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High Resolution 3D modelling of Cylinder shape bodies applied to ancient columns of the thirteenth century

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ABSTRACT: A multi-technique high resolution 3D modelling is described here aimed at the investigation of the state of conservation of carbonate columns of the ancient church of Buoncammino (thirteenth century) located in the homonymous district of the town of Cagliari (Italy). The integrated application of different Non-Destructive Testing (NDT) diagnostic methods is of paramount importance to locate damaged parts of the building material of artefacts of historical buildings and to plan their restoration.

FIRST STEP OF THE DIAGNOSTIC ANALYSIS

PETROGRAPHYCAL INVESTIGATIONS

The miocenic carbonate rocks called *Calcari di Cagliari* have been used historically to construct ancient monuments in the historical center of Cagliari. The *Calcari di Cagliari* are characterized by three transition facies, from top to bottom called: *Pietra Forte*, *Tramezzario* and *Pietra Cantone*. Our methodology begins with an accurate microscopic examination of petrographic thin sections and scanning electron microscope (SEM) analysis of the above carbonate materials in order to identify their textural characteristics and especially the nature and distribution of their porosity. The knowledge of these rock properties is fundamental to understand and interpret the acoustic behaviour of the study carbonate rocks also providing the best criteria for understanding their alteration processes.

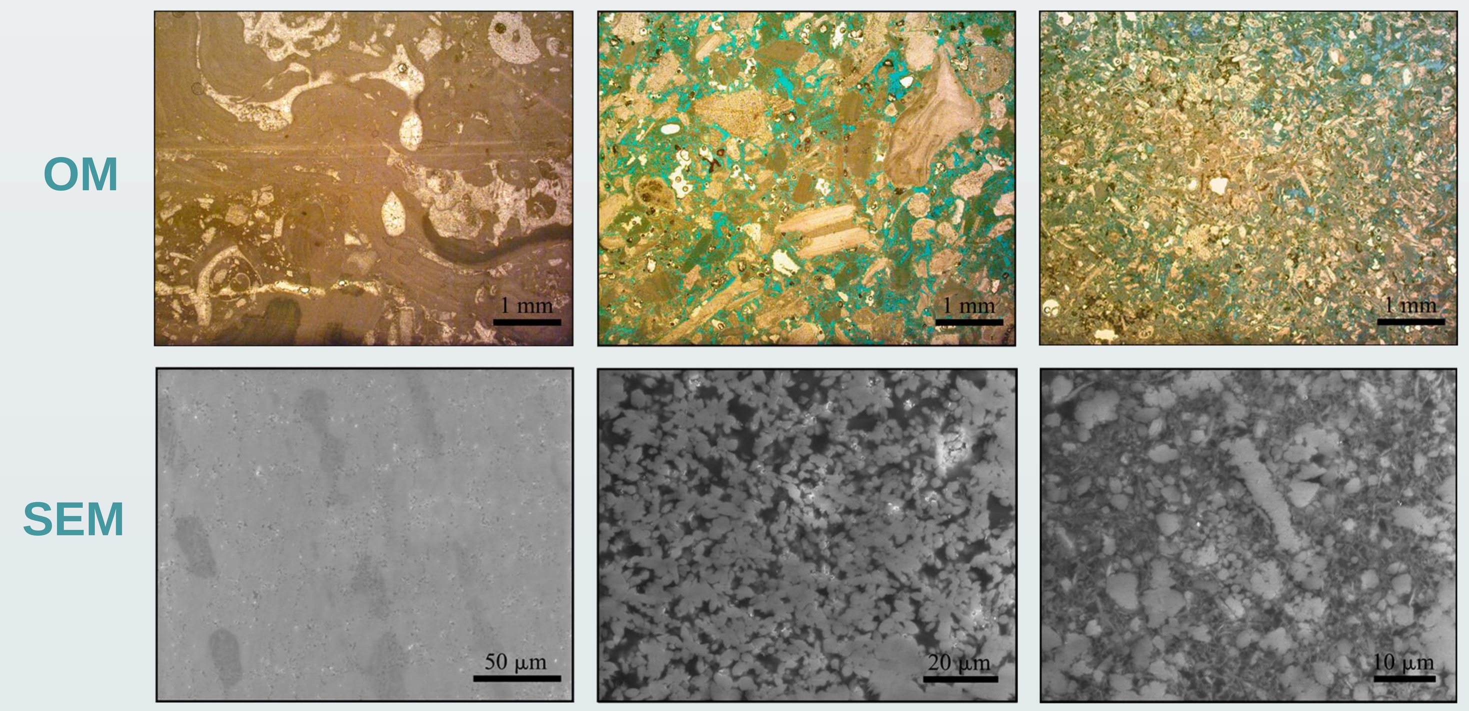

