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TECHNICAL STUDY OF GERMOLLES' WALL PAINTINGS: THE INPUT OF IMAGING TECHNIQUES

ESTUDIO TÉCNICO DE LAS PINTURAS MURALES DE GERMOLLES: LA CONTRIBUCIÓN DE LAS TÉCNICAS DE IMAGEN

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Abstract:

The *Château de Germolles* is one of the rare palaces in France dating from the 14th century. The noble floor is decorated with wall paintings that are a unique example of courtly love spirit that infused the princely courts of the time. After being concealed sometime in the 19th century, the paintings were rediscovered and uncovered in the middle of the 20th century and partly restored at the end of the 1990s. No scientific documentation accompanied these interventions and important questions, such as the level of authenticity of the mural decorations and the original painting technique(s) used in the medieval times remained unanswered. The combined scientific and financial supports of COSCH Cost Action and DRAC-Burgundy enabled to study Germolles' wall paintings using some of the most innovative imaging and analytical techniques and to address some of the questions raised. The study provided significant information on the material used in the medieval times and on the conservation condition of the paintings. The data collected is vast and varied and exposed the owners of the property to the challenges of data management.

Key words: Germolles, wall paintings, documentation, imaging techniques, painting techniques, data management

Resumen:

El castillo de Germolles es uno de los raros palacios principescos en Francia que data del siglo XIV. La planta noble está decorada con pinturas murales que son un ejemplo único del amor cortés, ese espíritu que se divulgó en las cortes de la época. Ocultadas desde el fin del siglo XIX, las pinturas fueron descubiertas en la mitad del siglo XX y fueron

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parcialmente restauradas al final de la década de 1990. No hay documentación científica que acompañe las intervenciones, y cuestiones importantes se quedaron sin repuesta, en particular el nivel de autenticidad de las decoraciones de las paredes, así como las técnicas pictóricas utilizadas en la época medieval. El apoyo científico y económico de la Acción Cost COSCH y de la DRAC de Borgoña permitió el estudio de las pinturas murales de Germolles con algunas de las técnicas de imagen y analíticas más innovadoras, con tal de responder a algunas de las cuestiones planteadas. El estudio proporcionó información relevante en lo que se refiere al material utilizado durante la Edad Media y sobre el estado de conservación de las pinturas. La toma de datos es amplia y variada, y expuso a los dueños de la propiedad al desafío de la gestión de datos.

Palabras clave: Germolles, pinturas murales, documentación, técnicas de imagen, técnicas pictóricas, gestión de datos

1. Introduction

The *Château de Germolles*, located in Southern part of the Burgundy region in France, is one of the few remaining princely residences of the end of the 14th century still surviving in France. It was owned by Margaret of Flanders, wife of Philip the Bold, Duke of Burgundy and brother of Charles V, the King of France. Built between 1380 and 1400 on an older fortified house, it is an example of the interest of French dukes in rural environments. Such a pastoral spirit, although interrupted by the second part of the Hundred Years' War with England, laid the foundation for the French Renaissance.

The finest artists of the Burgundian School, among which Claus Sluter and Jean de Beaumetz, were involved in the transformation of Germolles from a fortress into a luxurious country estate (Beck, 2002). After the collapse of the Burgundian dynasty in 1477, the château became property of the crown and the successive kings attributed Germolles to some of their close vassals. At the end of the 18th century, the south-west corner of the castle had lost its roof and the walls were demolished after the French Revolution. In 1873 a fire destroyed a full section of the eastern wing between the chapels and the main building (Fig. 1). It is just after this event that the current owners acquired the château which, in 1989, was listed as national cultural heritage and has been opened to the public for the last 50 years.

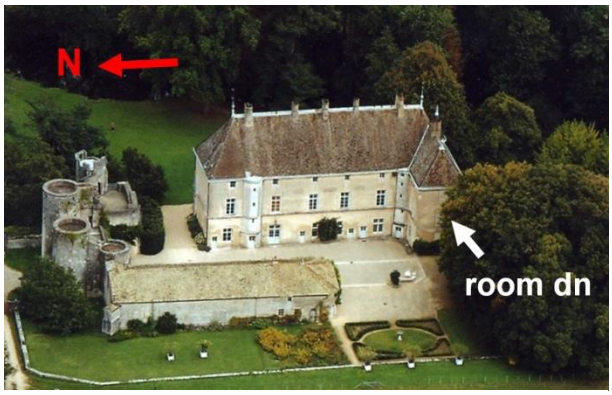


Figure 1: Bird's eye view of Germolles in 2007. The château was originally fully enclosed. The main building is visible on the top right of the picture with room dn © A. Rodrigue.

