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Application of shearography and the percussion method for the structural inspection of wall paintings: a case study of St. Christopher in the Mariakerk, Nisse

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ABSTRACT

Structural delamination in mural paintings is a complex phenomenon and is considered among the most frequent types of damage. In conservation practice, the most common technique to identify structural detachments is the percussion method. Full-field optical techniques based on interferometry, such as shearography, can provide a more scientifically substantiated evaluation of the condition of heterogeneous structures of wall paintings. The empirical nature of the percussion method was observed during the condition assessment of two medieval wall paintings in the Mariakerk, Nisse, the Netherlands. It can be argued that, to allow the formulation of specific treatment needs for structural delamination in wall paintings, accurate defect mapping and characterisation is needed. The application of shearography was believed to provide a holistic representation of the condition of the structure of the wall painting depicting St. Christopher in the Mariakerk. Preliminary comparison of the methods involved revealed a degree of matching between results obtained. Discrepancies, i.e. areas deemed extremely vulnerable during percussion testing that were not detected by shearography, are debatably caused by the misinterpretation of the acoustic response during percussion testing or the inability of shearography to detect in depth structural defects. Further research regarding shearography should focus on providing more information about the depth of structurally delaminated areas within the heterogeneous layered structure of wall paintings.

Keywords: shearography, percussion method, wall paintings, non-destructive testing, detachments, delamination, conservation and restoration, structural inspection.

1 INTRODUCTION

Delamination, detachments or structural defects are terms implemented to indicate the presence of a structural decaying process that is gradually causing the loss of adhesion and cohesion of heterogeneous layers in the structure of wall paintings, resulting in the partial separation between plaster layers, pictorial layers and their support[1,2]. In conservation practice, the identification of causes, location and progress of detachments is commonly based on subjective and empirical methods, such as the percussion approach[3-5]. The latter entails the gentle tapping of the painted surface with a finger or a suitable light weight instrument and the subsequent interpretation of the generated acoustic response[6,7]. Conflicting results can often emerge with this approach: this was observed during the condition assessment of the structure of two medieval wall paintings in the Mariakerk, Nisse, the Netherlands. Percussion tests were executed in different ways by conservators with different levels of experience, leading to substantially incongruent results. These measurements indicated the need to obtain more scientifically substantiated results about the presence of delaminated areas in wall paintings. As a result, the application of shearography coupled with thermography was tested with the aim of gaining a holistic depiction of the structural condition of the wall painting depicting St. Christopher in Maria Church.

The detection of structural detachments in wall paintings is regarded as an essential phase in the diagnostic investigation preceding a conservation treatment. The imprecise identification of structural detachments can lead to the inadequate injections of grouting materials which, in the long term, can generate structural inconsistencies. It can be argued that, in order to devise and perform effective remedial treatments, such as injection grouting, accurate defect mapping and characterisation of delamination is needed. Ideally, this step should be executed as part of a monitoring investigation, in which the structural condition of the wall painting and the progress of delamination are evaluated. Consecutively, specific treatment needs can be determined. Therefore, the use of non-destructive techniques, such as shearography, is explored in this paper because it is expected to provide a significant contribution to the accurate identification of structural delamination in wall paintings.

1.1 Case-study: Maria Church and St. Christopher

Maria Church is a protestant church, built during the first half of the fifteenth century. The church, a brick building constructed in the shape of a cross, has been registered as a national monument since 1967[8]. The Mariakerk is located in the picturesque village of Nisse, in Zeeland, part of the municipality of Borsele. A cycle of wall paintings decorating the interior of Maria Church was discovered during a restoration campaign in the 1920s. The wall paintings were presumably covered with layers of whitewash during the Protestant Reformation in the second half of the sixteenth century, and depict a total of four religious themes, including St. Christopher, represented on the north wall of the church (Figure 2). St. Christopher, the patron saint of travellers and pilgrims, is portrayed in Maria Church carrying the infant Jesus on his shoulder while he crosses a river. The mural measures around 6 m in height and 4 m in width and dates from approximately the second half of the 15th century. The general condition of the wall painting of St. Christopher is considered poor with several areas of flaking paint and degraded plaster affecting the nowadays hardly legible scene (Figure 2). Fluctuations of the relative humidity and temperature, the previous leaking of water from the roof, the presence of bat droppings and the application of organic materials during past restoration campaigns are believed to have caused structural defects in the layered structure of the wall painting of St. Christopher. Consequently, the latter was deemed suitable for the purpose of this research, due to concerns regarding its structural stability, the lack of previous research and diagnostic investigation and the rather easily accessible position of the mural.

