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**Title**

Monitoring the deformation of an historic painting on a wooden panel (16th century panel painting): effect of the frame, the cradle and microclimate variations.

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**Abstract**

Panel paintings are complex structures which have a physical response to variations of relative humidity sometimes leading to damage. Curators and conservators regularly make condition reports to describe the evolution of the artworks state over time. To better understand and describe the causes for deterioration of wooden panels, an experiment was set up in the Fabre Museum, Montpellier (France) in 2016. An hermetic humidity-controlled display case housed the painting whilst measurements of the deformation and strains on both sides of the panel were recorded using a double stereovision device which consisted of four cameras positioned on the walls of a museums exhibition room. The main objectives of this continuous monitoring project were to minimize the deterioration of the panel, to elaborate the best possible conservation treatment, to advise on the design of an auxiliary cradle, and to participate in the current reflections on climatic regulation in museums to reduce energy consumption.

**Key words**

wood, panel painting, cradle, deformation, environment, cultural heritage, monitoring, remedial conservation

**Introduction**

After six years of continued and constant scientific observation, we were finally able to switch-off the machines and are now pleased to present to the public some results of this experiment. Throughout this time, the panel painting *The Holy Trinity crowning the Virgin* (figure 2, 3), (Flemish, beginning of the 16<sup>th</sup> century) was analyzed and treated by a unique collaborative team which consisted of three engineering laboratories from scientific universities, two studios of painting conservators and the staff of the Musée Fabre. In order to explain this scientific research project, the whole experiment took place in one of the exhibition galleries of the Fabre Museum in full view of the visitors (Bousvarou, 2018; Bousvarou, 2020b; Nicolas, 2019). The visitors could appreciate the complex nature of the artworks conservation lead by a unique collaboration of experts (Bousvarou, 2020a).

Through this project we wished to understand and resolve the serious deterioration problems of *The Holy Trinity crowning the Virgin* artwork due to the deformation of the wooden support

leading to the formation of cracks, paint flaking and loss. To this end, the panel was continuously monitored through a controlled microclimate change and also through changes of its physical condition. The monitoring before, during and after conservation treatments aimed to demonstrate the advantages of this procedure for future conservation decision-making (Dupré, 2017; Jullien, 2020; Jullien, 2021). Thus, the painting was monitored during several stages: in its initial poor state of conservation, after the removal of its old frame, after the removal of the cradle and the remedial conservation of the wooden support and finally after the restoration of the paint layer. During each of these stages, the relative humidity (RH) was programmed as far as possible identical cycles rising and diminishing in increments of about 10% RH between 51 and 65% RH. The mechanical behavior of the panel was observed during these RH cycles at a constant temperature. The showcase was hermetic with controlled relative humidity and glazed on both sides.

After acquiring a set of data in order to understand the hygro-mechanical behavior of the panel, conservators and researchers created a new cradle, serving as an auxiliary conservation support that improved conservation conditions, avoiding further cracking and loss of paint. The new cradle was also designed to enable the panel to tolerate a wider range of ambient relative humidity conditions (figure 4).

### **Identification of the artwork**

Title: *The Holy Trinity crowning the Virgin*,

Date: beginning of the 16th century, Flemish

Inventory number: D61.1.379

Technique: oil on wood

Unframed dimensions: 113,7 x 97,8 x 0,48 cm

Weight: 32 kg panel with the cradle and frame, 15 kg panel with the cradle, 11 kg panel without the cradle.

### **Historical background**

The attribution of this painting is complex but it seems to have been created at the beginning of the 16<sup>th</sup> century by a Flemish painter, close to artists from Bruges such as Gérard David, Adriaen Isenbrant or Ambrosius Benson. The theme was identified as the Coronation of the Virgin by the Holy Trinity although the holy spirits' figure on the left is missing and two of the angels' heads are cut off, proving the existence of a larger initial composition.

