THE FACADE'S DOME OF THE ST. ANTHONY'S BASILICA IN PADUA

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ABSTRACT:

The basilica of St. Anthony in Padua (13th–14th cent.) is one of the most remarkable pilgrimage sites in Italy. To date, the monument itself has never been subject to a comprehensive stratigraphic analysis. Important information about the construction sequence of the building may be conserved in the domed roofs protecting the inner masonry shells.
The present paper will focus on the dome next to the facade[1]. During the survey, data acquisition via laser scanner have been flanked by standard tasks. Specifically, the stratification analysis of the timber framework of the dome requires to measure the entire structure, including parts with difficult access, and calls for many scan bases to go further the sight obstacles represented by the rafters and the horizontal collar-beams. Therefore, application of laser scanning might appear difficult at first sight.
The authors will show that the approach confirms the suitability of the laser scanner technology in facing the general complexity of the structure. The development of a graphic documentation in CAD environment entailed a manageable complexity in terms of time-consumption and precision in data processing. So far, the plans reveal the irregular profile of the dome in its inner masonry shell, and of the outer masonry drum. The sections show a two-centre curvature of the elevation of the outer timber shell. However, the joints among the rafters, ribs, and tie-beams still require a series of traditional in-depth assessments acquired in close-range access.
Nevertheless, the pragmatic investigative modus operandi, tested up to now, does represent a fixed protocol suitable to be iterated and perfected for each cupola. In such complex structures, the laser scanning process confirms to be a valid strategy to reach a good compromise between time consumption, human effort, and millimetre precision. In this way, the collected material provides a first contribution to acquire knowledge on this Italian medieval masterpiece, which stands out on the international scenario for its historical richness and architectural complexity.

1. THE DOMED ROOF IN ST. ANTHONY'S BASILICA IN PADUA

This contribution presents the survey underway in the domes of the St. Anthony's basilica in Padua. According to the references, the building begun in the 1230s, and was completed in the fifteenth century. The church has eight domes: two on the main nave, one on the crossing, other two on the wings of the transept, and the last three vaulting the choir, the presbytery, and the central radial chapel (Figure 1). These domed structures consist of an internal masonry shell and a timber superstructure, similar to the ones in St. Mark's basilica in Venice. In the history of the church, two main unfortunate events involved the roofs: a lighting strike in 1347 and a fire in 1748. During these instances, several domes were damaged, including the one at the crossing, the dome on the right wing of the transept, as well as those above the choir and the presbytery. In these domes, extensive repairs took place, whereas in the two on the nave, the structures were most likely preserved with their original components and configurations. So far, the construction of the domes has been dated between the thirteenth and fourteenth centuries, with claims of their final configuration accomplished in 1310 (Lorenzoni, 1981; Salvatori, 1989).

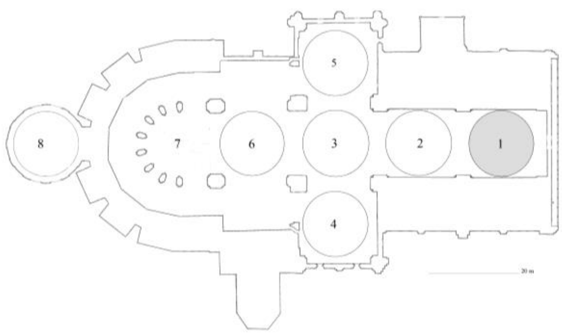

Figure 1. Distribution of the domes on the top of the basilica: 1. Façade's dome; 2. Intermediate dome; 3. Angel's dome; 4. St. Anthony's dome; 5. St. Jacob's dome; 6. Presbytery's dome; 7. Choir's dome; 8. Relics chapel's dome

Nevertheless, scientific findings about dating the elements of the domes, as well their in-depth recording have not yet been addressed in previous literature. In this paper, we present preliminary results and an overview of the methodology of a survey campaign focused on the dome above the west façade (Figure 2). The authors started an investigation process according to established workflows (Fregonese and Taffurelli, 2009; Schuller, 2003), involving a combination of conventional measurements and advanced laser-scanning techniques. By applying and developing this approach inside the complex domes of the Basilica in Padua (Figure 3), this paper

[1] The author is currently working on a complete survey and in-depth analysis of the domes, through a cooperation with the Presidency of the Veneranda Arca of the Saint. The project will finally also involve dendrochronological sampling and dating.