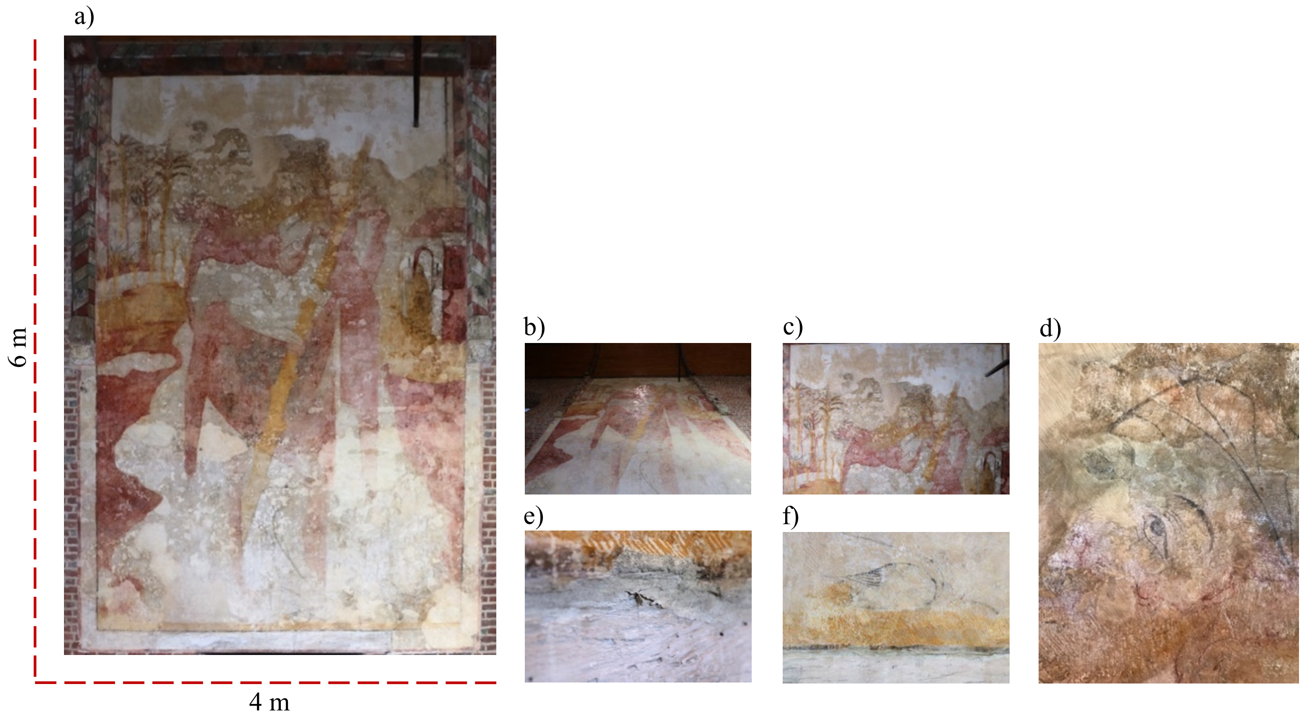

Figure 1. Wall painting depicting St. Christopher (a*), with close-up details and degradation phenomena: (b) widespread surface gloss, (c) large areas of loss and retouching, (d) extensive retouching and visible surface gloss, (e*) visible delamination, (f*) fading of painted system and extensive retouching. *Photo credit: Jorien Duivenvoorden

2 PERCUSSION METHODS

The adhesion between the plaster layers composing the structure of the wall painting depicting St. Christopher was verified with the percussion method. Different ways of executing this approach are described in the literature[6,7] some mentioning the traversing of the surface with a pencil or a stick, rather than its tapping. The acoustic response generated needs to be interpreted: usually a hollow sound is attributed to the presence of detachments, however, differences in intensity can be specific to a large (low-pitched) or small delamination (high-pitched).