This panel is related to three other versions of the similar composition and style: of which one was found in the Church of Santa Maria, Portugalete near Bilbao, Spain, An Immaculate conception in a similar style was found at the national museum in Warsaw, Poland and a Virgin Mary was located at the museum of Troyes, Troyes, France.

### **Description of the condition before treatment**

The original panel support consists of four vertical oak planks, three cut radially and one tangentially. The boards were glued together with three butt-joints, but had originally been attached by dowels. The panel was reinforced by a complex auxiliary fixed fir cradle which consisted of seven crossbars and six vertical bars, divided in six pieces for the four central ones. The cradle was glued and nailed onto the back of the planks and the whole back of the painting was coated with a thick brown paint layer which, after testing, appears to be very rigid and not very permeable. The panel was presented in a softwood frame, 135 mm wide and 40 mm thick on average. Height rigid steel plates held the panel in its frame (figure 3).

This painted panel has exhibited mechanical problems for many years. In 1963, the last conservation report suggested a drastic treatment consisting of an additional thinning of the panel and the transfer of the paint layer onto canvas (Claparède, 1963). The deterioration of

the paint and panel could be observed through the fifteen large vertical cracks on the painted side which mostly affected the entire thickness of the panel. In 1998 it was necessary to apply facing papers to prevent the cracks in the paint layer from extending further. The concave shape of the panel had a deflection of 4 and 16 mm (at 55 %RH) respectively (figure 6.a) at the bottom and top edges, with tenting and flaking of the paint layer were observed, caused by the instability of the wooden support.

### **Methods of study and sampling**

Before being subjected to the experimental procedure the paint layer was examined and consolidated. At each step or change it was re-examined and treated if necessary to prevent losses.

The different constituent materials of the artwork were identified and characterized. Specialists from the laboratory of research for historical monuments identified the wood of the panel as oak, and that of the auxiliary cradle as *Abies spp* (fir tree). The chemical identification of some pigments (green, red, yellow, those of the ground layer) and the stratigraphy of the paint layers, and also the chemical identification of the brown paint layer on the back of the panel were conducted by researchers from the Mediterranean institute of biodiversity and ecology.

Several series of studies were carried out on the panel inside and outside the showcase. The shape, its' variations (relative curvature) and the strains on the surfaces of the panel were measured on both sides of the panel by a non-contact optical method (Dupré, 2020). To measure 3D displacements, a stereo-images acquisition has been used coupled with a mark tracking technique or digital image correlation method for the images analysis. The choice of the image analysis depends to the contrast of the surface. In one hand, the mark tracking technique consist in detecting and following some dots (black or white) on the surface during the loading. In another hand, the correlation methods need a texture on the surface (natural in our case, i.e. the painting) to follow several small areas by a local matching between two images of different mechanical states. In this case, the natural contrast is not sufficient on the back face but also on the front face, then small round marks (Japanese paper reversibly glued with a weak adhesive) have been placed on the two faces and the mark tracking technique has been used. Images of the panel are taken every 30 minutes and recorded on computer. Simultaneously, the variations in the relative humidity in the showcase and the weight of the structure were also measured and recorded to evaluate the absorption and the loss of moisture by the artwork. These measurements were carried out on the panel in different configurations in order to characterize the response of the different structures to hygro-thermal variations: with the original cradle and the frame, on the panel with the original cradle, and on the panel alone, after the cradle had been removed by the conservators in their studio.

### **Diagnosis:**

The scientific study confirmed that the old auxiliary wooden cradle restrained the natural movements of the panel because it was fixed. Variations of humidity applied to a constrained wood induce locked-in strains (Mazzanti, 2010). It was necessary to remove this cradle in order to limit the damage to the panel, and therefore to the artwork as a whole. It was replaced with a self-tensioning spring system, designed to be less restrictive to the natural movement of the panel (Ciatti, 2016; Marcon 2012, 2015). This new system would enable the panel to tolerate a wider range of ambient humidity conditions in the museum.

