3D Technologies for the Digital Documentation of an Ancient Wooden Structure

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Abstract:

In this paper we would like to present an operational procedure for surveys of complex structures, such as the wooden dome of SS. Giovanni e Paolo in Venice. The aim of this work was to analyse the shape and the geometry of this very articulated constructive technique: because of its complexity, a laser scanning survey, with the support of more traditional methods, such as direct and topographic survey, seemed to be the best way to analyse this structure: from the data elaboration it was possible to create a 3D model of each element as in reality, without any simplification. In line with the growing demand of digital documentation in the field of Cultural Heritage, the 3D technology applied to this research allowed an immediate reading of the whole architectural system. This paper analyses the difficulties encountered during the survey and illustrates the solutions chosen to overcome them.

1. Introduction

The aim of this research was to define a methodology for creating accurate digital representations, starting from a high-resolution laser scanning survey, in order to analyse the shape and the spatial complexity of an intricate structure. At the end of this work we obtained an operational procedure for future surveys of similar structures.

This work arose from the will to study and analyse one of the most fascinating and particular architectural techniques in Venice: the wooden domes. The dome of SS. Giovanni e Paolo was the perfect case study: it had not been entirely studied yet and it was possible to access it safely to carry out the survey and the necessary geometrical analysis.

The result, obtained after the editing of point-clouds, is a 3D model of each one of the dome’s elements, regardless if it is a wooden, wall, or metallic element. Different phases were needed to achieve the final result: on-site inspections in the Basilica and in the dome, on-site
data acquisition, which was carried out in two days and finally data elaboration and creation of the 3D model. It was also necessary to scan the interior of the Basilica, in order to study the curvature of the wall intrados of the dome. The survey has been carried out together with an historical research with the aim of acquiring as much information and drawings as possible on the architectural evolution: the graphic and bibliographic documentation of the wooden dome was indeed scarce. The survey allowed us to obtain a deeper knowledge of the structure and therefore to read the XIX-century drawings and historical representations in a more critical way than when we first started. The model shows the formal differences of the structure in comparison with the historical representations. Not only the wooden elements are represented in a different position, but they are also represented with a more regular and simplified geometry than in reality.

Data acquisition through the laser scanner and the further 3D modelling is a very well known method in architecture and in the field of Cultural Heritage [1]. Thanks to the laser scanning technique it is possible to analyse and study the object in a 3D environment, even from the georeferencing of the point-clouds obtained from the scans [2]. In addition, with this model it is possible to understand the geometry of the wooden beams and it also works as a support for further analysis, for example in the conservation field. The representation of the three dimensions allows the reading of the condition of elements, and the model can be used as a database of the architectural parts [3].

A wooden system, as complex as the one of the Venetian domes, can only be represented with a 3D model. This is the only way to clearly read the whole structure in its complexity. At first, large architectural structures can be very difficult to read and to separate into their different parts; this happens because more elements were added during later restoration works that can alter the original shape, which becomes often more complex. However, with the model it is possible to read the single parts and understand the hierarchical structure. The laser scanning technique was the best procedure to create a 3D model of such a geometrical complex structure such as the dome of SS. Giovanni e Paolo. The model not only had to be accurate, but also easily understandable in each of its different elements and this was possible only thanks to the applied survey method. Moreover, the model was not only thought to be an end in itself, but also to be measured and analysed in the future, adding new information, if necessary [4].

In the following paragraphs a brief historical introduction of the dome of SS. Giovanni e Paolo will be made (Sec. 2, 2.1), followed by a description of the methods used to carry out the survey of the wooden and wall structure. Data acquisition (Sec. 3) and elaboration processes
(Sec. 4) are described together with the creation of the 3D digital representations (Sec. 5). To conclude, final considerations on the research and the aims achieved are presented (Sec. 6,7).

2. The Dome of SS. Giovanni e Paolo Basilica

The SS. Giovanni e Paolo Basilica (Fig. 1) is located in central Venice and it overlooks the northern part of the lagoon; the dome was built around the half of the XV century, even though a precise date is not known [5]. What is known is that this dome is part of an architectural tradition that was born with the 5 domes of St. Mark’s Basilica: at first the reason of this complex structure might seem the protection of the dome from weather conditions. However there were lots of simpler and less articulated ways to protect the elements from the rain, therefore the real aim of the choice of this particular technique was the will of elevation.