Whilst this method appears to be an extremely common approach for the identification of detachments in wall paintings, only a few publications describe it in a meaningful way[3,7,9] with many others simply mentioning it[4, 10- 13] and potentially, believing it to refer to a standardized method. Ultimately, the quality of the interpretations and the results directly corresponds to the experience of the conservator.

In the Mariakerk, two percussion methods were adopted to identify delaminates areas on the wall painting of St. Christopher, with the aim of evaluating differences and similarities in the results obtained. The first method involved the gentle tapping with a nail whilst the second one entailed the rolling of an acoustically isolated plastic ball on a flexible mount[7] (Figure 2). Both methods exerted a degree of mechanical pressure on the surface and, therefore, areas with visible flaking paint and friable plaster had to be avoided. The performance of these tests extensively instantiated that the suitability of any percussion method relies on the condition of the pictorial layer of the wall painting and that some degree of unintentional damage can be generated. Ultimately, it can be stated that whilst results obtained by this technique do not inform about the rate of deterioration or the extension of the detachments, its use, combined with thorough observations of the surface, can provide a holistic picture of the general condition of the mural in question[7].

Figure 2. Percussion testing in Maria Church, wall painting depicting St. Christopher.

3 SHEAROGRAPHY INSTRUMENT

In this project, shearography was used for the structural inspection of the wall painting to complement the two aforementioned percussion methods. Shearography (speckle pattern shearing interferometry) is an optical full-field speckle interferometry technique with high sensitivity to the surface displacement gradient when the object is deformed. Shearography theory and the principle of its operation are well described in literature[14- 17]. For this inspection, one channel of the previously developed and reported 3D shape shearography instrument[18,19] was used (Figure 3) together with thermal loading (heating) of the painting. The choice of one shearing camera oriented perpendicular to the painting with the main sensitivity to the out-of-plane surface displacement gradient was made based on a preliminary inspection of a representative reconstruction with intended internal delamination.

The wall painting was illuminated with the Torus 532 laser (optical power of 500 mW, wavelength of 532 nm by Laser Quantum) through expansion optics, including a diffuser ED1-S20-MD by Thorlabs (Figure 3 (b)). The speckle pattern was imaged by a Pilot piA2400 camera by Basler with Linos MeVis-C 1.6/25 imaging lens through a Michelson interferometer with temporal phase-shifting realised by a piezo-electric actuator PSH 4z (Piezosystem Jena; 3 steps, the full phase-shifting cycle takes about 2.8 s). The suitable shear distance of 4.9 mm (approx. 30 pixels) in the horizontal direction was experimentally identified to produce reliable phase maps. Given that the shear amount was significantly smaller than the distance to the wall painting, an assumption was made that the shearography phase maps correspond to the out-of-plane surface strain component.