### **Remedial conservation**

The treatment consisted of removing all previous additions. The vertical and horizontal bars of the cradle, glued and/or nailed on the back side were removed. Old glue residues were eliminated. The four planks were correctly reassembled and the lost dowels were replaced. All

these treatments were done by the conservators from “Atelier Tournillon”. The data gathered through the different measurements taken during the experiment was analyzed by the team of Italian engineers and the French wood conservator who collaborated to design and manufacture a new cradle and a novel way of fixing it to the original boards. Observations made since the addition of this newly designed auxiliary cradle indicate that it has reduced the rate of damage to the paint layer, these observations are ongoing.

In addition to the work on the panel support, the paint layer was cleaned and the old repaints were completely removed before the restoration of the losses was carried out.

## **Experimental results**

### *Mechanical effect of the frame and of the cradle on the panel*

The panel stabilized at 65% RH showed a strong concave shape with a 15 millimeters maximum deflection (Figure 6a). While the removal of the frame had almost no effect on the shape (slight twist of +/-1mm) (Figure 5), the removal of the cradle reduced the curvature to 3 mm (Figure 6g).

### *Effect of moisture variation on the panel with the original cradle*

An increase and decrease of humidity have been carried out at each state of the panel. When the panel with the cradle underwent an increase in humidity from 50% to 65% RH, a relative convex curvature was observed (Figure 6f), with a maximum deflection of about 2 mm instead of 1.5 mm for the panel with the frame (Figure 6b). Moreover, the horizontal swelling of the panel reached a maximum of 0.1% in strain in some areas. We attribute the convex curvature variation to the effect of the horizontal crosspieces which were oriented in the longitudinal direction of the wood. Because they were much more rigid than the wooden panel itself, oriented in the direction of the wood grain, they limited the lateral swelling, especially of the reverse side. A decrease of humidity (Figure 6d) had the inverse effect increasing the concave curvature by 2 mm and a shrinkage of about 0.1% in the horizontal direction.

### *Effect of moisture variation on the panel, without the original cradle, after conservation*

When the panel without the cradle experienced a desorption from 64% to 56% RH, the curvature of the panel varied by about 4 mm (Figure 6h), which is twice the effect observed with the cradle (Figure 6d). As the initial curvature is small, this humidity variation allows to pass from a slight negative curvature to a positive one. The horizontal strains were in the same order as in the case of the panel with the original cradle, about -0.1%, but were less homogeneous. Indeed, each beams are not reinforced by the cradle and local strain can now occur due to local properties or defects of the beams.

## **Consequences of the supports' remedial treatment**

The results obtained from this scientific project showed that the presence of the frame had very little influence on the shape of the panel with its original cradle, whereas the removal of the cradle modified its curvature by 3 mm. As the relative humidity increased, a slight convex curvature was observed when the panel is with its original cradle; and a higher concave curvature was observed, when the panel is without the cradle. Horizontal swelling was observed in both cases. As expected, it is larger in the case of the panel without cradle. The stability of the panel in terms of curvature or strain was reached in four weeks, and thus independently of its state (with or without cradle). The behavior of the panel with its new cradle is still in analysis.

## **Conclusion**

This innovative experiment made it possible to measure the deformations and strains of this 16th-century painting on a wooden panel support, with and without its frame, and with and

without the original cradle during relative humidity variations. The effect of moisture variation on the panel with the new cradle is under progress and will be the object of further communication.

The microclimate inside a display case designed specifically for this study was monitored and the response of the artwork to variations in humidity was measured. These measurements were carried out continuously, in the museum exhibition space, in full view of the public. Advances in imaging equipment and data processing suggest that continuous monitoring of artworks within museums is indeed possible. The further development of this type of instrumentation within museums would allow a wider range of measurements to be obtained, on different types of panels, different structures, different woods, etc. The information thus gained would make it possible to regulate the climate in museums in an informed way, limiting the risk of the degradation of artwork and it would contribute to current reflections concerning the climatic regulation of the museums in relation to their energy consumption, in order to meet the current requirements of energy reduction.