The SS. Giovanni e Paolo dome, as well as all the domes of the same period, presents a few differences in some of the system’s wooden elements from those of St. Mark’s Basilica, but the architectural model is pretty much the same: wooden structures that start from the tambour of the wall domes and that rise on the lagoon landscape, looking for the volumetric elevation in comparison to the surrounding buildings. As a matter of fact the SS. Giovanni e Paolo dome is the first example of the willingness to change of the constructive process. In fact, for the first time in the Venetian tradition, the wall dome has an oculus in the central part but with the actual wooden structure it is impossible for the light to illuminate the inside of the Basilica: certainly a different kind of structure must have been thought and planned. We do not know the reason of this attempt, but what is known is that the oculus was closed with a wooden plank and the dome was built with a much more traditional shape. It is only in the second half of the XVI century, with the construction of the San Giorgio Dome by Palladio, that tradition undergoes a simplification process, influencing wooden structures from then on [6].

Figure 1. The Basilica and the dome of SS. Giovanni e Paolo in Venice.
2.1. The historical evolution of the wooden dome

As far as the architectural evolution of the dome of SS. Giovanni e Paolo is concerned, the documents we have found are dated from the XIX century (Fig. 2). Around the half of the century substantial changes were carried out that radically modified the wooden structure. In addition to some important but routine maintenance works, such as the reconstruction of the wooden roof and of the external lead structure, a new complex system of wooden and metal elements was added. This completely changed the overall architecture of the wooden dome.

The most radical changes of the wooden system were done between 1826–28 and 1850–53. During the first period the lower crossed timbers in the central part of the structure were renovated and a new horizontal curved structure made of oak wood was added, supported by a new system of twelve larch elements. Furthermore in the fifties, because of the conditions of decay of the structure, a new radical restoration intervention was planned: on this occasion other three horizontal curved structures were renovated and a new elements’ system to support them was created. It was also decided to add a new system of metal tie beams useful to join together the horizontal element added in the twenties and the centre of the wall dome. Finally, also the structure of the lantern was radically modified. In the following years until today, all changes were made to preserve the structure but no substantial alterations were made to the wooden system.

3. Data Acquisition

Given the features of the space and due to the survey problems encountered since the first inspections in such a complex environment, it was decided to use the laser scanning technique. The reduced visibility due to the absence of lighting, a very small
planking level and a high number of wooden elements with irregular shapes make this structure fascinating and extremely complex to be surveyed at the same time. The base has a width of approximately 14.5 metres, the height from the planking level to the roof is approximately 10 metres and these become 23 metres with the lantern and the cross on the top. The planking level, where the wooden elements of the structure are based, has a width of 60cm. Moreover, inside this environment, there was not any artificial illumination and the natural light was all coming from the upper part where a little trapdoor allowed people to go outside. The difficulty of using traditional survey methods such as direct or photogrammetric survey became clear, and therefore it was decided to use the laser scanning technique for the metric survey [7]. With this technique it was possible to overcome all the problems described above: contrary to the passive sensors (topography and photogrammetry), while making the measure the laser scanner uses an encoded light (active sensor) that is almost indifferent to the environment’s light conditions in which we operate [8]. For this reason, thanks to the indifference of the laser scanner to lighting it was possible to solve the problem of reduced visibility, its ability to acquire a huge amount of points allowed us to accurately identify the geometry of the structure and thanks to the short scanning time it was possible to reduce the on site survey time. Moreover, the reduced dimensions and weight of the laser scanner we used - definitely more handy than those used a few years ago - allowed us to take it up to the dome with no problems.

The structure has an octagonal scheme but with the changes made in the XIX century, the observer will perceive a different division, highlighted by the 12 systems of wooden elements. This is the reason why we decided to put the laser scanner in each of the twelve spans. The other scans were carried out from the intermediate and top landing of the staircase that takes you to the top part of the dome, and from the stairs that go outside: in this way it was possible to scan a great part of the lantern.

For all the scans, we used the laser scanner phase shift FARO Focus 3D. This laser scanner has a range from 0.6 m to 120 m, with an accuracy of ±2mm for distances included in a range from 10 to 25 meters. It has a vertical visual field of 305° and a horizontal one of 360°. Moreover, it has a measurement speed up to 976,000 points/sec. A digital camera with a 70 megapixel resolution is integrated in the laser scanner. The acquisition resolution selected for this work was set up to have one point every 6 mm at a distance of 10 meters; however the high number of scans and their very close distance to the analysed object have permitted to obtain very dense point clouds, for
a total of 800 millions points. The main problem of such a huge quantity of data acquisition is the very difficult management in the next phase of data processing.

In the processing phase the scans’ elaboration software easily recognizes some signalization systems. For this reason high-contrast and spherical targets (with a diameter of 12 cm) were positioned (Fig. 3). The acquisition of the scans with the laser scanner was carried out together with a topographic support for a better control in the alignment and registration phases and especially due to the complexity of the structure of the space; for the acquisition of the points we used the total station Leica TCR 1103. In this case, for the collimation of the control points, local lighting systems were used to identify the targets. Finally, the wooden material’s response to the laser scanner did not cause any particular problems in terms of the intensity value.

