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Follow-up of a panel restoration procedure through image correlation and finite element modeling

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ABSTRACT

Residual stress estimation is an important question for structural integrity. Since residual stresses are self-balanced stress fields, a classical way to obtain information on them is to remove a part of the structure, and observe the structure displacement field arising from the stress redistribution. The hole-drilling method is such an approach. In some cases, as for the present one concerning a painted panel of cultural heritage, the hole-drilling method is not suited (a structure with a complex geometry, few tests allowed) but one can take advantage of structural modifications if they are monitored (here, a restoration act). We therefore describe in this article a model updating approach, focusing on the residual stress estimation and not on the material parameter identification.

This study couples an optical non-invasive shape measurement (digital image correlation, using a projected speckle pattern on the painted panel, with luminance compensation) and a numerical approach (3D finite elements) for the model updating. The 3D stereo-correlation is used to measure a partial displacement field between three different states of the structure (at three different times of the restoration act). The numerical part concerns stress evaluation, once the model and the experiments are compared using a geometric mapping and a spatial projection of discrete fields. Using modeling and identification, the simulation is used to obtain the residual stresses in the panel, before and after the restoration.

1. Introduction

Conservation of paintings of cultural heritage on wood panels could gain from using tools of wood science and structural mechanics, to guide decision for curators and restorers. Indeed, the consequences of a restoration act on the future integrity of an artwork can be assessed with virtual (numerical) simulation once a predictive model has been designed. Such numerical simulations in the same context have recently been used for painted panels, for instance in Dureisseix et al. (2006), Chassagne et al. (2006) and Marcon (2009), for musical instruments, Saft and Kaliske (2009) and Leconte et al. (2009), for other wooden structures, Braovac et al. (2007) and Chassagne et al. (2007), for ancient buildings, Mele et al. (2003), Rafiee et al. (2008) and Valluzzi et al. (2002), and even for natural parks (Cavagnero and Revelli, 2009).

Since each artwork is a particular case, it requires an identification step to nurture the model. Objects of cultural heritage are often unique and precious artworks, and few mechanical tests can be conducted to identify the present state of the structure, that cannot be estimated with the evolution it was subjected to, due to the lack of past measurements. The present study mainly deals with a model design, based on finite elements, to couple simulations and experiments during a particular restoration act. The concerned artwork is 'Baptême du Christ', from an anonymous artist, stored in 'Palais du Roure', Avignon, France, Fig. 1(left).

An early restoration act, performed in the 70s but typical of the 19th and beginning of the 20th century, was a french parquetage (or cradle) on the rear side of the painted panel. This cradle consists of eight vertical beech beams, glued on the panel rear side (485 mm $\times$ 405 mm $\times$ 12 mm), and crossed with eight horizontal beech beams, Fig. 1(right). This kind of restoration aims to rigidify the wooden support to avoid excessive movements (mainly bending due to dissymmetry in moisture exchanges on both sides of the panel) that may endangers the pictural layer. The drawback of such a rigidification is the increase in internal stresses with humidity variations of the environment (see Rothe, 1998). Moreover this panel exhibits two cracks; they will not be taken into account herein.

The new restoration act dates back to 2007 and has been followed in this study: the replacement of the horizontal beams of the cradle by new ones made in spruce. The initial horizontal beams were partly glued and partly clamped due to a permanent long-term deformation of the panel that installed itself after the

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Fig. 1. *Baptême du Christ*, Palais du Roure, Avignon, France (left) and its cradle (right).

initial restoration (mainly due to the mechanosorption effect). For the former beams to be replaced, they had to be cut, Fig. 2. This illustrates the presence of internal (or residual) stresses. The restoration has been monitored with image analysis: the shape of a part of the front painted side has been measured (i) before the removing of the former horizontal beams, (ii) after this removing and (iii) after mounting the new horizontal beams. These experimental data has to be used in conjunction with a structural analysis, in order to estimate the residual stresses in the panel, which is one of the goals of this study. Section 2 describes the experimental technique, while Section 3 focuses on the finite element model and its comparison to the measurements. Finally, Section 4 uses these tools for the residual stresses estimation.

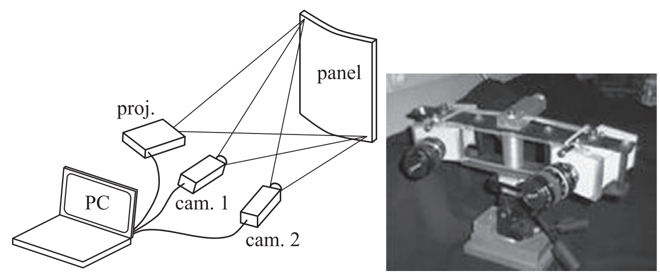

Fig. 3. Principles of the measurement technique (left) and stereo cameras (right).

2. Shape measurement with 3D stereo-correlation

This non-invasive optical technique allows measuring a 3D shape of a part of the surface of a structure. For artworks of cultural heritage, this technique is useful since no contact with the artwork is needed; nevertheless, no continuous measures can be obtained along time, only several ones at particular instants, due to the delay needed to install and calibrate the acquisition chain which is composed (Fig. 3) at least of:

- two stereoscopic cameras,
- a video beam projector,
- a processing unit (computer) to capture and correlate images from the cameras.

With two camera images taken from different points of view, the 3D position of visible and identifiable points (or patches) can be obtained by image correlation. The basic images of the artwork cannot be used due to too much contrast on the pictural layer, between large surfaces of too small contrast (aplats or flat tints). Therefore, a more suited pattern (classically a speckle pattern) should be substituted to the original image of the panel. Since no physical speckle pattern can be marked on the painting, a virtual speckle pattern image is projected onto the painted surface, once the initial painting is virtually rubbed out. To do so, an initial image is taken, is numerically treated to produce a 'negative' image that is back-projected to the panel to compensate the initial picture luminance (this is the so-called 'extinction' of the painting). The virtual speckle pattern is then added to the projection to appear on the panel, Fig. 4. The correlation of the images taken from this virtual speckle pattern by the two cameras allows to derive the 3D position of patches of pixels, as in Maigre and Morestin (2008). This leads to approx. 80,000 3D point locations on a large part of the pictural layer (not up to the border, nevertheless).

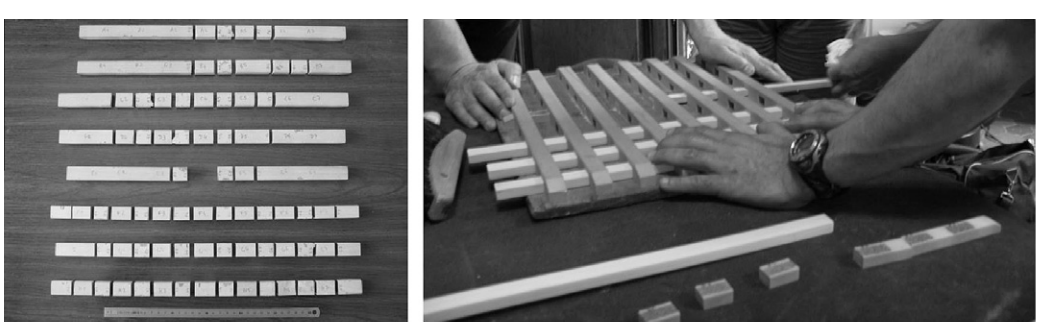

Fig. 2. Former horizontal beams (left), cut to be extracted (central part missing, used for material identification) and replacement of horizontal beams.