The wall paintings produced by Jean de Beaumetz and his workshop are on the first floor of the main building. This was the ducal floor and it was originally organized in apartments comprising a large bedroom and its dressing room. In modern times partition walls were erected to subdivide the apartments of Margaret of Flanders, Philip the Bold and their daughter-in-law, Margaret of Bavaria (Countess of Nevers). Only the dressing room of Countess of Nevers (room dn) was not subdivided and is preserved in its original volume (see location on Fig. 1). All rooms were re-decorated at the beginning of the 19th century with stucco plaster and wall paper.

During World War II, the medieval wall decorations of the *Château de Germolles* were rediscovered under the 19th century plasters. The paintings of some rooms (dressing rooms) were restored between 1989 and 1995. These paintings show a regular distribution of large letters (initials of the first names of the Duke and/or the Duchess) alternated with flowers (thistles, roses, marguerites) on green background (Fig. 2). In Countess of Nevers' dressing room, the series of letters "P" and "M", as well as of flowers form diagonals (red dashed lines, Fig. 2) while the upper part of the letters and of the flowers are aligned (blue lines, Fig. 2). In addition to the wall paintings, the rooms were decorated by floor tiles matching the floral decorations of the walls. These motifs are characteristic of the courtly love spirit that was very fashionable among princely courts at the end of the 14th century.

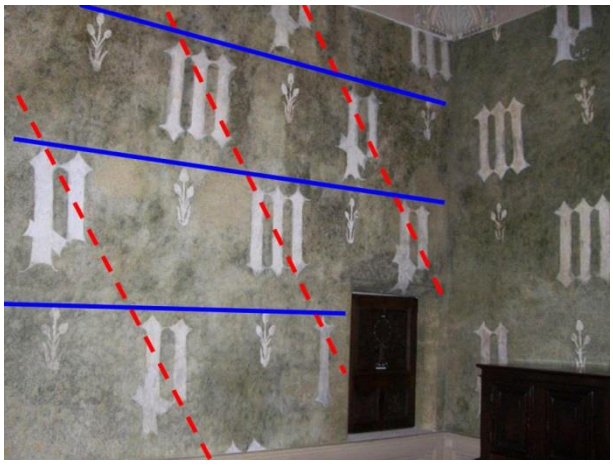


Figure 2: Wall paintings decoration of Countess of Nevers' dressing room after conservation work (1989-1995). The red dashed lines and the blue lines illustrate the geometrical repetitive pattern of the decoration © Germolles.

The medieval accounting notes (ADCO B4434 -1) of the Château are preserved in the Departmental Archives in Dijon and list in detail the materials acquired to decorate the walls of the castle (see Table 1 below). Although extremely accurate, they do not match perfectly the composition of the existing paintings. In particular the large amounts of metal leaves described were not visible on the paintings. This intriguing mismatch between the archival data and the material evidence as well as the question of authenticity, were the main reasons for

setting up the Germolles case study. Non-invasive imaging techniques and point analyses, followed by more traditional analytical techniques, were used to record and study further the wall paintings decoration. The project benefited both from the technical, scientific and financial support of the EU COST Action TD1201: Colour and Space in Cultural Heritage (COSCH) (www.cosch.info) and from funding from the Regional Direction of Cultural Affairs in Burgundy (DRAC-Burgundy). Although all wall paintings decorations were examined, the article focusses on the large number of comparative observations and analyses conducted in Countess of Nevers' dressing room.

2. Preliminary documentation

A photogrammetric campaign using a Canon EOS 6D digital camera equipped with a 16-35 mm stabilized zoom lens set at 16 mm, was performed to obtain orthophotographs that were used as basemaps for documentation. Tracing manually the outline of letters over these digital basemaps showed that all "M" letters have the same form (Fig. 3) while "P" letters were further decorated with arabesques at their bottom parts (Fig. 5).