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## Figures

Figure 1: Exhibition room N° 3- Rubens room, hermetic show case, 3D cameras, *The Holy Trinity crowning the Virgin*, 16<sup>th</sup> century, oil on wood, Anonymous, Montpellier, Musée Fabre, front side September 2019. © CNRS

Figure 2: *The Holy Trinity crowning the Virgin*, 16<sup>th</sup> century, oil on wood, Anonymous, Montpellier, Musée Fabre, front side after restauration, September 2021. ©Danièle Amoroso.

Figure 3: *The Holy Trinity crowning the Virgin*, 16<sup>th</sup> century, oil on wood, Anonymous, Montpellier, Musée Fabre, back side, before remedial conservation, September 2016, room N° 10- salle du jeu de paume. ©Musée Fabre.

Figure 4: Mounting in the hermetic showcase in room N° 3, Musée Fabre, Montpellier, September 2019.

Figure 5: Colored relief deformation of the panels surface (in mm) showing shape deformations of the surface, October 2016. © PPrime Institute

Figure 6: Effect of a 10% variation of relative humidity on the shape of the panel. © PPrime Institute

## Contribution by each author

D. Jullien initiated and participated in the scientific study and discussions, coordinated the different teams, participated in the analysis of the results and in the writing of the article

M. Bousvarou initiated and participated in the scientific study and discussions, obtained funding, coordinated the different teams, participated in writing the article

P. Stepanoff initiated and participated in the scientific study and discussions, obtained funding, supervised the museum teams, participated in writing the article

J.C. Dupré initiated and participated in the scientific study and discussions, conducted the image correlation measurements, participated in the analysis of the results and in the writing of the article

C. Gauvin participated in the scientific study and discussions, participated in the analysis of the results and in the writing of the article

L. Riparbelli participated in the scientific study and discussions, conducted the local strain measurements, participated in the analysis of the results and in the writing of the article





