Journal of Cultural Heritage 15 (2014) 391–402

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Original article

Locating contact areas and estimating contact forces between the "Mona Lisa" wooden panel and its frame

Giacomo Goli[a,*], Paolo Dionisi-Vici[b], Luca Uzielli[a]

[a] GESAAF, University of Florence, Via S. Bonaventura, 13, 50145 Firenze, Italy
[b] Department of Scientific Research, The Metropolitan Museum of Art, Fifth Avenue, 1000, 10028 New York, USA

ARTICLE INFO

Article history:
Received 14 May 2013
Accepted 26 August 2013
Available online 23 September 2013

Keywords:
Mona Lisa
Painted panels
Mechanical constraints
Contact pressure
Contact forces

ABSTRACT

Since 2004 an international research group of Wood Technologists has been given by the Louvre Museum the task of analysing the hygro-mechanical state of the Poplar (*Populus alba* L.) panel on which Leonardo da Vinci painted his "Mona Lisa", namely verifying the appropriateness of the thermo-hygrometric conditions in its exhibiting showcase, where the microclimate is actively controlled, and assessing the potential consequences of any hypothetical fluctuation. In order to acquire data about the mechanical behaviour of the panel, and to feed and calibrate appropriate simulation models, the team has not only set up a continuous monitoring by means of automatic equipment, but has also performed manual measurements on the occasion of the annual openings of the showcase where the masterpiece is conserved and exhibited. This paper reports about techniques used for estimating the forces acting between the wooden panel and its frame (the *châssis-cadre*), and their location, such data being of primary importance for evaluating the panel's internal stresses. The contact forces have been calculated on the basis of the local contact pressures, imprinted on a pressure-sensitive foil as a range of saturation values of the colour developed in the contact areas. The forces calculated as above have also been compared with the contact forces between the panel's back face and the crossbeams pressing it against the *châssis-cadre*, which have been measured by means of a load cell. As could be expected, the results from so different techniques do not strictly coincide; however the agreement is fairly good.

1. Research aims

The research presented in this paper aims to provide realistic information about magnitude and location of the forces acting between the wooden panel on which Leonardo da Vinci's "Mona Lisa" is painted, its crossbeams and its frame. Such data are of primary importance for analysing the mechanical situation of the panel and calibrating an appropriate simulation model of deformations and stresses produced by the environmental fluctuations, in order to evaluate and optimize any measure, which could improve its conservation.

2. Introduction

2.1. A short description of the Mona Lisa panel's structure and geometry

Approximately five centuries ago, Leonardo da Vinci painted his world-known Mona Lisa on a panel made of a one-piece tangential board of Poplar (*Populus alba* L.) ~ 79 × 53 cm, ~ 13 mm thick, which arrived at our age almost unaltered except minor interventions (for further details see [1]).

Only the front face is painted, whereas the panel's original wood surface shows up on the back face.

The panel features a complex double curvature, developed throughout the centuries under the effect of the mechanical constraints and the environmental variations to which it has been exposed, and also influenced by the ~ 11 cm-long crack, running parallel to the grain through the panel's whole thickness, starting from the upper edge, and reaching the lady's forehead, above her right eye.

The panel is inserted in a frame (*châssis-cadre*) made of Oak wood, and is slightly forced against the 7.5 mm wide rim of the frame by means of four Sycamore (*Acer pseudoplatanus* L.) wood crossbeams, which are fixed by screws to the *châssis-cadre* and hold the panel flatter than it would be if unconstrained. Due to the longitudinal curvature of the panel usually only two of the crossbeams (the top and the bottom one) press against it, occasionally a third one can be in contact with the panel.

Panel and *châssis-cadre* are inserted in a larger wooden gilded frame, the only visible by the public.

An exploded drawing of the assembly (painted panel, *châssis-cadre*, crossbeams, frame), made in 2004 by the restorers in charge

* Corresponding author. Tel.: +393290656674; fax: +39055319179.
E-mail addresses: giacomo.goli@unifi.it (G. Goli), paolo.dionisivici@metmuseum.org (P. Dionisi-Vici), luca.uzielli@unifi.it (L. Uzielli).