Fig. 1 – Thin sections of the threee facies of *Calcari di Cagliari*: OM = optical microscope (thin sections treated with blue dye); SEM = scanning electron microscope.

Fig. 2 – Building materials of the investigated coloumns.

Image elaborated by Metigo Map Software.

SECOND STEP OF THE DIAGNOSTIC ANALYSIS

3D Modeling with Terrestrial Laser Scanner (TLS) and Close Range Photogrammetry (CRP)

Terrestrial Laser Scanner technology and Close Range Photogrammetry are useful tools to compute 3D model of buildings and architectural elements like wall, cylindrical shape bodies like columns, and so on.

We operated a Leica HDS-6200 TLS (Fig.3a) together with a single lens reflex digital Camera Nikon D5300 (Fig.3b)(24.2 MegaPixel resolution) on 20 station points inside and 15 outside the church in order to collect data of 41 point clouds, (hundreds millions of points) these clouds were filtered, registered, and aggregated to form the model of the investigated building elements. Moreover, in a second step we aggregated the data of four very dense point clouds to compute the 3D model of the three inner columns located inside the ancient church of San Lorenzo located on the top of the hill Buoncammino, in the historical center of Cagliari town, Sardinia, Italy (Fig.4 a,b). In the following Fig.5) is represented a view of the 3D model obtained after registration and aggregation of all the point clouds pertaining to this monument, the radiometric information represented in color scale is the geometrical anomalies pattern of the materials of the outer surface of the investigated columns.

Fig. 3 - a) The Leica HDS-6200 TLS. b) The Camera Nikon D5300.

