Mona Lisa's digital twin: identifying the mechanical properties of the panel combining experimental data and advanced finite-element modelling

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Poster C19

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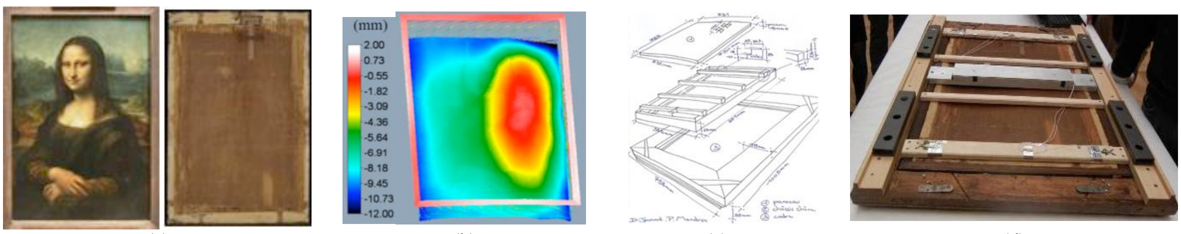
Background and objectives

Since 2004, the "Mona Lisa" painting by Leonardo da Vinci has been studied by an international research group of wood scientists and several experimental campaigns have been carried out to understand its characteristics and provide indications for its conservation. Based on the collected data, a numerical model of the wooden panel has been developed to simulate the mechanical interaction with the framing system. The main objective of this modelling work, described in this paper, is to extract as much information as possible from the experimental tests carried out and, thus, reach a sufficient level of scientific knowledge of the mechanical properties of the panel to build a predictive model. It will be used to predict the effect of modified boundary conditions and as a tool of preventive conservation.

Material and methods

The artwork is painted on one face of a flat-sawn poplar (*Populus alba* L.) panel (Fig.1a) doubly curved toward the front side (Fig 1b) and pressed on a chassis rebate by the action of crossbars screwed on the chassis (Fig.1c) ; the external frame contributes to the stiffness of the whole through metal legs (Fig 1d). An ancient crack runs through the wood from the left upper edge of the panel down to the top of the Lady's face.



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

Fig. 1 : Mona Lisa panel painting (a) Painted face and back face; (b) Shape of the panel obtained by fringe pattern profilometry; (c) The panel and its framing system, chassis with crossbars and gilded frame; (d) View of the monitoring systems and the complete assembly

The observations methods, partly described in early reports (Mohen et al 2006, Gril et al 2015), include: (i) optical measurements of the form (Fig. 1b, Brémand et al 2011); (ii) scientific and technological analysis of the wooden support; (iii) continuous monitoring of the forces applied by the crossbars on the back of the panel, and of the central deflections relative to an additional metallic crossbar equipped with transducers (Fig. 1d); (iv) determination of contact areas between the front of the painting and the chassis rebate using pressure-sensitive sheets (Goli et al. 2013).

Based on these results, a finite-elements digital twin was built according to the following steps:

1. Acquisition of the object's shape through optical methodologies and reconstruction of a three-dimensional geometrical model (Fig. 2).
2. Enrichment of this geometry with additional entities defining the boundary conditions (positions and contact areas detected by pressure test on the front side, position of the load cells attached to the crossbars on the back side), the crack on the upper side of the panel. The position of the pith with respect to the panel was also taken into consideration, for the definition of cylindrical coordinates to define orthotropic characteristics.
3. Acquisition and treatment of experimental measurements related to load cells and transducers that continuously record the panel status, in addition to the experimental data acquired by the research group in various studies over the years.
4. Construction of the numerical model using the finite-element method (FEM), evaluation of the discretization, boundary conditions and contact mechanics modelling (Fig. 3).
5. Iterative optimization procedure, through Nelder-Mead (downhill simplex) scheme, for the calibration of the mechanical characteristics of the model based on the experimental response and the control of results consistency.

All the analyses are performed with the FEM solver Code_Aster in the Salome-Meca ecosystem.

Results and discussion

In summary, starting from the shape detected by the optical measurement and through an optimization process that determined the elasticity properties of the wood, a non-linear model that accounts for the complex unilateral contacts detected during specific experimental campaigns, and for the orthotropic anatomy of the panel, has been developed.

This calibrated model (digital twin) is then used to understand the stress and deformation states related to changes in the boundary conditions, to correlate the forces (measured by the load cells the panel is equipped with, or hypothesized on a simulation level) and the stress states to which the panel is subjected.

The digital twin is also used to assess the effect of inserting a layer of viscoelastic polymer foam for protective purposes between the painting and the chassis (Fig. 4).

Finally, a methodology for comparing two different mechanical configurations is proposed through the numerical computation of point-by-point stress and deformation differences, in order to provide information to the conservators, such as optimizing setting and constrains.

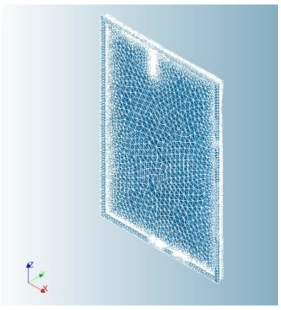


Fig. 2 : Quadratic Mesh of the assembly panel - chassis with mesh refinement on crack and contact areas: 194714 tetrahedrons

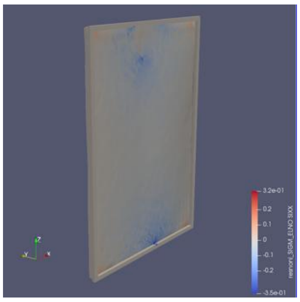


Fig. 3 : Stress generated by wood-wood non-linear contact with friction between the panel and the chassis

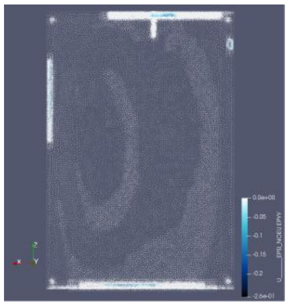


Fig. 4 : Simulation of the deformations of a viscoelastic foam between two wood interfaces with non-linear contacts

Acknowlegments

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