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The Mona Lisa Project: an update on the progress of measurement, monitoring, modelisation and simulation

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1 Introduction

Since 2004 an international research group of wood technologists has been given by the Louvre museum the task of analysing the mechanical situation of the wooden panel on which Leonardo da Vinci painted his “Mona Lisa” (Fig. 1a), possibly between 1503 and 1506. The general purpose of such study was to evaluate the influences that could possibly derive from environmental fluctuations in the showcase where the painting is exhibited as well as outside the showcase for occasional checks, and develop measurements and models to improve its conservation conditions. To acquire data on the mechanical behaviour of the panel, and to feed and calibrate appropriate simulation models, the team has set up a continuous monitoring by means of automatic equipment (Fig. 1c). The “Mona Lisa” is painted on a poplar panel (*Populus alba* L.) ~790 x 530 mm, ~13 mm thick, which is inserted in an oak frame (called *châssis-cadre*), and is slightly forced against it by means of four crossbars, holding it flatter than it would be if unconstrained. In turn the *châssis-cadre* is inserted in a wooden gilded frame (Fig. 1c). In 2006 a book was published [1] offering a wealth of scientific studies and researches concerning the “Mona Lisa”. Also in 2006 a report about finite elements model was presented [2] and in 2011 a scientific article on the modelisation was published [3].

2 Development of measurement and monitoring techniques

Initially the panel shape has been determined through manual shape measurement by means of a mechanical comparator and a reference bar. This technique is slow, and allows surveying only a limited number of points. Then optical techniques shadow moiré and fringe pattern profilometry –FPP– have been used to measure [4], on both front and rear faces, relief (Fig. 1b) and out of plane deformation field. To obtain the 3D surface displacements in some points of the panel stereo-optical tracking [4] has been used (following image contrast and *craquelure* pattern). Accurate and reliable data about the forces exerted between panel and crossbars are obtained thanks to self-designed equipment including four sub-miniature load cells incorporated into the crossbar thickness (next to the panel's four corners). The deflection variations along time are measured by means of three deformation transducers, located inside a thin reference aluminium profiled crossbar (carrying data-loggers, transducers and instrumentation), fixed on the *châssis-cadre* and providing records of both (a) transversal deflection at the panel centre with reference to the lateral edges, and (b) longitudinal deflection with reference to the *châssis-cadre*, see Fig. 1c. The contact forces between panel and *châssis-cadre* have been localized and estimated on the basis of local contact pressures through a pressure-sensitive foil as described in [5].

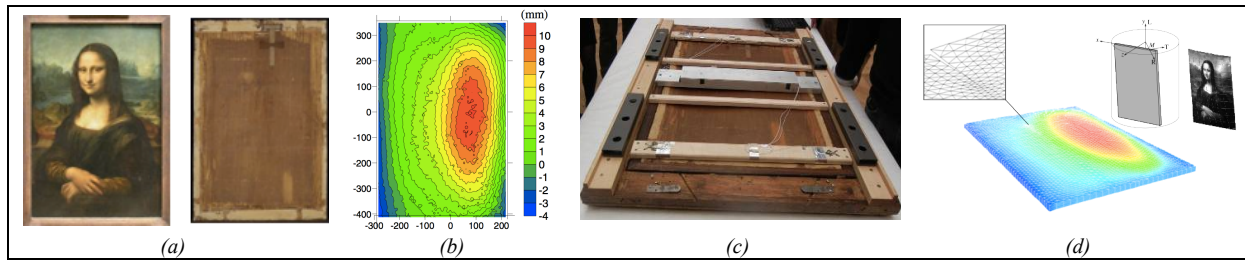


Fig. 1 (a) The painted face and the back face; (b) Shape of the panel obtained by FPP; (c) Completed assembly of the Mona Lisa: panel, crossbars, *châssis-cadre*, gilded frame and the monitoring systems; (d) Mona Lisa numerical finite elements model.

3 Modelisation and simulation strategies

The results from the above mentioned measurements are being processed to be included into a 3D numerical finite elements model to simulate the panel behaviour under environmental fluctuations, see Fig. 1d. We focus herein on a numerical strategy, taking into account the panel specificities, including its shape and thickness, its sawing pattern (the elastic behaviour is orthotropic, roughly with a cylindrical symmetry), the boundary conditions imposed by the *châssis-cadre* (contact area and forces [5]), the crack at the upper edge of the panel and the remedial wooden butterfly, the unpainted back face of the panel responsible for the out-of-plane movements caused by moisture gradients across the panel's thickness and resulting moisture-induced expansion during relative humidity fluctuations. Such elements -mostly based on measurements- are essential to propose a model that can simulate with accuracy the Mona Lisa behaviour and are exposed in detail in [3] and [6]. The aim of this strategy is to improve Mona Lisa's preventive conservation by virtually testing and predicting, via numerical simulation, if the masterpiece will be safe under various scenarios.

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