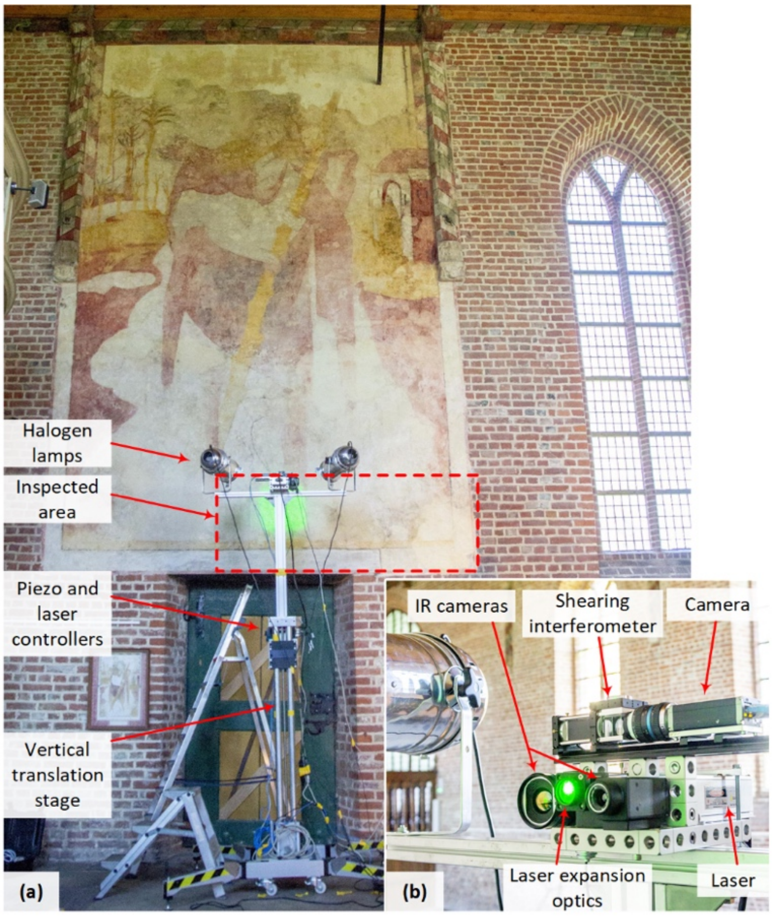

Figure 3. Testing campaign at the Maria church: (a) the overview of the shearography instrument mounted on a translation stage and the inspected area, (b) shearography instrument with a Michelson interferometer and IR cameras.

During the inspection, the shearography instrument was mounted on a motorised rigid platform (Figure 3 (a)) that provided scanning in the vertical direction. The horizontal scanning was performed manually. The individual field of view was approx. 400×335 mm^2 (green square illuminated by the laser in Figure 3 (a)). Two halogen lamps of 1000 W each were used for the heat excitation of the painting and its internal structure. Two infrared (IR) cameras (A615 and A65 both by FLIR) measured the surface temperature during heating and cooling.

4 CASE STUDY RESULTS

4.1 Percussion methods

The execution of the two aforementioned percussion methods was quite complex and time-consuming. The acoustic response generated by both the tapping and rolling action can be difficult to interpret since, sometimes, differences in sound can either be minimal or they can be emitted by materials of different composition and density. This was noticed during the inspection of an area where several losses had previously occurred and were presumably filled with materials of a different composition than the original plaster. In this instance, the scattering of sound resulted in differences not only between the original plaster and the fillings but also between the different fillings. It was therefore impossible to establish whether the difference in sound was generated by a structural deficiency or simply by differences in the material composition among the fillings applied during the many previous restoration campaigns of St. Christopher.

The percussion tests were executed in a collective approach, in order to reduce biases and subjective inclinations (Figure 2). After the tapping or the rolling of an area had occurred, the generated acoustic reactions were discussed and subsequently mapped (Figure 4 (a)). It can be easily observed that the implementation of the two percussion methods, despite involving the same mechanism of interpretation and collection of data, gave somewhat different results (Figure 4 (a)). It can be stated that the percussion method involving the tapping of a nail resulted in identifying more areas with delaminations than the percussion methods involving the rolling of the acoustically isolated plastic ball. In overall, some similarities in the results obtained were observed, especially in areas surrounding the wooden lintel, part of the door underlying the wall painting of St. Christopher (left and right side on the lower part of the wall painting in Figure 4 (a)).