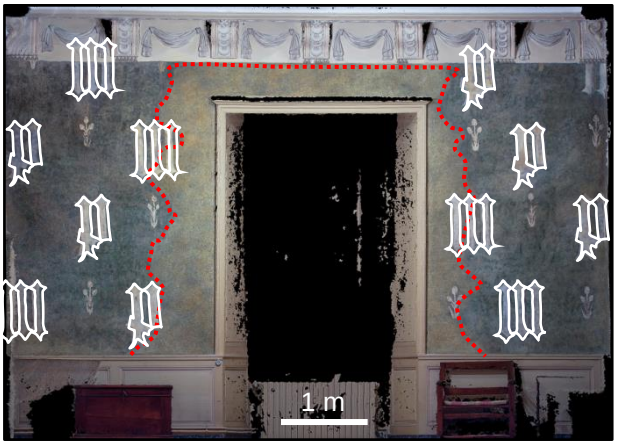


Figure 3: Orthophotograph of room dn south wall. The opening of a window in the 19th century caused loss of original decoration. The red dotted lines mark the edge of original plaster. The profile of "P" and "M" letters is indicated in white, photograph © Guery and outlines © Germolles.

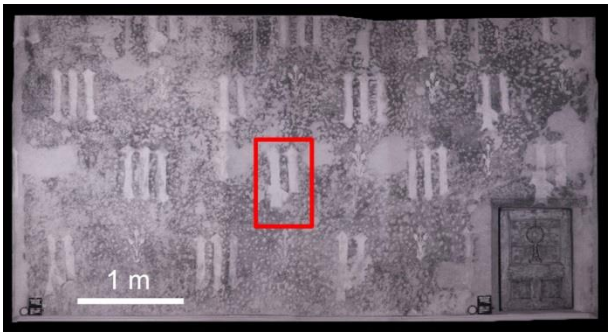


Figure 4: IR photographic image (approx. 830-1000 nm) of room dn west wall with location of the letter "P" further examined in Fig. 5 © Piqué.

Infrared (IR) pictures (approx. 830-1000 nm) of the walls obtained with Canon EOS 5D Mark II digital camera and halogen Lowel V (500 W) light were effective in revealing the extension of 20th century conservation work. This intervention consisted in filling the holes left by the keying process before the application of a concealing stucco plaster. The missing decoration was recreated over these fills by repainting with material transparent to IR (Fig. 4). On the contrary, the original green used to paint the background is opaque to IR and appears dark grey. Due to this optical behaviour difference, IR pictures clearly showed areas original and not original. Hyperspectral imaging was used to investigate further the embellishments at the extremities of the "P" letters. The CCD camera (HS-XX-V10E), developed by SPECIM provides a 1600 x 840 pixel resolution, a spectral resolution of 2.8 nm and a wavelength range between 400 to 1000 nm. The wall paintings were illuminated by two halogen lamps oriented to 45°. The data processed with ENVI 5.2 + IDL software allowed to obtain an RGB image (R=650 nm; G=540 nm; B=450 nm) and greyscale images at wavelengths ranging from 500 to 1000 nm. These pictures were used as basemaps to indicate specific features such as the original profile of the "P" letters (Fig. 5, picture at 1000 nm) and their embellishment by medieval artists (Fig. 5, RGB picture). It appears that the addition of the arabesques was done over the original green background making each letter "P" appear a little different in visible light.

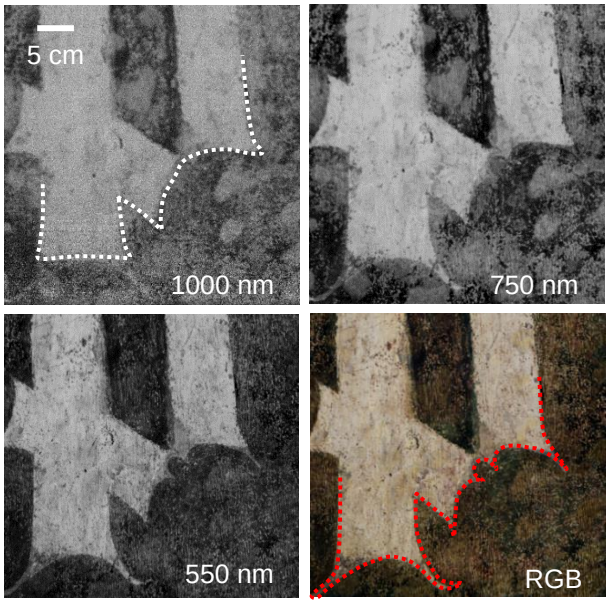
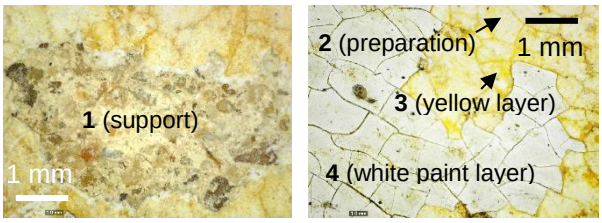


Figure 5: Hyperspectral imaging of the lower part of the letter "P" shown in Fig. 4. The white dotted line on the "P" photographed at 1000 nm shows the original profile of the letter while the red dotted line on the RGB picture shows the profile of the letter after embellishment © Mounier.