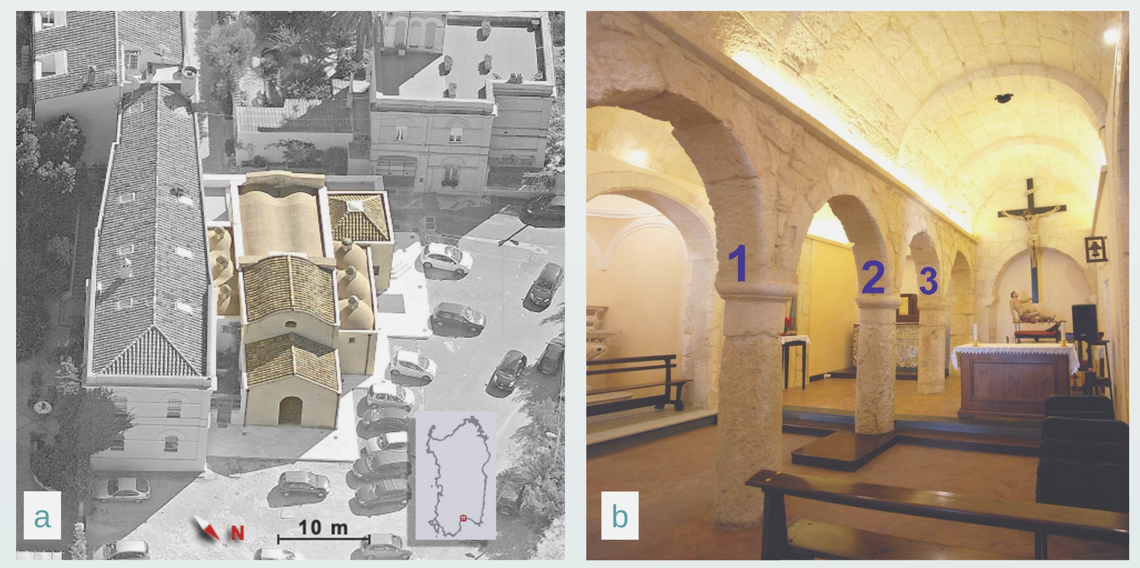

Fig. 4 – a. Aerial view of the old precious church of San Lorenzo in the historical city center of Cagliari (elab. from www.sardegnageoportale.it); b) view from Nord side of the three inner columns in the Romanesque interior of the church. The arches resting on squat columns of limestone blocks monitored in this study.

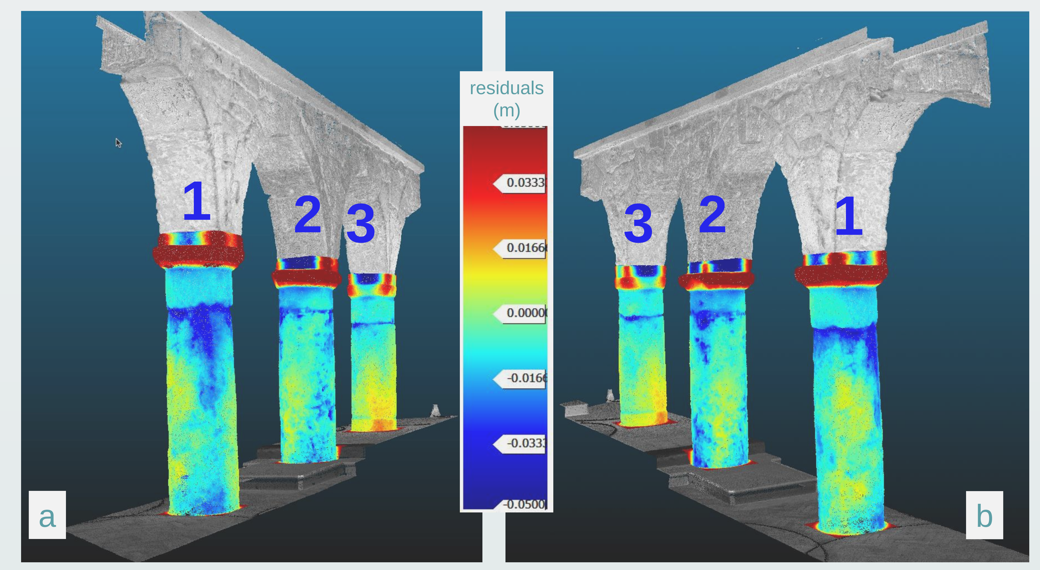

Fig. 5 – Northwest a) and Northeast view b) of the geometrical anomalies of the limestones inner columns: the colors represent the residuals in meters inferred by the geometrical anomalies of the aggregated point cloud with respect to a cylinder geometrical model.

THIRD STEP OF THE DIAGNOSTIC ANALYSIS: ULTRASONIC LABORATORY AND IN SITU MEASUREMENTS AND THEIR INTEGRATION WITH THE LASER SCANNER 3D MODELLING

ULTRASONIC LABORATORY MEASUREMENTS

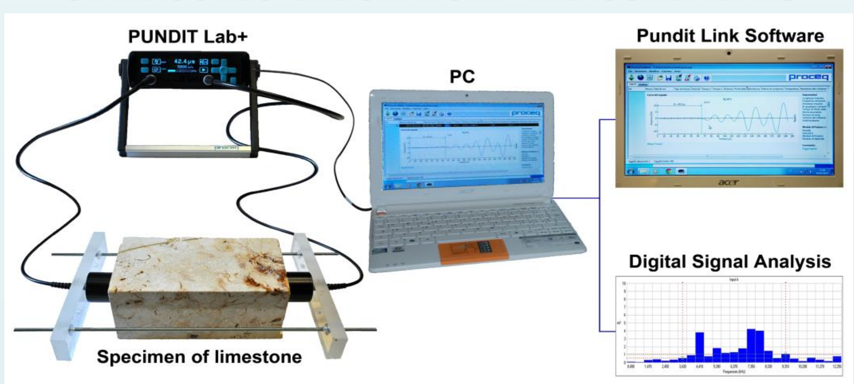

Fig. 6 - Setup used for the ultrasonic laboratory measurements. *Courtesy from: Casula et al., 2015.*