Fig1



Fig 2

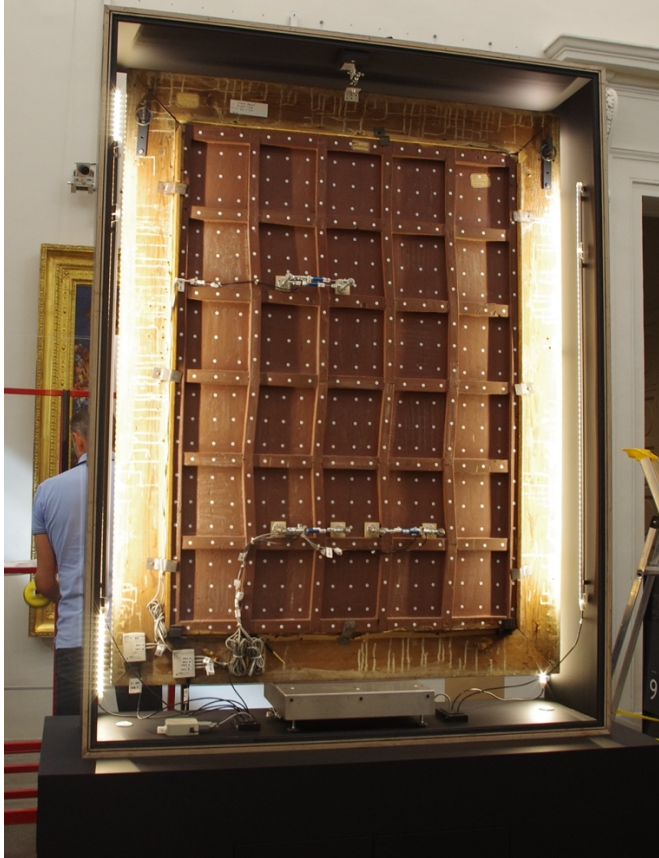


Fig 3

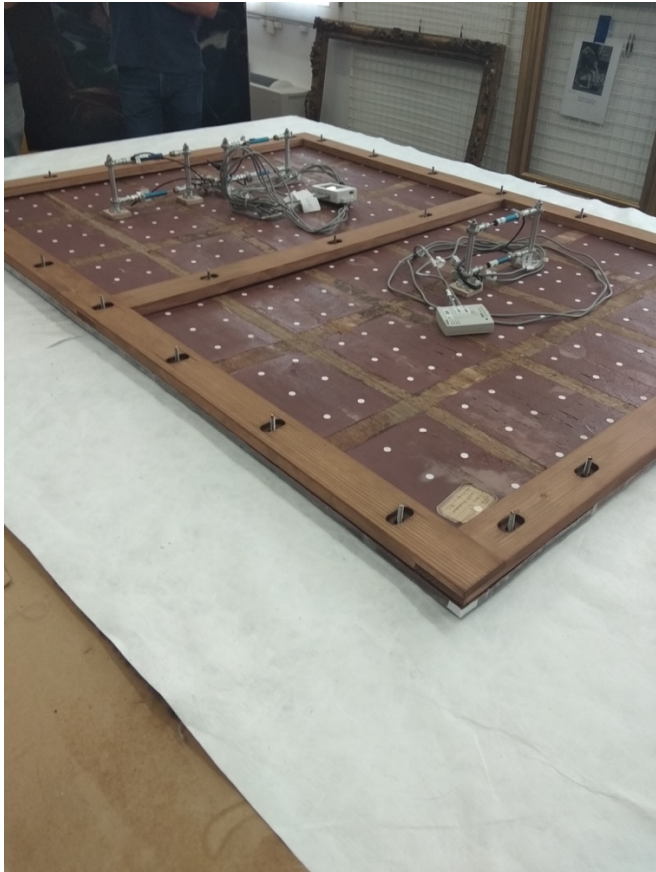


Fig 4

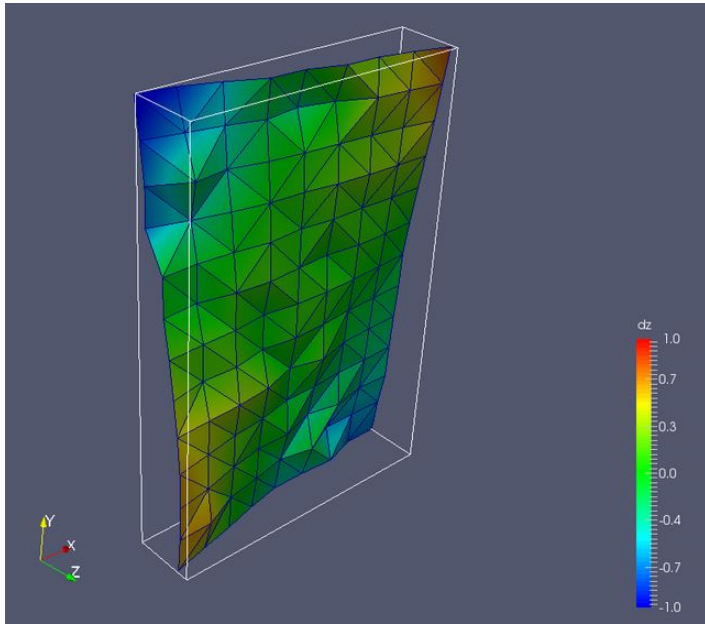


Fig 5

	Relief, initial state <i>relief map (amplified by 10 in Z direction)</i>	Relief after relative humidity variations <i>relief map and shape deformation</i>
Panel with the frame and the original cradle	<p>(a) RH=52%</p>	<p>(b) Effect of an absorption from 52 to 63% RH</p>
Panel with the original cradle	<p>(c) RH=65%</p>	<p>(d) Effect of a desorption from 65 to 51% RH</p>
Panel with the original cradle	<p>(e) RH=54%</p>	<p>(f) Effect of an absorption from 54 to 64% RH</p>
Panel alone	<p>(g) RH=64%</p>	<p>(h) Effect of a desorption from 64 to 56% RH</p>

Fig 6