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demonstrates the general benefits and usefulness of the methodology, while documenting the geometry, construction, and alterations of the domes themselves.

Figure 2. The dome of the facade of the St. Anthony's basilica in Padua. External overview of the north elevation

Figure 3. Interior of the western dome

2. SURVEY

2.1 The survey

The *Bauforschung* approach examines the elements' joints on site, with their identification and classifications. However, the complexity of the structure of the domes required the fundamental support of geomatic techniques. For example, to acquire the whole geometry and a distribution of the construction unities, as well as to detect parts not always reachable by operators. Particularly, the intricate system of struts and beams makes the data acquisition slow, requiring redundant scans to bypass sight obstructions.

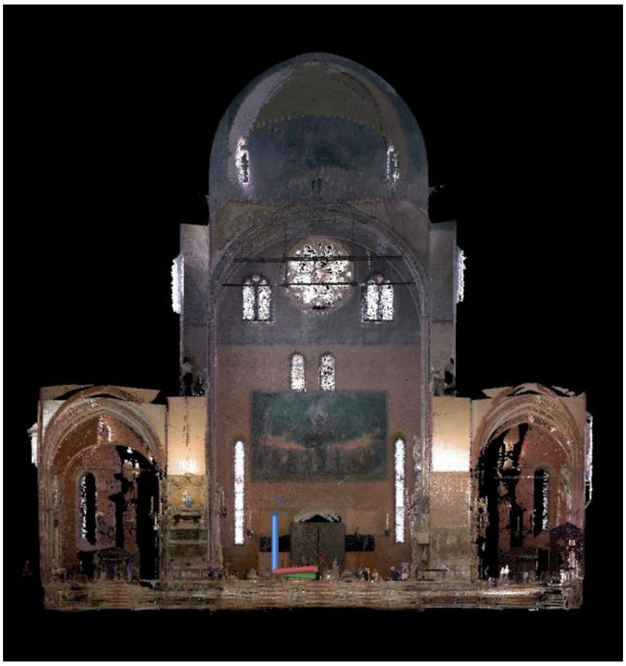

Figure 4. View of the point cloud of the first central bay

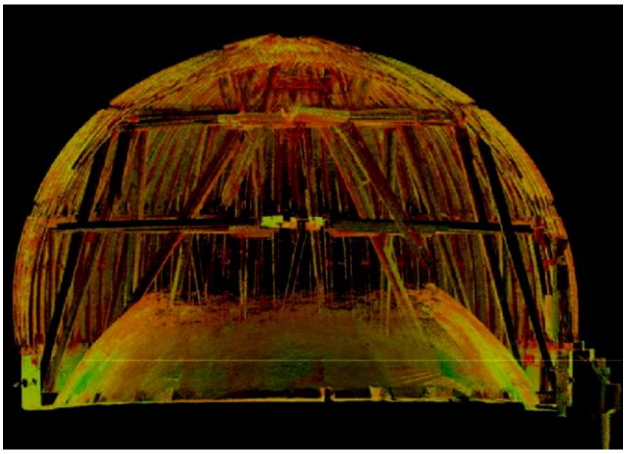

Figure 5. Section of the point cloud along the E-W axis

The dome has an external perimeter that can be approximated by a circle with a 7.70 m radius. The space of the attic has been covered by 23 scans, with the scanner fixed on a tripod, and located in the interspaces between the main struts. The use of a Leica BLK 360, with an accuracy of 4 mm at 10 m, proved to be convenient in the limited space. The presence of obstructions further necessitated a system of targets to allow a safe registration process. As the scanning focused on the geometry of shells and beams for a 3D digital-reconstruction (Figures 4 and 5), the scanner was operated with a medium resolution. Concerning the timber superstructures, in-depth measurements supplied the knowledge about joints and irregular profiles.

2.2 The data processing and modelling

The scans in .blk format have been registered in Cyclone, to be later exported in ReCap, and finally modeled in CAD (computer-aided design) environment (Figure 6). The irregular shapes of the elements have been managed starting from planar sections and extruding the surfaces along their profiles. This general workflow has been also used in other surveys such the one in St. Mark Basilica (Fregonese and Taffurelli, 2009) and in Ss. Giovanni and Paolo in Venice (Balletti et al., 2013), and establishes a fairly automatized processing procedure, even for such complex structures.

Analysis of the dome curvature was processed in the open source CloudCompare software. In particular, the curvature profiles have been exported into CAD in .dxf format, and then analyzed through the horizontal and vertical cross sections. These sections are obtained by simply slicing the point clouds parallel to the XZ- and the XY-planes (Figures 8 and 9).

