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Application of micro-CT for the study of mural paintings – the case of São Tiago Church

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Introduction

São Tiago Church of Folhadela (Vila Real) is a Romanic religious building from the 13th century. Its granite walls are adorned with mural paintings from the 15th and 16th century much like the majority of temples in the northern region of Portugal. Its singularity is that on the main chapel several different campaigns are overlaid, visible at the bottom of the wall among the lacunae areas.

Objectives

In order to understand the complex microstructure of the mural paintings multi-layers, a novel method of analysis has been applied from the field of medicine into the cultural heritage. X-ray micro focus computer tomography (micro-CT) is a non-destructive imaging technology. It can scan a sample from any angle, characterizing its entire volume and giving three dimensional data. It also measures thickness of layers, fissures, their location in space, porosity and pore characterization. It allows us to perceive the degradation occurring inside mural paintings.

Materials and methods

A mural painting sample with several layers was collected from the bottom wall of the main chapel of S. Tiago Church in Folhadela, Vila Real (fig.1).
The SkyScan 1276 (www.skyscan.be) (Bruker) was used in this study with the SkyScan Software Version 1.0.11. In order to characterize the internal structure of the sample, scans were performed under tube voltage of 85 kv, and tube current of 200 μA using a 1mm aluminum filter. The image pixel size was 20.01 μm and 901 projections were taken with 400 ms exposure and 16 bits of depth at 360º rotation. The reconstruction of the sample was made by Nrecon (reconstruction software, version: 1.7.4.2) and shown in Dataviewer (1.5.6.3) in three orthogonal directions (fig.2a,b,c) and the program CTVox [3.3.0r1412 (64bits)] was used to render volume in 3D (fig.2d). The porosity models were generated in the analysis software CTAn (version 1.17.7.2+) for quantitative measurements and visualized in SkyScan CTVol software (fig.3). The 3D analysis of the porosity parameters is depicted in Table 1 and the 2D pore size distribution analysis is contemplated in Figure 4. Different colours were assigned to the different porosity models - yellow was selected for the total volume of interest (VOI), red was selected for all the pores and green for the open pores. The pores (opacity 60%) was set to transparent as well as the VOI (opacity 40%), allowing to observe the pores inside the VOI (fig.3).
Scanning electron microscopy (SEM) was performed with the SEM Jeol JSM-5600LV equipment for direct viewing of the mural painting surface of the sample (fig. 5) as well as the mortar substrate (fig.6).

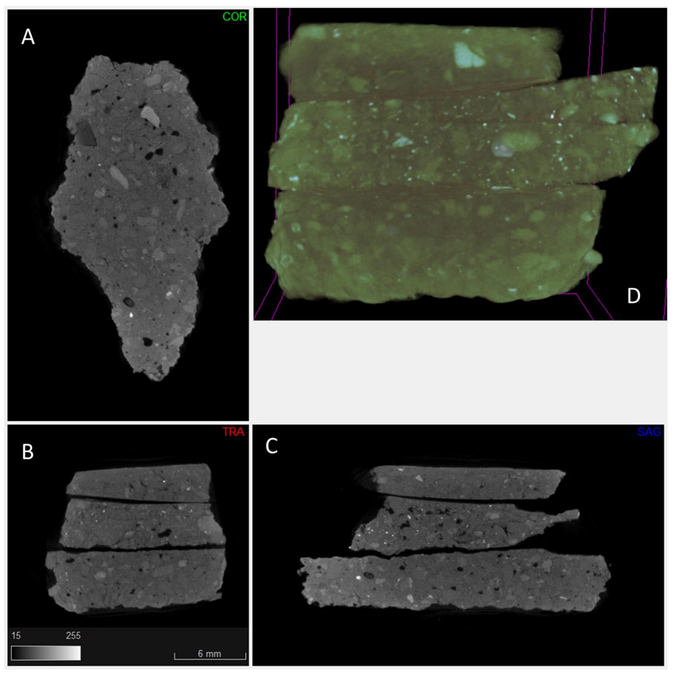

Figure 2. CT images view (A) above; (B) top; (C) profile; (D) 3D render showing 3 separate layers and an additional stratum (cohesive) in the 2nd fragment layer.

Figure 1. 16th century mural painting at the bottom wall of the main chapel in S. Tiago Church, Folhadela, Vila Real.