IN SITU ULTRASONIC AND TERMOGRAPHIC INVESTIGATIONS

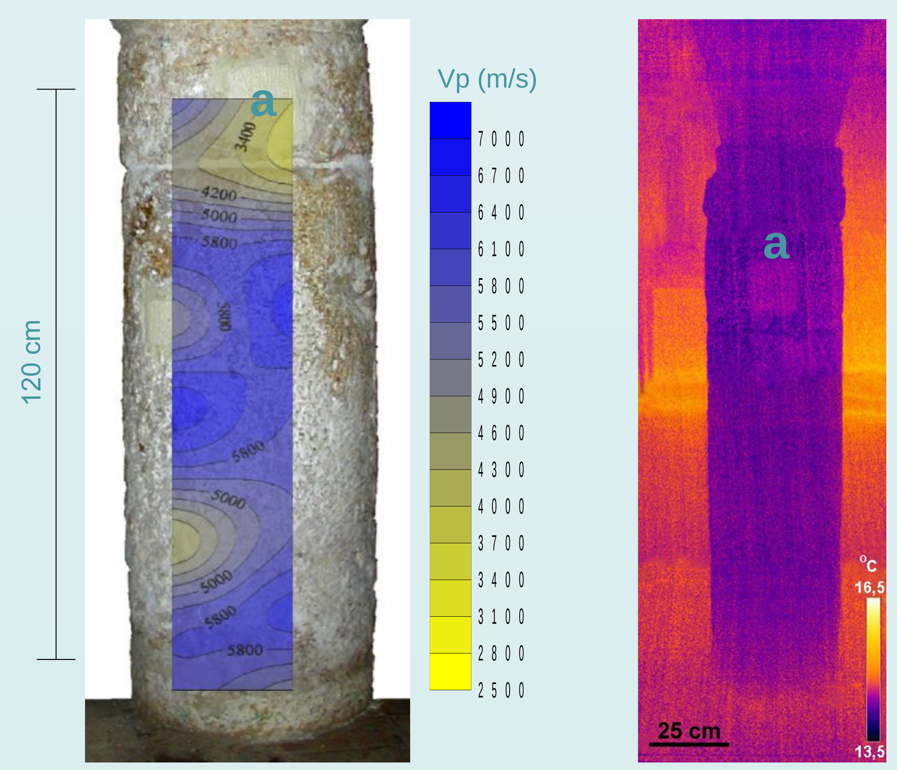

Fig. 7 – a) Ultrasonic longitudinal wave velocity map superimposed to the column 3 ; b) Thermographic image of the same column. a = ashlar of *Pietra Cantone* (restoration action).