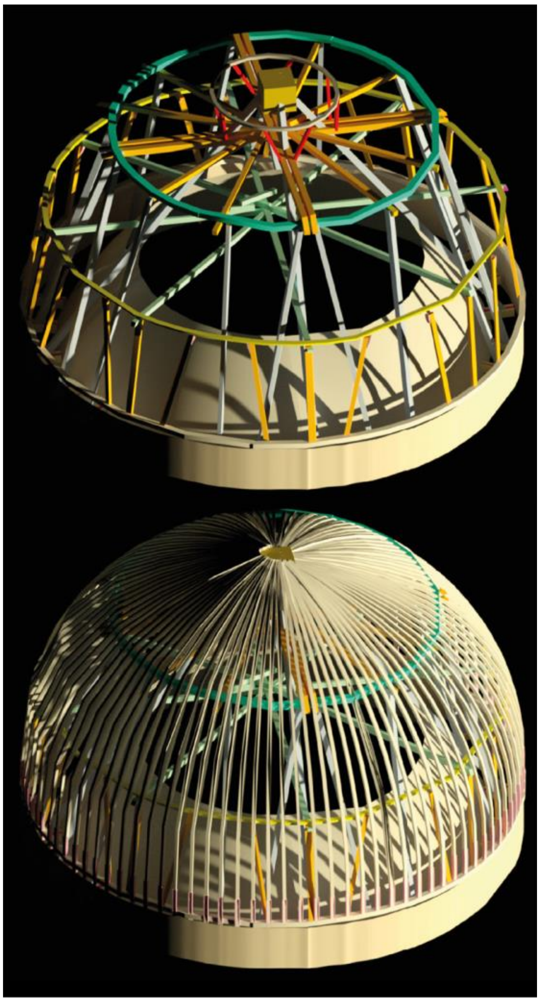

Figure 6. Simplified model of the timber framework

2.3 Output

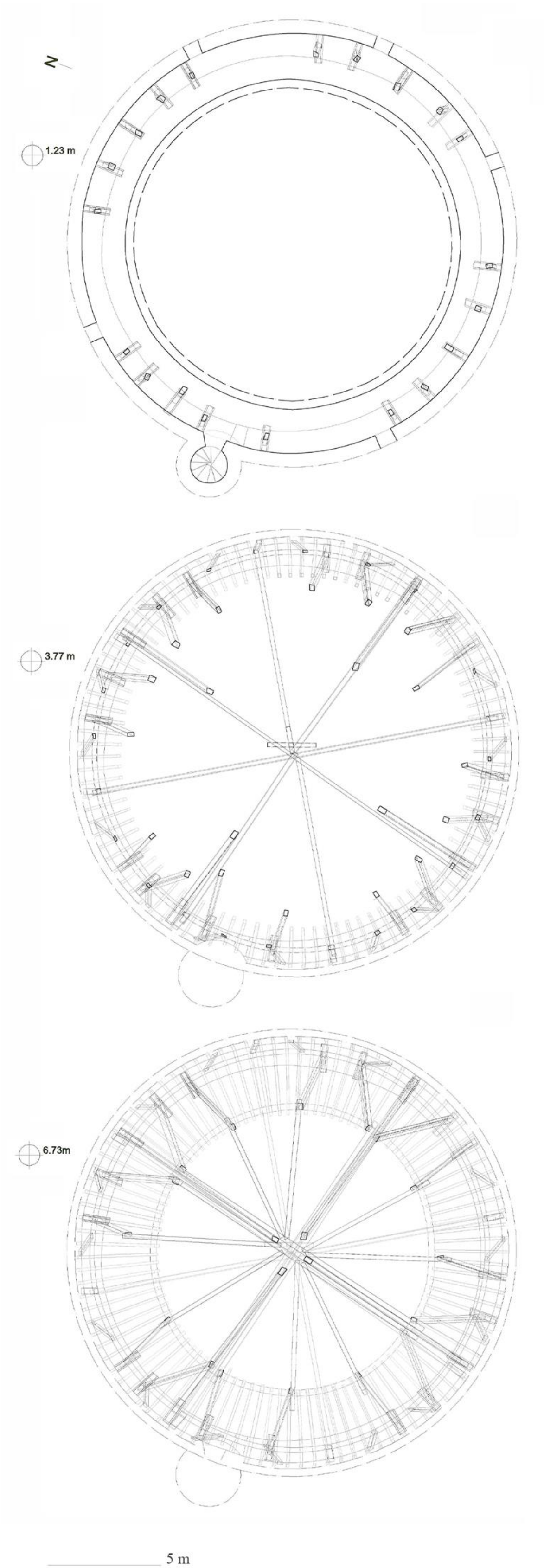

Figure 7. Plans of the timber framework at 1.23 m, 3.77 m, and 6.73 m

This first scheduled on-site survey involved the acquisition of two different point clouds, respectively located in the first span of the central nave, and in the roof space above the masonry vault. In this way, it has been possible to acquire the intrados and the extrados of the masonry shell, as well as the intrados of the outer timber coverage. The cloud produced from inside the roof amounts to 205,936,561 points. The cloud from the nave has been limited to 10,024,224 points. The resultant plans of the dome consist of 2D drawings at heights of 1.23, 3.77, and 6.73 m above the base of the dome (Figure 7). Furthermore, 2D sections can be extracted along different axes if needed, while a 3D model represents the complete construction arrangement of the framework.

3. ANALYSES OF DATA AND TECHNIQUES

3.1 Geometries of the shells

To evaluate the diameter of the horizontal sections taken at different heights or levels, the authors extracted the contour lines through an automatic software processing setting in CloudCompare. Slices and contours have been generated from both point clouds in order to graphically compare the dome's diameter on different horizontal planes, its deformations, and curvature trends. From the point cloud acquired in the nave, 32 contours have been extracted parallel to the XY-plane. The first curve could be approximated by a semi-circle having a radius of 7.18 m. In the same way, 44 contours have been extracted parallel to the ZX-plane from the same cloud.

The profile of the masonry intrados measures to a maximal height of 36.34 m from the Basilica floor. The curvature of the masonry intrados is approximately equal to a semi-circle with a radius of 7.07 m. The circular vaults of the intrados rises above the pendentives, with a horizontal section having a 7.19 m radius at the quoted reference height of 25.95 m from the floor. The uppermost central section, measured from the starting point of the drum, is 10.95 m in height. (Figure 10).

The profile of the masonry shell derived from measurements in the roof space yields an approximate radius of 6.66 m. With regards to the outer wooden coverage, the vertical section in the centre of the geometry could be approximately traced through two arches, with radii of 7.45 m and 7.70 m.

Considering these approximations were evaluated graphically, the overlapping of curves allows the investigation to consider a vertical section of around 0.30 m in thickness.

The resulting thickness of the masonry shell is indicator of a satisfactory accuracy of the graphic analysis of the dome's geometry. In fact, the authors agree with what has been found out during last interventions in the roofs between 2009 and 2013. In those occasions, a crack in the shell revealed a two-headed arrangement of bricks.