Data acquisition was carried out in two days. During the first day we created the topographic support with the total station, we carried out the scans from the intermediate landing, the top landing and three scans of the planking level. During the second day we finished all the spans at the basement. A total of 20 scans and 860 million points were acquired inside the wooden dome. During the modelling phase, to analyse the curvature of the intrados, it was necessary to do other two scans from inside the Basilica. In this case the targets were positioned in the apsidal part and in the last two columns of the aisle before the transept.

4. Data Processing

After the acquisition of the data, the first step was the alignment of the twenty scans through the semi-automatic recognition of the targets positioned on the timber elements in the acquisition phase; the average precision obtained in the scans alignment was 4 mm. Some targets were collimated with the total station to guarantee the verticality of the local reference system and to georeference the point-clouds in the same reference system, after their alignment.
In this case, the point-clouds were exported only with the intensity value (Fig. 4): the RGB values, recorded by the laser scanner camera, had not been used due to the weak lighting conditions illustrated before. The same processing job was done with the two scans inside the Basilica. However, in this case the light conditions made it possible to realise a better photographic acquisition than the one done in the dome, so for this reason it was possible to have the scans also with the radiometric values.

At the end of the process we obtained a very dense and detailed quantity of data: in the case of the 20 scans of the wooden system a total of 863,665,301 points were scanned, processed and registered. The point-clouds were then edited: all the data recorded by the laser scanner that were considered unnecessary were deleted, like a few parts of the roof that could be seen through the holes at the base of the dome. At the end of the elaboration process, the cloud had a total of 861,912,073 points.

The software that we used for data processing are FARO Scene, for the alignment and the registration of the point-clouds, and Pointools, that allows a better management of the data: with this software it is possible to visualise in a rapid way a huge number of points and to take the distance measurements and to extract the coordinates of the points. Moreover, it is also possible to create 3D visualisations of point clouds directly from Pointools (Fig. 5): in this work some fly-through animations have been prepared for future demonstrations in order to show the survey’s first results. The final elaboration of the data allows a representation for the 1:50 scale, as previously set during the survey’s
project phase; however the traditional drawings allow only in part to understand the wooden system in its spatial complexity and to analyse the process carried out during the technical construction phase. For this reason we decided to choose a 3D digital representation: in fact, a 3D model allows a clear vision of the structure’s complexity and in an immediate way.

Moreover, once the accurate 3D model is created, it is possible to extract the useful 2D information and views, directly and automatically from the 3D environment. Applying this procedure, it is important to check that the measurements comply with the representation scale chosen for the work [9].

5. Modelling and Data Representation

The virtual reconstruction of a complex historical architecture is also an important communicative tool [10]: this way of analysing the geometrical information is easier than the 2D traditional drawings and it can be considered fundamental for spreading this constructive technique to a non expert-eye.

After the processing of the point-clouds, we moved on to the 3D modelling. The entire model was created using Autocad. The workspace choice does not allow any automation during the modelling process, and it guarantees the coherence of the model with the surveyed data. In fact, thanks to Pointools for Autocad plug-in, it was possible to visualize and work directly on the point-cloud to extract the sections or the useful profiles. Each vertical and oblique element was modelled with solid and loft surfaces from the extraction of profiles derived from horizontal sections of the cloud at different heights. The horizontal elements, geometrically simpler, were then created with the extrusion of solids from vertical profiles. For the curved objects, such as the wall dome, sections were extracted radially, with respect to a common centre (Fig. 6).

The solid modelling and loft surfaces allow to keep a good adherence to the data surveyed; in fact, the cross sections define the profile of the resulting solid. With the more complex elements we made a high number of sections and we specified the path or the guides for

Figure 6. Generation of solids and loft surfaces from laser data sections.
a better control on the surface or solid shape, as for the curved roof elements. Thanks to the Boolean operations, all the wooden system's joints were made. These conditions, together with the possibility of using a high number of profiles directly from the point cloud, guarantee the geometrical coherence with the real data. All data for the graphical part come from the processing of the twenty scans of the wooden dome and the two scans from inside the Basilica. Only for the modelling of the external cross, aerial Lidar data were used, acquired for a bigger research of Venice and of SS. Giovanni e Paolo insula; in this way we were able to read some of the measures between the summit points, despite being sparse, and getting the size of the cross on the lantern.

The modelling process of the wood, metal and masonry elements present in this environment, was carried out without applying a general simplification of geometry and space. We did not use the rationalization of the structure, which instead was represented by its spatial irregularities and formal anomalies of the elements that compose it.