Ultrasonic Tomography

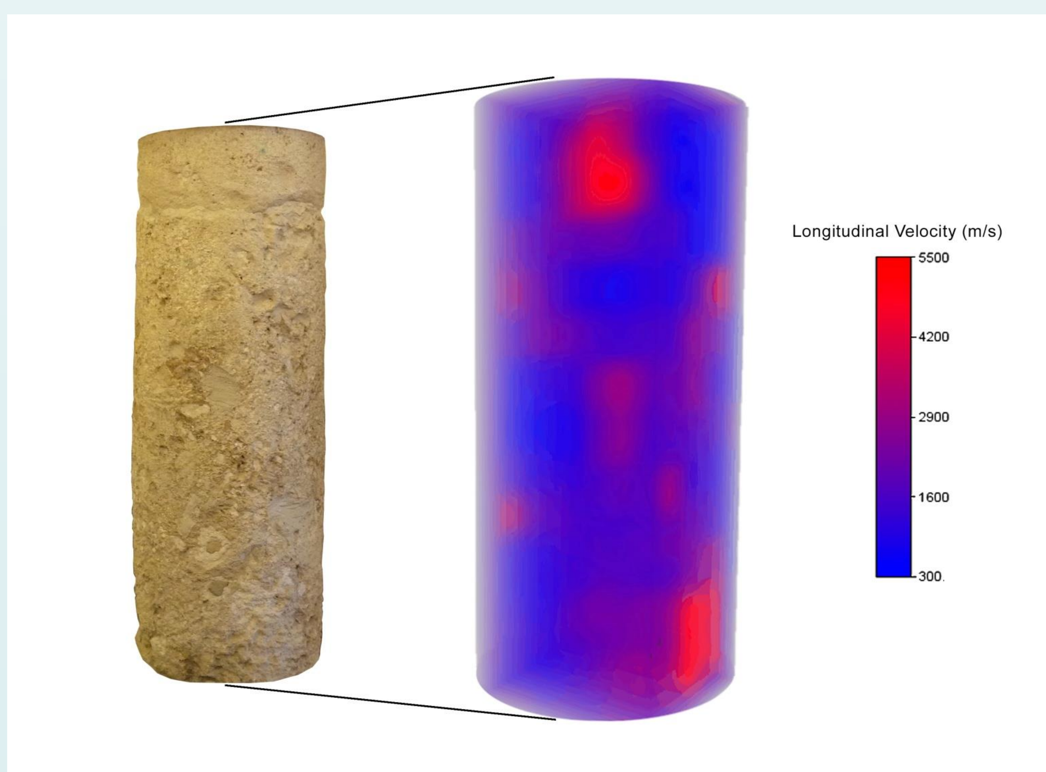

Fig. 8 – Ultrasonic tomography results in the column 2.

Ultrasonic tomography data acquisition was carried out using the standard tomographic scheme. Transmitters and receivers (24 kHz) were positioned to obtain a good coverage of ray paths associated with longitudinal elastic waves propagating through the materials.

The 3D ultrasonic tomographic reconstruction (P-waves velocity model) was carried out to achieve an accurate knowledge of the internal structure of the column and formulate a correct diagnosis of the state of preservation.

The longitudinal velocity distribution reflects the higher heterogeneity and apparently lower quality of the carbonate materials inside the column.

A third step of our procedure was complemented by ultrasonic in situ and laboratory tests in the 54kHz - 82kHz range. The ultrasonic parameters, especially longitudinal and transversal velocities, can be correlated with various material properties with reasonable confidence. On the basis of the results of the laboratory tests, *in situ* ultrasonic surveys on a significant monumental structure in order to check zones of weakness, to assess the weatherability of the carbonate stones have been carried out. The figure 7 shows the ultrasonic longitudinal wave velocity map obtained by surface modality (Normal 22/86) and the thermographic image of column 3. The integrated use of the two methods allowed to assess the conservation status of the shallow part of the building materials of the analyzed architectonic element.

3D Modeling with TLS and CRP

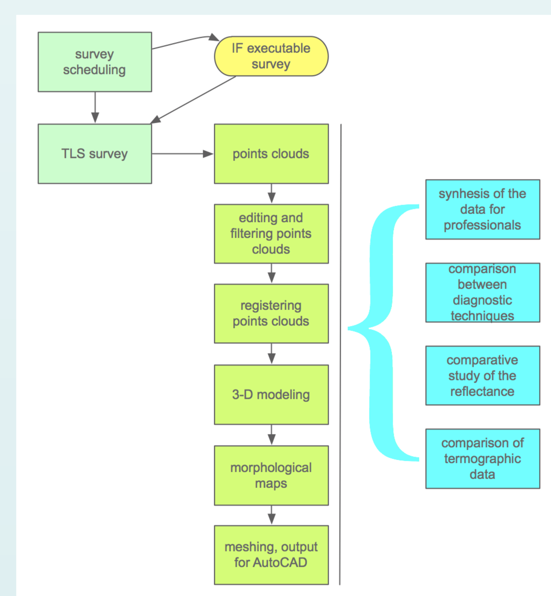

Fig. 9 Flow chart of TLS data acquisition and processing.