3. Stratigraphy of paint layers

3.1. The letters

The mural decorations were studied by visual examination with the help of good lights, portable microscopy and micro technical photography using Dino-lite digital microscope AD4113T (Fig. 6). The painting technique used to create the "P" and the "M" letters is the same and results in the following stratigraphy: the white preparation layer (2, Fig. 6b) applied on the



(a) (b)

Figure 6: Micro observation of an "M" letter with Dinolite® microscope: a) support material; b) preparation, yellow and white paint layers b) © Papiashvili.

support (1, Fig. 6a) is covered with a yellow underlayer (3, Fig. 6b) and the letters are executed with a white paint layer that appears heavily cracked (4, Fig. 6b).

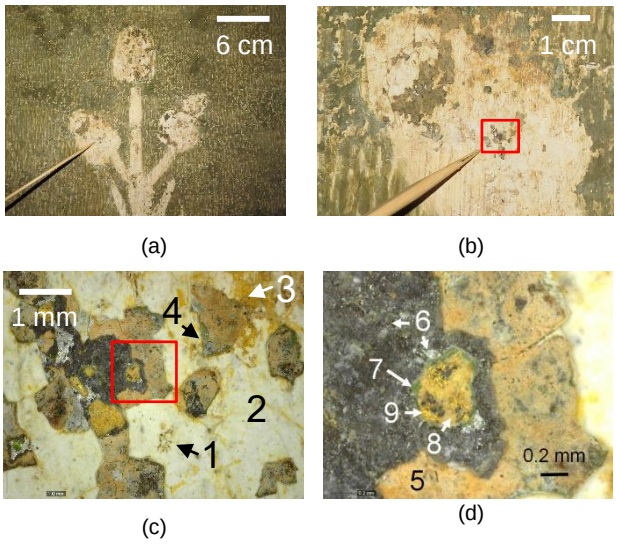
Non-invasive X-ray Fluorescence spectroscopy (XRF) using Thermo Scientific Niton XL3t 900 spectrometer equipped with a 50 kV X-ray tube with silver anode max. 40 µA and Si detector with 195 eV resolution showed that the preparation layer is rich in calcium (Ca) while the yellow layer contains iron (Fe) and the top white paint layer is rich in lead (Pb). Traces of titanium (Ti) and zinc (Zn) were detected. Micro-destructive examination by Laser Induced Breakdown Spectroscopy (LIBS) using 3 Ocean Optics range between 200 and 950 nm (from 200 to 340 nm and from 335 to 445 nm, 1800 mm^{-1} grating, resolution 0.1 nm; from 510 to 940 nm, 600 mm^{-1} grating, resolution 0.31 nm) spectrometers and data processing with CALIBSO software confirmed the elements and the stratigraphy of the different layers. The presence of Zn and Ti was validated on the white paint layer where barium (Ba) was also identified, suggesting that possibly lithopone (barium sulphate combined with zinc sulphite) and titanium oxide were used during the recent conservation work.

3.2. The thistles

The technique used to paint the thistles in between the letters is different and the stratigraphy examined is indicated on Fig. 7 showing the detail of one of the flowers. Currently, most of the thistles appear white because only the white Ca-based preparatory layer remains (Figs. 2 and 7a). Green paint layers as well as isolated black remnants of paint are visible in small amounts (Fig. 7b) and were sometimes toned down by white repainting applied during 1989-1995 conservation campaign.

Visual examination of the paint remains, documented with portable microscope shows above the yellow underlayer (3 on Fig. 7c, similar to 3 on Fig. 6b) a green layer (4, Fig. 7c) that corresponds to the background of the wall decoration. Over this green background layer, the thistles were made with a complex stratigraphy comprising metallic foils applied as finishing layers (Fig. 7d). We find successively a silvery layer (6) on an orange layer (5) covered with a transparent green layer (7) and a gilded layer (9) on another orange layer (8).

The analysis of these metallic remains by XRF revealed the presence of tin (Sn) and gold (Au), while copper (Cu) and Pb were identified on the green background layers. LIBS confirmed these results. Tin (silvery layer) oxidises with time and turns black as shown on Figs. 7c and 7d.



(a) (b) (c) (d)

Figure 7: Macro (a and detail b) to micro (c and detail d) observation of a thistle with Dinolite® microscope. The stratigraphy comprises the underlayers (support material (1), preparation with regular strokes (2) and yellow layers (3), the green background (4) and the finishing metallic layers (5 to 9) © Papiashvili.