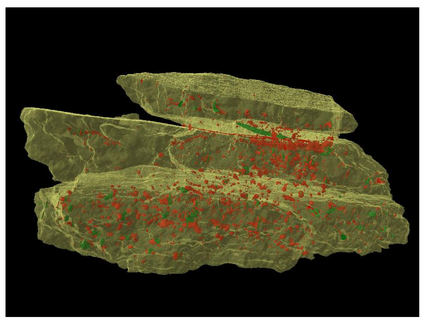

Figure 3. Porosity model – yellow for the VOI, red for the total pores and green for the closed pores.

Results and discussion

The analysis based on CT images has advantages over the cross-section. The samples for cross-section must be prepared with resin and polished, being time consuming as well as requiring the destruction of the sample rendering it useless for any other analysis. Also, CT enables the analysis of the entire volume of the sample rather than just one view or cut.
The sample used for this investigation is of a fresco mural painting with a mortar mixture of lime (calcium carbonate) and fine sand river. Three layers were visible performing the CT scan since they detached themselves due to lack of cohesion of the substrates. However, another stratum in the second layer was made perceivable with the 3D render volume (fig.2d).
The 3D analysis established that the sample has a very high percentage of total porosity. If on one side, mural painting materials are very porous, on the other, the degradation process occurring in its inner strata increased that percentage. SEM examination also confirms the poor condition of the mural which is exposed to extreme humidity, lack of adequate cleaning and ventilation, with cult duties being performed only 2 days a week. Although the painting surface doesn't seem to present severe porosity (fig.5), when the magnification is higher and the substrate is visible, the granular disintegration is shown (fig.6).

Table 1. 3D analysis of porosity parameters

Total VOI volume	14.8 cm^3
Object volume	2.46 cm^3
Number of closed pores	2375
Volume of closed pores	$6.57x10^{-3}$ cm^3
Closed porosity (percent)	0.267 %
Volume of open pore space	12.40 cm^3
Open porosity (percent)	83.40 %
Total volume of pore space	12.40 cm^3
Total porosity (percent)	83.40 %
Density (g/cm^3)	1.67

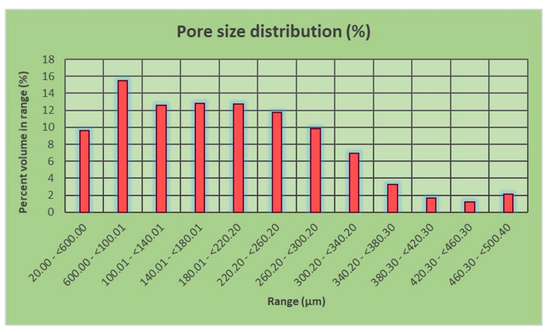

Figure 4. Pore size distribution analysis

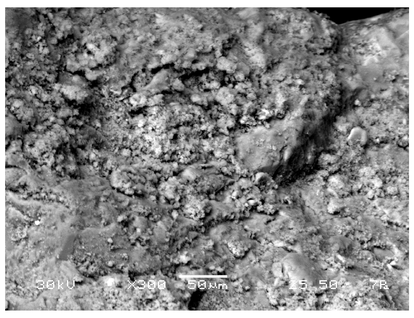

Figure 5. SEM micrograph of mural painting surface

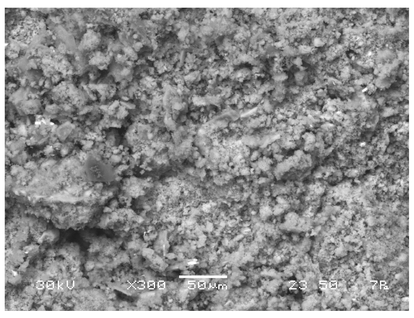

Figure 6. SEM micrograph of mortar layer

Conclusions

Micro-CT is a non-destructive technique that has potential for the cultural heritage preservation of rare artifacts or limited samples' use. It allows to look at a 360º view of the sample but also at its interior, observe its structure, composition, different layers, different materials and establish the total sample porosity as well as its opened and closed pores. The images can be exported in 3D or in video format, displaying the entire sample or selected cross-sections.
The composition of the layers is heterogeneous and the differences in grain materials, size and opacity can be observed. The high level of porosity ascertained is probably due to temperature and relative humidity fluctuations occurring in the S. Tiago Church.
This study is to be further developed adding elemental information to the sample materials and density analysis comparing different test samples to ultimately compose a strategy for conservation treatment employing biotechnological solutions for sustainable preventive conservation instead of curative.

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