After an examination of the target object, the survey is scheduled to search the appropriate place to where is better to settle the station points. Every station point cloud is rotated and translated with respect to each other and one of them is used as an intrinsic reference system (IRS). The clouds elaboration process can be summarized as follow: point cloud input and format conversion, point cloud pre-processing and automatic filtering or manual editing with the elimination of data out of tolerance and unusable points, cloud to cloud draft alignment and fine registration with iterative closest point (ICP) algorithm, cloud aggregation, 3D modeling and computation of morphological maps, output in *dxf* format suitable for input on AutoCAD® (Fig.9).

We applied *INSPECTION* module of release 3 of software JRC 3D Reconstructor® suitably implemented to compute the geometrical anomalies of the aggregated point cloud as residuals with respect to a best fitted cylindrical geometrical model adopted as reference (Fig.10). The resulting highlighted surface anomalies are useful for the comparison with other diagnostic techniques able to investigate the internal structure of the *Calcari di Cagliari* columns. In Fig.10 the color scale anomalies are expressed in m.

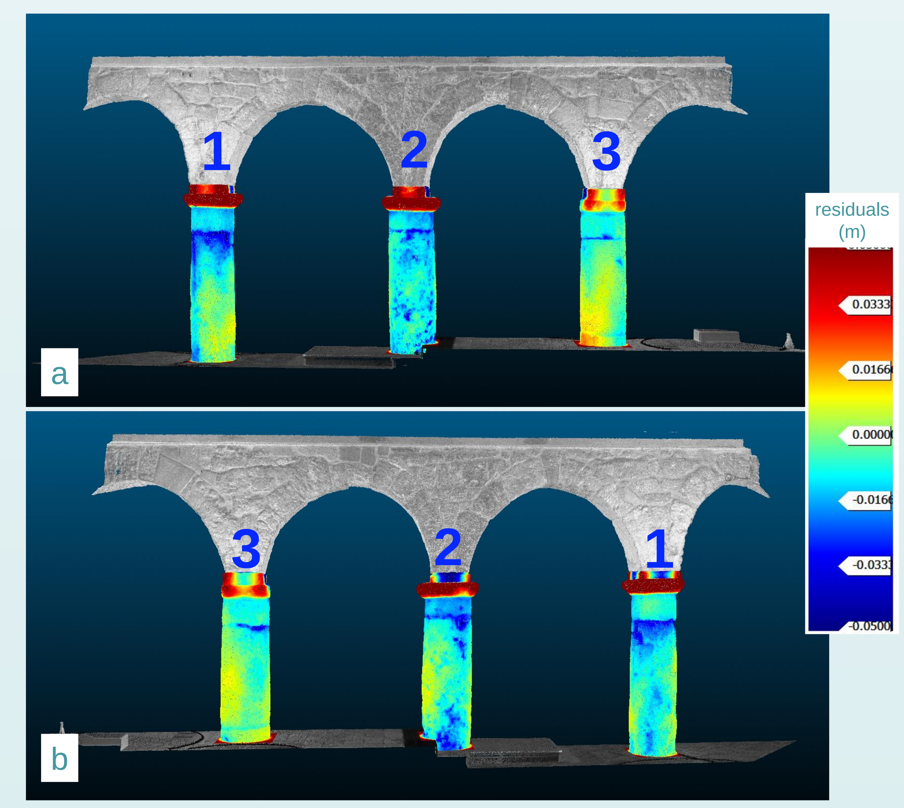

Fig. 10 - View from East (a) and West (b) of the geometrical anomalies of the achitectural element investigated.

Concluding Remarks: The integrated application of TLS and CRP technologies together with the ultrasonic method contributes in overcoming ambiguities in the interpretation of the individual dataset. Therefore the methodology proposed in this study has proved to be effective in giving useful indications aimed at formulating a recovery and preservation plan for a monumental structure and to monitor its conservation status in time.

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