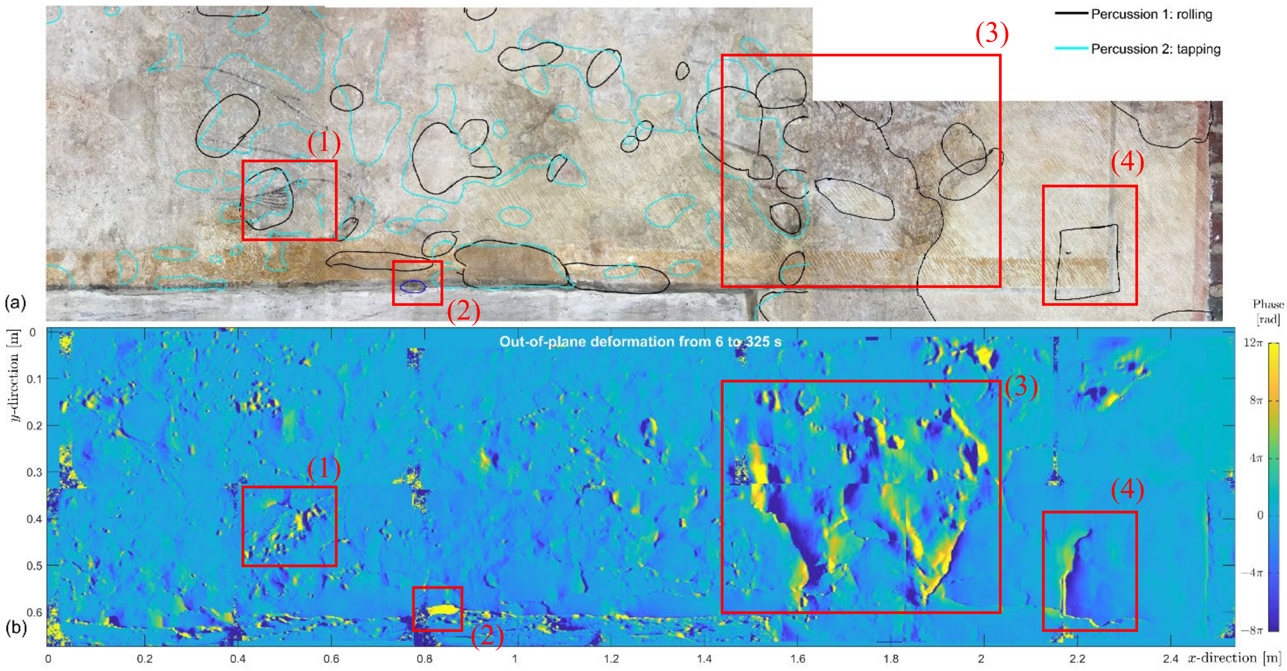

Figure 4. Comparison of the inspection results obtained with (a) two percussion methods (shown as contour plots) and (b) the total phase difference obtained with shearography corresponding to the out-of-plane surface strain component. Four areas of particular interests have been identified in red, to facilitate argumentation.

Ultimately, it was difficult to determine which percussion method should be considered more reliable and realistic. Whilst the execution of the percussion method involving the tapping of a nail was considered easier than the one involving the rolling of the plastic ball, it can be argued that the use of such a light-weight instrument would offer the advantage of avoiding any contact between the wall painting and any potential dirt and grime of human derivation. Furthermore, it was possible to ascertain that both methods involved a small degree of accidental damages to the painted surface, in the form of losses of paint and the generation of plaster debris.

4.2 Shearography results

The inspected area included 14 adjacent fields of views (each approx. 400×335 mm^2, 2 in the vertical direction by 7 in the horizontal) with a minor overlap for stitching, which resulted in a total area of approx. 2.55×0.68 m^2. All field of views were inspected one after another with repeating thermal loading: first, heating for 2 minutes, then continuous monitoring for 5 minutes 30 seconds during the painting cooling. The shearography instrument was continuously recording phase-shifted sets of speckle interferograms, which resulted in 117 sets for each field of view. All sets of interferograms were processed, stacked and stitched together to give the phase map that reveals the evolution of the out-of-plane surface strain over the monitoring time (Figure 4 (b)).