Although the regularization of the wooden structure would have allowed a process simplification in the modelling timing, we decided not to do any rationalization of the shapes, in order to analyse the real geometry and to allow future applications of the model in the restoration and structural analysis fields, if required. For this reason, every single element was modelled according to the geometry and the real position.

The final result was obtained after some months of data elaboration and modelling in Autocad. The 3D model visualization and the video-animations were made by 3D Studio Max (Fig. 7); in particular, these are very important to understand the constructive process of this Venetian architectural technique. In fact, thanks to the 3D digital representation and to the subsequent animations that can be achieved (Fig. 8), it is possible to clearly grasp the spatial distribution of all the elements that compose the dome of SS. Giovanni e Paolo. In particular, three video-animations were made in order to show the complexity of this amazing structure: an animation of the entire system and two animations of two different details. In the first case every single element was virtually disassembled, from the external lead structure up to the wall dome, with the intention of showing the hierarchical structure and to make the viewer able to easily understand the constructive technique. The second video animation focused on one of the twelve main wooden elements added in the 1850s that support the entire dome: in this case, with a much more detailed view, the aim was to underline that every element is different from the others and also that every wooden joint of the system were created. Finally, we also made an animation of the staircase that
takes people up to the top, in order to show that every single element, functional or structural, was modelled according to the real geometry, only thanks to the methodology applied in this research.

6. Results and Reading of the Model

The knowledge method applied in this study case, with the laser scanning survey and digital modelling, allowed us to understand the geometry and the spatial complexity of one of the most particular techniques of the Venetian architectural tradition. Moreover, this procedure allowed the comparison of the actual survey with the historical representations to understand the difference of the timbers’ position.

Because of the complexity and constructive peculiarity of this structure, there are very few examples on the wooden systems of domes that can be compared, except for the analysis conducted on two of the five domes of St. Mark’s Basilica: Pentecoste and Profeti [11]. Often in fact, survey and structural analysis campaigns are carried out on the intrados of the wall domes and vaults [12]. Moreover, even though the general organization of the wooden beams derives from St. Mark’s domes, each Venetian dome is a case on its own with a different element composition and its collocation in space.

The 3D model allows an immediate reading of the information about shape and dimensions of the structure; the virtual navigation allows to perceive the whole architectural system, which is impossible to clearly recognize in the real environment. In addition, the animations created allow to spread the knowledge of this construction.
technique to people who are not specialized in this sector. The analysis of the shapes of this structure is fundamental not only for the knowledge of the complicated wooden system and of the ranking composition of the elements that create it, but also for other analysis and considerations, for example about the state of condition and decay [13] or its historical architectural evolution.

Thanks to the model obtained through the above-described procedure, it has been possible to compare a section of the actual state of the dome with a drawing realized around the 1850s. As we can see from the pictures (Fig. 9), the XIX-century drawing was realized with some simplification of the elements, preferring a much more artistic but geometrically less correct view. Not only some wooden beams are represented in a different position compared to reality, but also the geometry of some elements, as the curvature of the roof and of the wall dome, is represented with a regular shape, whereas the model shows us that they cannot be brought back to a known geometry.

7. Conclusion

The methodology applied to this research allowed the representation of the 3D modelling of the dome in its actual state of conservation with all the irregular shapes and the geometry’s deformations. To conclude it can be said that this research showed that the SS. Giovanni e Paolo dome was the perfect study case of the laser scanning survey for
complex structure analysis. In fact, thanks to the accuracy and the large amount of laser scanner data acquisition in a relatively short time, it was possible to study in a very detailed way an architecture with such a geometrical and spatial complexity [14].

The 3D model allows to clearly and quickly understand a structure that is otherwise hard to comprehend. Moreover, the model was created not only as an instrument for the geometrical and spatial knowledge of the dome, but also in order to be useful for further researches: the survey is firstly an analysis of the shapes and then it can be used as a support for other investigations in the architectural field. For example, its application in the conservative field becomes obvious as a spatial support for every worthwhile analysis [15]: the model becomes an important documentation of the state of condition of the wooden beams and it also might be used as an archive of each one of the objects that contributes to compose such an interesting structure with such an important architectonic value.

The survey and the subsequent 3D modelling, allow an easy comprehension of the wooden elements of this complex constructive system and they are the basis for the creation of a database where it is possible to georeference the information about the wooden structure. Every single element can be catalogued, for example, according to its structural function, type of wood, conservation status and maintenance and renovation interventions carried out in the past. The results allow many future applications, especially in the conservative and diagnostic field.

At the end of this work, we would like to present this methodology as an operational workflow for the survey of Venetian historical wooden roofs and, in particular, for wooden domes.

8. References

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