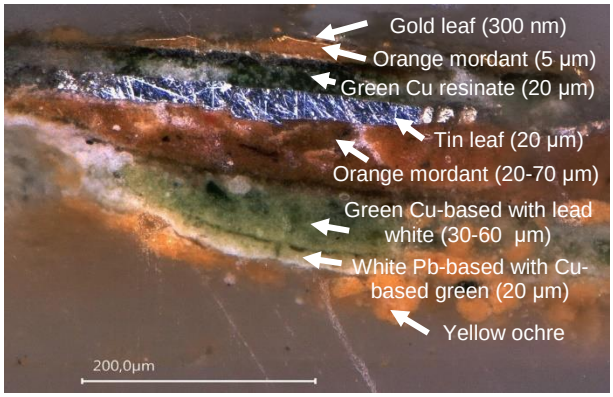


Figure 8: Cross-section of a fragment from a thistle observed in visible light under optical microscope. The identification of the material was carried out combining FTIR and SEM-EDS analyses © Piqué & Martos-Levif.

A fragment of a thistle stratigraphy was mounted in cross-section and examined under optical microscope. The complete stratigraphy of layers with their respective thickness could be visualised from the yellow underlayer to the upper gold leaf (Fig. 8). Energy Dispersive Spectroscopy associated to Scanning Electron Microscopy (EDS-SEM) using JEOL JSM-5600LV at low pressure (17 Pa) and voltage of 15 kV as well as Attenuated Total Reflectance - Fourier Transformed Infrared (ATR-FTIR) spectroscopy using PerkinElmer spectrum 100 equipped with deuterated-triglycine sulfate (DTGS) detectors (4000 at 400 cm^{-1}) allowed to further characterize each layer. The yellow underlayer contains both Fe, aluminium (Al) and silicium (Si) and is probably a yellow ochre rich in clays. The green background is made by two layers both containing Cu and Pb, the first layer is whiter and contains mainly lead white $(PbCO_3)_2Pb(OH)_2$ while the second is greener and is richer in Cu-based green. The binder of these Cu and Pb based layers is probably linseed oil, as seen by FTIR.

The orange layers under the metallic leaves have a variable thickness and act as mordants for these layers. The orange layer below the tin foil contains an ochre, Pb and linseed oil. The green layer on top of the tin is a copper resinate, as seen by FTIR. The orange layer supporting the gold foil is composed of ochre and Pb mixed with linseed oil similar to the layer under the tin foil.

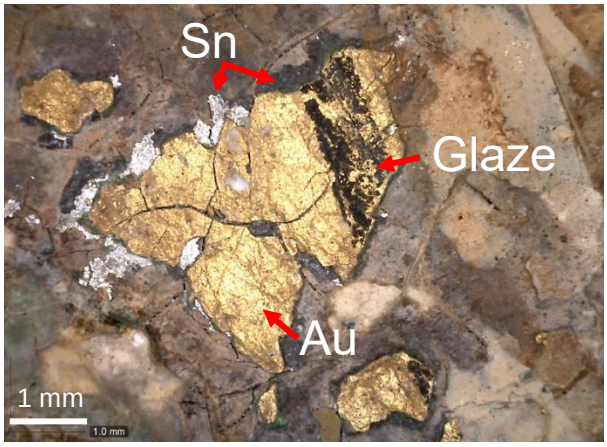
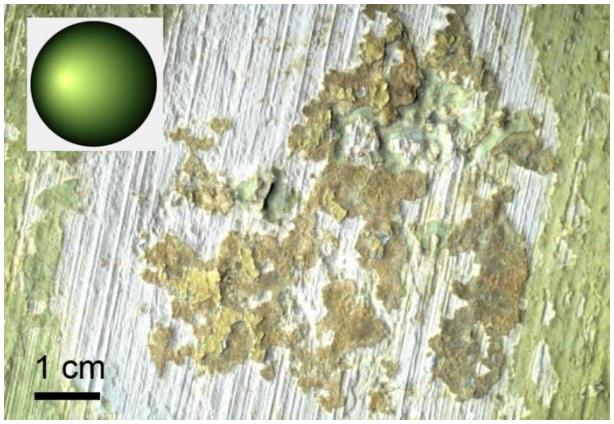


Figure 9: Micro-photography of a gold leaf from a thistle in the upper parts of room dn showing traces of a black glaze or paint layer © Piqué.



