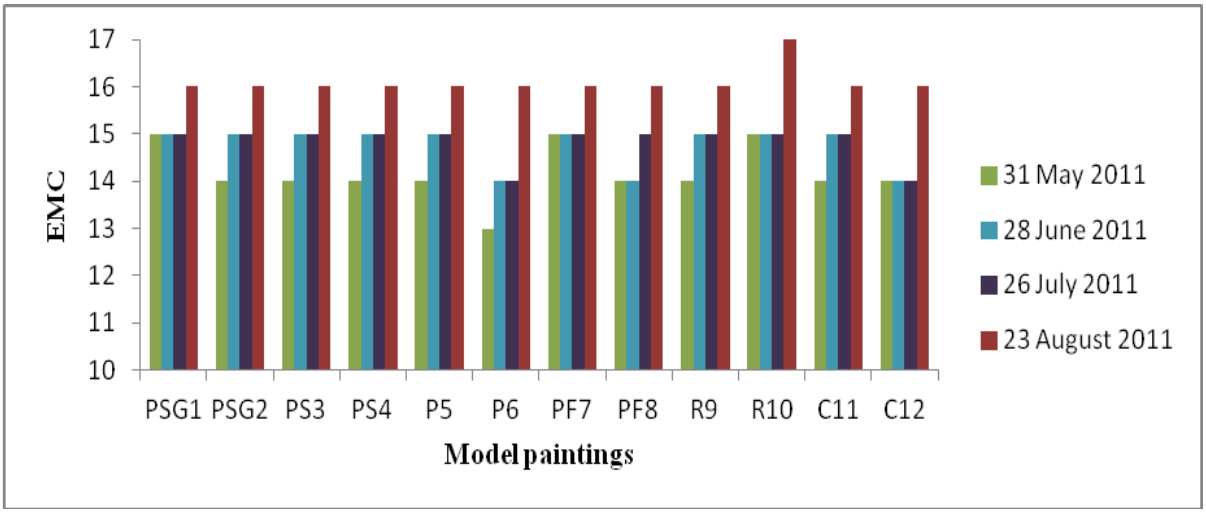
Temperature: room versus sets



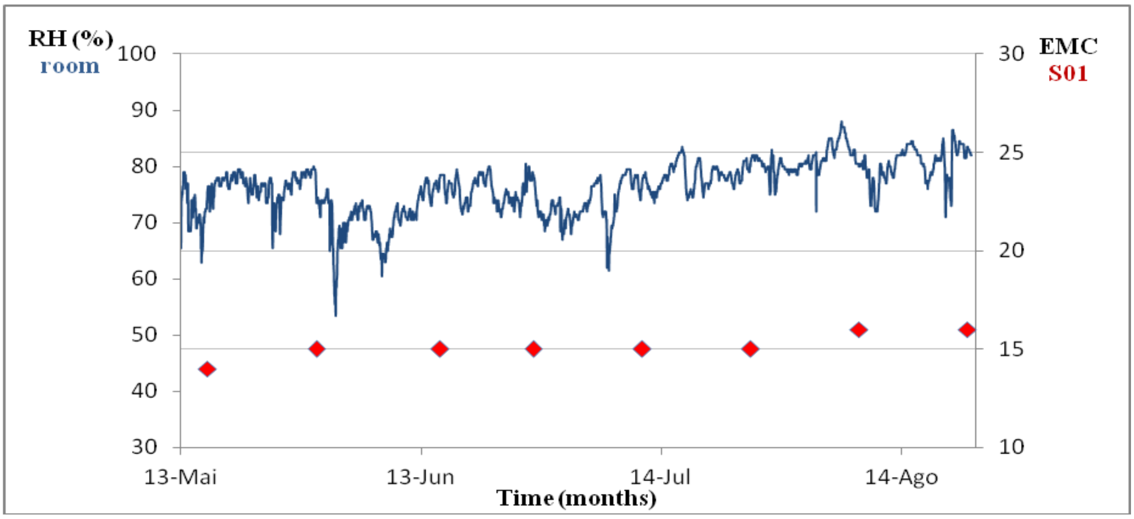
Graphs IX.3. Four month period of temperature readings for Room (black line) and the six different Sets (coloured lines).



Graph IX.4. Four month period of temperature (red line) and RH (blue line) readings for the room.



Graph IX.5. Equilibrium Moisture Content measured on the wooden strainers of the twelve model paintings in the days: 31th May, 28th June, 26th July, 23th August.



Graph IX.6. RH of the room between May and August (blue line) and the units of EMC measured on model painting 1 (set PCP with Artsorb and glazing) (red dots) showing the relationship between RH and EMC.