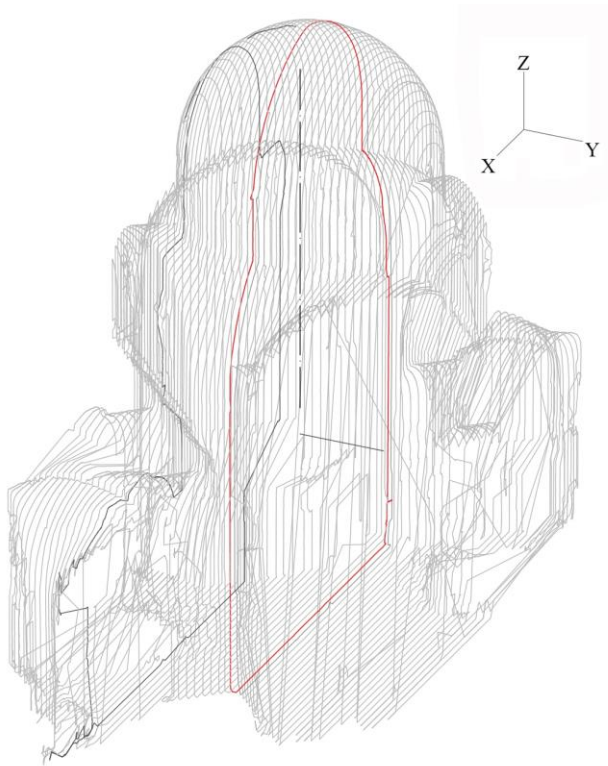

Figure 8. Contour lines on ZX-plane

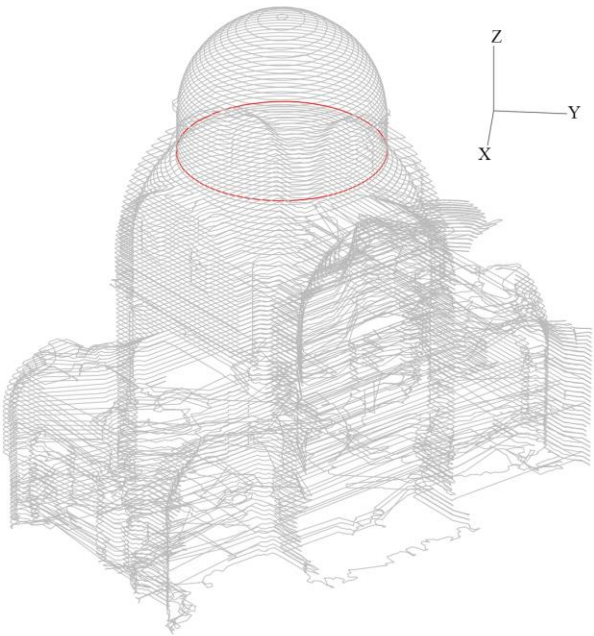

Figure 9. Contour lines on XY-plane

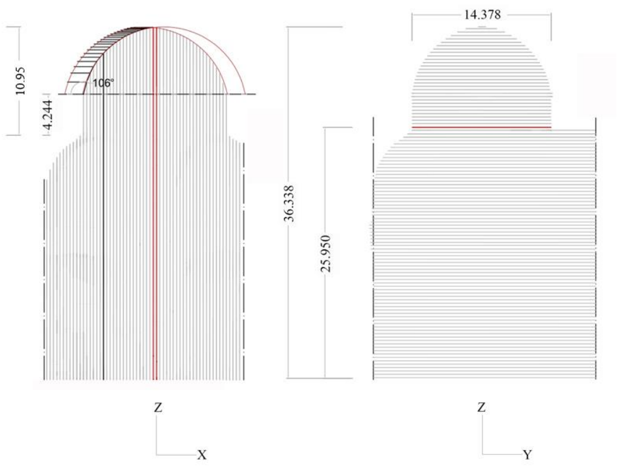

Figure 10. Measurements of contour lines extracted on XY-, and ZX-planes

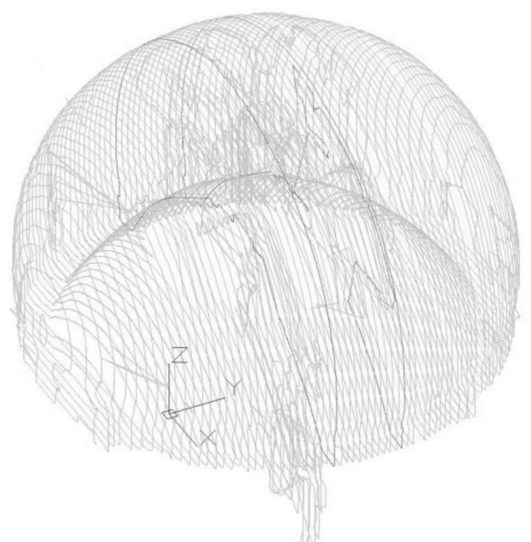

Figure 11. Contour lines of the inner masonry extrados, and of the external intrados of the coverage on the ZX-plane

3.2 Timber superstructures

The construction techniques of the timber superstructure are comparable with the ones in Venice's lagoon (Piana, 2009). The bearing system is based on twenty major struts, which are supported below at the level of the system's floor plates, and reaches the third rings at a height of about 7.70 m from the roof's floor. The struts are connected to the floor plates through mortise and tenon joints. Four wooden ties, having circular cross-sections, span the width of the dome, and anchor the meridians of the external coverage. Between the level of the footsteps and the extrados, two systems of radial collar-beams overlap each other, respectively at the quote of the second and of the third ring.

The complexity of this system therefore demands conventional measurements as well as detailed survey reports. In particular, for the case of the scarf joints of the curved purlins, and for the nailed sections between the minor rafters and the radial ties.