(a)

(b)

Figure 10: H-RTI snapshots under different illumination angles and application of diffusion gain. Gold remains are evident on picture a) but not so much the stratigraphy of layers. The reverse is observed when the surface is illuminated from the opposite direction b) © Germolles.

Further close observation of the metallic remains on the thistles of room dn showed the presence of black glaze or paint layer on top of the gold foils that was certainly applied to give some relief to the gold background (Fig. 9) (Mounier, 2010).

Raking light is certainly one of the best way to observe the stratigraphy of layers on the thistles. However, shadows are problematic and difficult to avoid. Therefore Highlight-Reflectance Transformation Imaging (H-RTI) using a Nikon D 7100 digital camera equipped with a variable focal (DX-VR, AF-S 18-140) used with maximum magnification (140 mm), at a working distance of approximatively 25 cm, was tested as an alternative to raking light to better visualise details and stratigraphies of these paintings illuminated with a torch equipped with a LED of a power of white light (XM L2) (Duffy, 2013).

H-RTI data processing can be done with open source softwares available to end-users (RTIBuilder® and RTIViewer®), making this imaging technique a low-cost accessible one. Fig. 10 shows two snapshots of an H-RTI recording of a thistle. The remains of the gold foils are clearly visible on Fig. 10a while the layers' stratigraphy is more legible on Fig. 10b.

3.3. Painting techniques used

A good understanding of the original painting techniques used at Germolles by medieval artists can be reconstructed from all the data collected. First the yellow ochre underlayer was applied uniformly on a lime based preparation layer. The large letters "P" and "M" were created using stencils while a green background was painted all around the stencils in two sub-layers with different Cu/Pb ratio probably binded with linseed oil. A lead white in linseed oil layer was used to paint the letters on the yellow ochre. The profile of the "M" letters was not further modified while arabesques were painted over the green background at the extremities, particularly at the lower parts of the "P" letters.

Table 1: Painters' materials in the ducal accounts 1375 – 1416 for four major ducal sites (from Nash, 2010).

	Germolles	*Rouvres*	*Argilly chapel*	*Champmol abbey*
Gold foils	2 400	2 400	61 841	66 850
Gilded tin foils	720	348	288	1 524
Green tin foils	1 908	60	17	1 524
White tin foils (unprepared)	540	492	612	840
Bresin (lb)	1 ¼			
Vermillion (lb)	8	4	86	59
Lead red (lb)	59	6	158	110
Indigo (lb)	1		10	7
Pouille ($CaCO_3$) (lb)	60	6	6	10
Ochre–berry (lb)	120		68	46
Linseed & walnut oils (pints)	18		238	190
Varnish (lb)	89	22	72	82
Paper (quires)	9	4 ½		3

The technique used to create the thistles is more complex. Green tin foils were cut in the shape of the flowers, were gilded and further decorated with either black glaze or paint layer to create a relief effect. Medieval records show that large quantities of green tin foils, almost 2000 pieces, were purchased for Germolles (Table 1). Fig. 8 shows that these foils were used in the finishing layers of the thistles.

Unfortunately, only remnants of the thistles complete stratigraphy are surviving in the exposed parts of the paintings. Furthermore traces of metallic decoration were found in all portions of the thistles. Therefore it was not possible to determine their full original appearance. In particular, it is not clear if the thistles were fully or only partly gilded. If fully gilded, it is intriguing that such large amounts of green tin were used at Germolles (Nash, 2010) especially considering that green tin was much more expensive than white (not coloured) tin.

3.4. Conservation condition

As part of the study, the colour of several parts with different paint layers was measured with Minolta CM-700d handheld spectrophotometer. Comparison between a recently exposed green background and a portion opened in the 1970s showed that colours had not changed significantly. Today a strict preventive conservation policy is applied by the owners and includes keeping the internal shutters closed as much as possible to reduce exposure to sun light which may cause colour fading.

The paint layers were consolidated with Paraloid B72® at the end of the 1989-1995 conservation campaign (Takahashi, 1991-1994). Therefore the paint layers are generally well adherent to the surface of the walls. However, the metallic remains are flaking in a few parts.

The white paint layer of the letters has a greyish colour in some areas along their profile (particularly the “P”, see Fig. 11). This seems to be related to the well-known lead white alteration process (Giovannoni, Matteini, & Moles, 1990). It is noteworthy that this alteration seems to be limited to areas where the lead white is covering the Cu-based green background.