The relatively long and strong heating time of 2 minutes was used to focus the inspection on the deep delaminations and structural defects (up to 5 mm in depth). An average increase of +6°C was measured by the IR camera in the center of the heated area. This temperature increase of the top layer was considered to be acceptable as the natural temperature variations are of similar magnitude (e.g. direct sunlight increases the surface temperature of the wall painting by +4°C).

The resultant phase map reveals multiple structural defects that relax after the thermal excitation to a stable state causing mechanical out-of-plane surface strain. The colour code in Figure 4 (b) is directly proportional to the strain magnitude.

4.3 Comparison of the experimental results

Four main areas of interested have been identified and plotted in red in Figure 4 (b). As it can be observed by comparing area 1 in Figure 4 (b) and the correspondent area in Figure 4 (a), the presence of large areas of structural delamination was only identified by the percussion methods; shearography only detected a slight surface displacement, indicative of the presence of some structural defects. Area 2 has been mapped during all testing executed; it must be noted that the area in question was showing visible surface delamination and, therefore, could be easily identified with the naked eye (Figure 2 (e)). Similarly, strong correspondence in the detection of large areas of structural defects can be observed in area 3 in Figure 4 (b); the latter depicts a strong strain displacement which was also perceived as a vulnerable area during both percussion tests. Ultimately, it was deemed of interest to examine area 4 in Figure 4 (b). The latter is indicating an area where delamination might be occurring, which was only detected during the percussion testing that involved the rolling of an acoustically isolated plastic ball.

In conclusion, a partial correspondence between results obtained with the percussion methods and shearography was established. It can be argued that, areas perceived as vulnerable and indicative of the presence of delamination (such as area 1 in Figure 4 (a)) could not be detected by shearography because of two reasons:

1. The acoustic response documented during percussion testing was generated by the presence of materials of different composition and density.

2. The delamination might be relatively deep and might not affect the surface strain, therefore it would not be detected by shearography.

5 CONCLUSIONS

Structural delamination, detachments or defects are terms used to refer to an ongoing degradation process that generates the loss of adhesion and cohesion of heterogeneous layers in the structure of wall paintings and architectural surfaces[1,2]. This complex type of damage is often encountered in conservation practice, however, its identification relies on empiric approaches, such as the percussion method[3-5]. The latter is based on the documentation of the acoustic response generated by the tapping of the pictorial surface of the architectural element and it can lead to confusing results, due to its poor repeatability and subjectivity.

The case study of the wall paintings representing St. Christopher in the Mariakerk exhaustively illustrates the limitations of this method: two different percussion methods were tested, giving somewhat divergent results. The elaboration of specific treatment needs, such as the injection of grouts, to re-establish the cohesiveness of the structure of a wall painting, requires the accurate documentation of both location and size of the delamination. The application of shearography coupled with thermography was believed to provide a holistic representation of the condition of the structure of the wall painting depicting St. Christopher. Furthermore, the equipment is categorised as non-contact and non-destructive, allowing the inspection of wall paintings and architectural surfaces from a distance.

Initial comparison, between results generated by the two percussion methods and shearography, shows a degree of matching. However, it can be observed that areas that were deemed extremely vulnerable during percussion testing, such as area 1 in Figure 4, were not detected in the same way by shearography. Arguably, such differences can be spawned by either the relatively deep location of the delaminated areas and the inability of shearography to detect them or the misinterpretation of the acoustic response generated during percussion testing.

In conclusion, shearography results can be improved during future experimental campaigns, e.g. the resultant phase map in Figure 4 (b) can be improved by more accurate stitching of the individual field of views. In addition, optical vignetting and shading in the Michelson interferometer cause low signal in the corners of the field of views (e.g. areas with coordinates around (0.8; 0.35), (0; 0.3..0.7)), which results in the significant noise areas that can be misinterpreted. Moreover, further research should focus on providing more information about the depth of structurally delaminated areas within the heterogeneous layered structure of wall paintings.

In this case study, the IR camera was used to condition the heating excitation for the shearography inspection. However, the same instrumentation can provide full-scale thermography NDT of the painting. This will be one of the future directions for this project.

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