1296-2074/$ – see front matter
http://dx.doi.org/10.1016/j.culher.2013.08.003

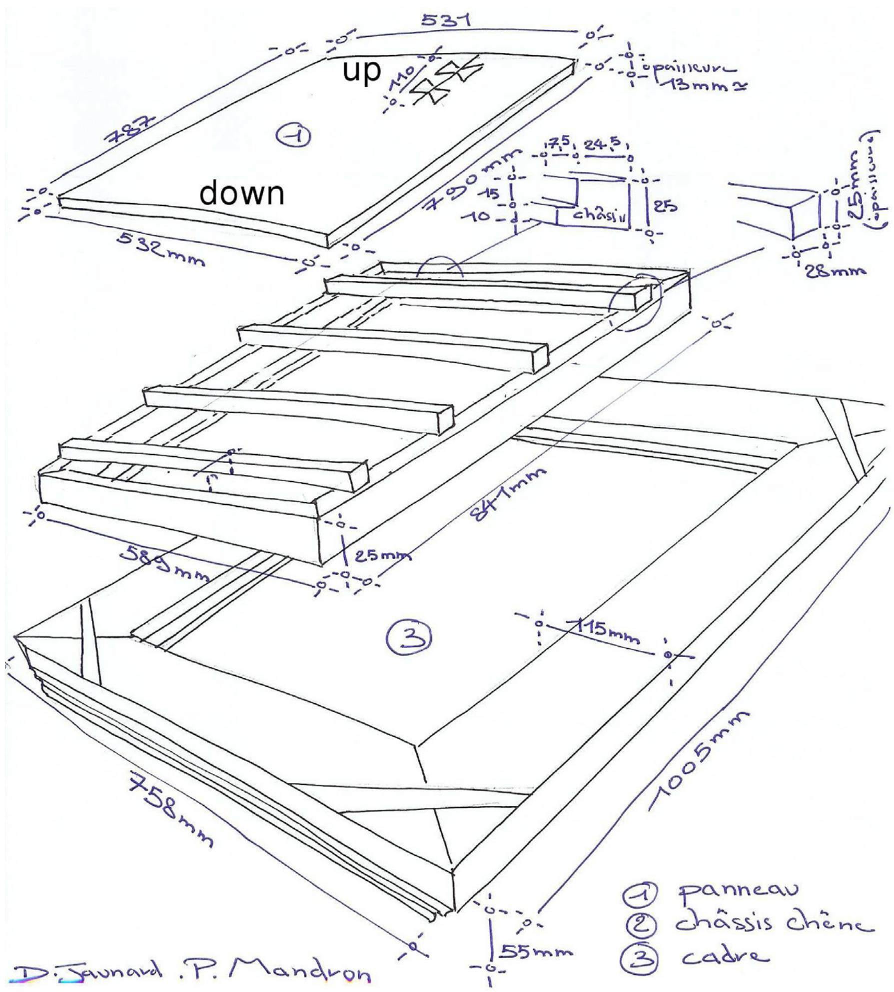

Fig. 1. An exploded drawing of the assembly: painted panel (1), *châssis-cadre* with crossbeams (2), gilded frame (3). The fissure is in the upper part of the panel. *Drawing by D. Jaunard and P. Mandron, 2004 modified.*

of the wooden support, is shown on Fig. 1; due to successive interventions, the cross-sections of the present crossbeams are slightly different from those shown in the drawing.

The panel is maintained into a climate-controlled display case, which gets opened yearly to check the conditions of the painting.

2.2. The main studies carried out to analyze the mechanical situation of the panel

Since 2004 an international team of scientists has been given by the Louvre Museum the task of analysing the hygro-mechanical state of the Poplar panel. The questions asked by the Museum's Curators were basically to evaluate the climatic specifications for the display case, assess the risk of crack propagation, suggest possible modifications to the framing system, and suggest any measure, which could improve the conservation conditions or the annual check-up procedure. An in-depth study of the panel, including its wooden support and the system of cracks in the paint layers, is presented in [2] and [3]. An analysis of the risk of propagation of the fissure laying in the upper part of the panel is reported in [4].

In order to have a better understanding of the physical and mechanical behaviour of the panel, specific simulation models were developed and validated against measurements and monitoring of its actual behaviour.

The measurements include:

- the forces exerted by the upper crossbeam on the upper part of the panel, being automatically measured at 20 minutes intervals by a monitoring equipment purposely developed and adapted (see [5]);
- the forces exerted on the contact points between the panel and the crossbeams, manually measured every year on the occasion of the annual opening of the showcase;
- three transversal profiles of the panel, measured manually every year by means of a precision comparator on few selected points;
- the shape of the panel's convexity, also measured yearly by means of optical techniques: in particular the 3D surface inside and outside its frame was reconstructed by the means of stereo imaging and light projection systems (see [6] and [7]).

A FEM model based on heat & mass transfer + hygro-mechanical behaviour was also implemented, and calibrated by means of the collected data (see [8] and [9]).

Work is still on going, and further data keep being collected, both with the same techniques and with new or improved ones.

2.3. The objectives of this paper

If the panel's shape were perfectly cylindrical, it would touch the *châssis-cadre* only in the central parts of its upper and lower rims. On the contrary, the complex shape of the panel makes the contact zones quite irregular and difficult to be identified.