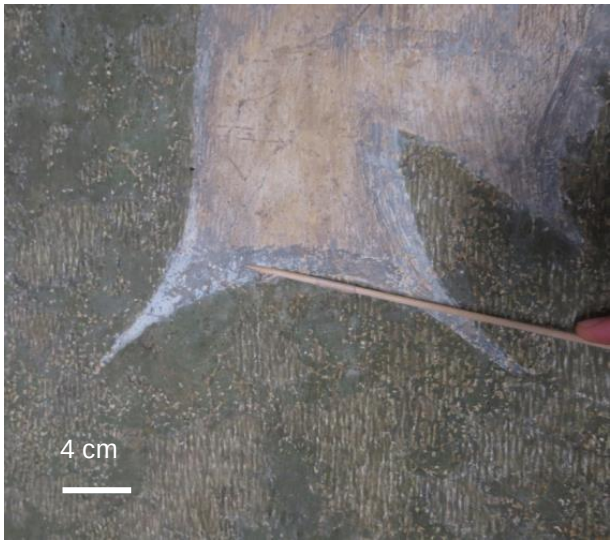


Figure 11: Alteration of lead white creating a shadow effect observed on the edges of a “P” letter © Piqué.

Investigation with IR Thermography (IRT) using a thermocamera testo 890 equipped with IR-FPA (focal-plane array) detector was carried out to assess large cracks observed on the 19th century cornice of the room. IRT was accompanied by tactile assessment to detect delaminated areas. Fig. 12 shows (on the IR basemap of Fig. 4) the location of detachments perceived by touch (knocking tests). As shown on Fig. 13, the results obtained by IRT and by knocking were similar.

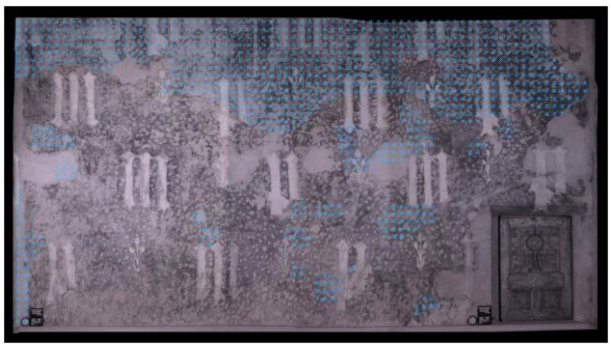


Figure 12: Graphical representation (over IR image) of areas of detachment in blue as recorded by tactile assessment (knocking method) on room dn west wall © Papiashvili.

Figure 13: Representation of areas of detachment detected by IRT on room dn west wall © Tedeschi & Cucchi.

4. Alignment of data

The amount of data collected so far as part of the Germolles case study is enormous. Therefore it was important for the owners of *Château de Germolles* not only to plan their archiving and storage but also to deal with their integration, interpretation and management. Challenges included managing very large files which are processed and can be visualized only with specific softwares.

In particular, the alignment of data is a field of research that requires specific expertise in data management (Manuel, Gattet, De Luca, & Veron, 2013). Some preliminary tests were carried out using the large volume of data collected at Germolles.

Fig. 14 shows for instance how from a photogrammetrically-based point cloud of room dn south wall, tie points were searched and found with other pictures having different resolutions and taken with another camera. This alignment process brings new

perspectives on the possibility to locate pictures of details taken on the walls during a conservation campaign (documentation, conservation condition and/or intervention).

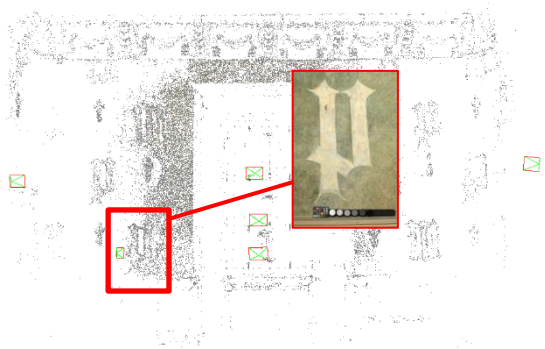


Figure 14: Tie points between the point cloud of room dn south wall and a technical picture of one of the "P" of the same wall © Pamart and Piqué.