A second system of twenty-four minor struts rise from the first ring to support the second ring directly above. The connection at the base of each minor strut consists of a nailed locking system, which varies according to the beam sections and to their dimensions. Each of these connections has been recorded and 3D modelled for accuracy and completeness. In the case of the struts, however, the laser scanning has been able to detect only three of the four surfaces of each individual strut. The hidden surface, usually facing the outer shell, has been modelled by interpolating the 2D sections of each strut. In a similar fashion, the ribs profiles have also been accurately measured and interpolated. It is then known that they are supported by the first circular tie, in which they are grafted with an in-depth section varying about 0.02 and 0.025 m.

An illustrative example of the necessary interactions between the scanner surveys and traditional recording can be seen in the curved rafters. The rafters can be described as the meridians of the outer shell, with their geometries and sections derived from the point clouds measurements. However, they have many features that had to be considered beyond what the point cloud measurements could offer. For instance, parts of the certain rafters are composed of two flanked elements, and each rafter consists of overlapping and varying vertical segments. The segments can be joined with scarf joints, or by simply alternating the horizontal splices (Figure 13). Compared to the relatively complex process of laser-scanning and processing point cloud results, alternative methods with basic reports, photographs, and conventional measurements are well suited for such details (Figure 12). They do not replace bur rather complement the point-cloud geometry findings. The two general methods can be purposefully combined, yielding more detailed results and a deeper understanding of the dome's geometry and construction.

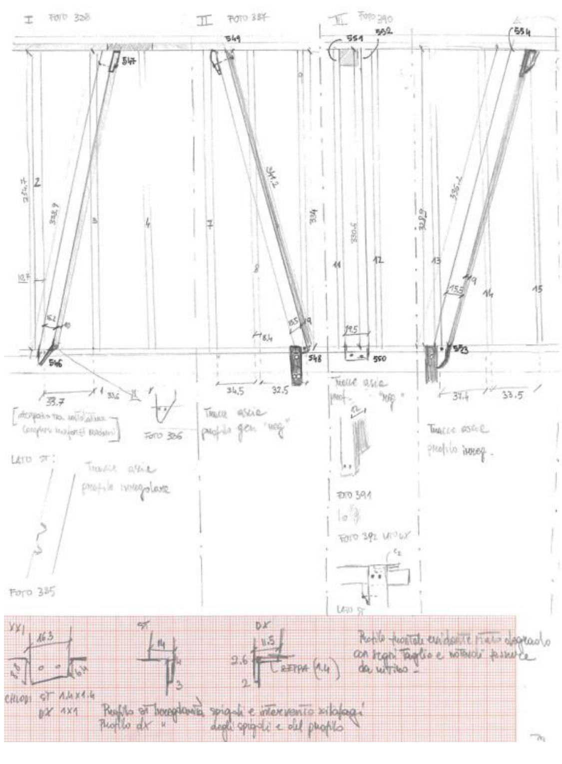

Figure 12. Report on site of intermediate struts details

Figure 13. Construction details (from above): Different ribs compositions in the outer coverage; Nailed connection of a minor strut to the first wooden ring; Junction among minor strut, radial tie and second wooden ring

4. CONCLUSIONS AND FURTHER RESEARCH

This article presented preliminary operations and methods carried out in documenting one of the most interesting cases of Italian cultural heritage, one that has not yet been digitalized or studied in-detail in terms of its construction techniques. The paper reviewed a multi-task investigation on timber superstructures, where geomatic technology and 3D modelling represent a fundamental first step; they are further complemented and completed with conventional methods focused on construction techniques and details. This paper has finally presented the process of data acquisition of a research project still well underway; this method still offers flexibility, and can undergo further developments and refinements when applied to other domes in the Basilica in Padua.

In summary, the authors found that the simplifications of the point-cloud model are suitable for a creating a general 3D model. Furthermore, the 2D drawings confirm their necessity to better describe the construction techniques, projecting in detail the inner joints. This methodology will also offer an option to create a database, and codifying each element and creating short individual reports in a shared information system. In general, the point cloud results represented a reasonable process to accomplish measurements and determine geometries of building’s contours.

The data extracted through CloudCompare and available as .dxf format are expected to provide statistics about the profiles of various elements, and estimates of the deviations from regular circumferences. Far from automated processing, however, the complexity of ancient timber frameworks still demand traditional measurements and evaluations. In cases like these, conservation practice requires specific preliminary knowledge of construction techniques, which are obtained only through direct investigations by operators. In the future though, this general methodology is intended to be repeatable and perfected through its application in the other domes of the church, with the possibility of detailed comparisons among the geometries and components throughout.

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