Another promising application (SIVT – Spatial Image analysis and Viewing Tool – Wefers, Reich, Tietz, & Boochs, 2016) was tested to contribute to a combined visualization and analysis of images displaying details of Germolles wall paintings. The orthophotograph of room dn south wall (Fig. 3) and other 3D datasets (a 2.5D image, a normal image and a difference image) were generated from the five high dynamic range photographs of the wall. They were all registered and integrated into SIVT as basemaps. Applying the shading functionality onto these datasets, the irregularities of the wall surface were better visualized to aid conservation analysis. Additionally, images displaying details of the wall painting (such as an IR image of the same "P" as on Fig. 14) were semi-automatically registered allowing a combined visualization of the orthophotograph and detailed images (Fig. 15). For this task corresponding information between the orthophotograph and the detailed images need to be taken at hand. As this can be problematic for displaying the spectral images IR, reflected IRr, UV-induced visible fluorescence (UVf), and IR false colour (IRfc) information, matching points of all spectral images taken from the same position with the same device were compiled. Through this approach all spectral images including those with low correspondence could be rectified and registered using one transformation.

Figure 15: Snapshot from the SIVT application tested on Germolles case study data. The rectified and registered IR image of the "P" (red arrow) is displayed on top of the ortho-photograph of room dn south wall ©Wefers and Reich.

All data integrated in SIVT can be analysed using the functionalities "water-filling", "colour mapping", "moveable virtual light source", and "edge filter". Functions such as layer-structure and transparency functionality allow a combined analysis. Especially the "edge filter" e.g. applied on the orthophotograph supports the analysis of the painting technique as stencils of each letter can be easily created for comparison (Fig. 16).

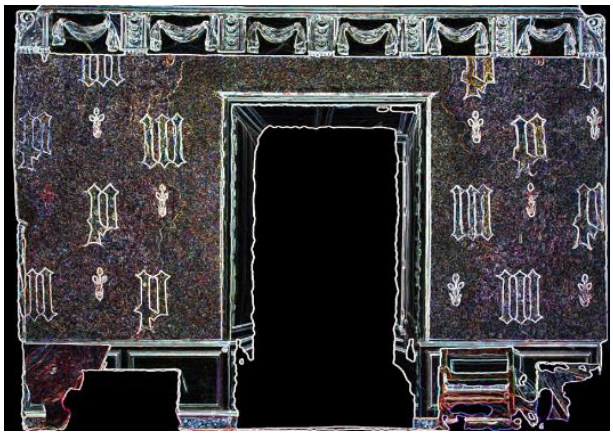


Figure 16: Snapshot from the SIVT application tested on Germolles case study data. Edge filter applied on the registered orthophotograph of room dn south wall ©Wefers and Reich.

5. Discussion

The appropriate combination of imaging and analytical techniques has allowed us to answer some of the questions raised initially, in particular the use of green tin foils and gold leafs mentioned in the medieval records that had not been detected until now. Furthermore the arabesques at the end of letters "P" can now be considered as original embellishment made by the medieval artists.

New questions have come up and would require further investigation such as the "shadow effect" on the edges of the same "P". We made the hypothesis that it might be due to an alteration of the paint layer but LIBS analyses of hatchings in these areas (that look very different from the retouching technique used during the conservation campaign of the 1990s) revealed the presence of silver.

Another important question is the surface rendering of the metallic decorations. The presence of metallic remains with the stratigraphy described in Fig. 8 and found on different parts of the thistles (flowers, leaves and stems) seems to indicate that they were completely gilded over the green tin and further decorated on top with black paint or glaze.

A systematic observation and analysis of both the letters "P" and the metallic remains on the thistles at macro and micro levels may help answering these questions.

6. Conclusion

The vast amount of data and the documentation collected during the Germolles case study using spatial and spectral imaging techniques in combination with

more traditional analytical techniques provided a better understanding of the painting techniques and confirmed their authenticity. It was possible to correlate the information from the medieval records listing the materials purchased for Germolles and the surviving constituents of the wall paintings.

The wall paintings are generally in stable condition even though the IRT campaign showed that the top part of the walls are suffering from delamination processes. In addition the painting surface, particularly the metallic remains, suffer from flaking.

The tools available within the Cost Action COSCH, such as the short term scientific missions, and the task force meetings have been considered essential in bringing to the *Château de Germolles* wall painting conservation professionals and imaging experts that contributed to the study of the paintings and to the collection of documentation data. The multidisciplinary approach and the integration of the information obtained by the various experts were important to reach this level of knowledge. The financial support of DRAC-Burgundy gave us the possibility to invite other experts (French) that joined the multidisciplinary team constituted.

The next challenge for the owners of the *Château de Germolles* is the alignment of these different data. We are just at the beginning of this process but the new management tools currently developed are offering promising perspectives.

Among the imaging techniques tested at Germolles, some appeared particularly adapted to end-users. A COSCH training school finalised the case study to demonstrate the possibilities of photogrammetry, technical photography and H-RTI applied to the documentation of wall paintings.

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