THE SURVEY OF THE WOODEN STRUCTURE OF THE ROOF OF PALAZZO DUCALE IN VENICE

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Abstract

The wooden structure that supports the roof of Palazzo Ducale is very complex becouse of continuous works of maintainance and restoration occurred during centuries.

The photogrammetric laboratory of CIRCE – IUAV is employed in the survey and representation of the overstanding structure of Major Council Hall that, by one side, supports the covering and , by the other, upholds the box ceiling of the hall.

The truss structure is trampleble and visitable only throught a thin catwalk standing on the middle of the orizontal tie beam.

A traditional topographical survey appears hard just becouse of the unavoidable movement of the structure that is very elastic. Photogrammtery is unproposeble just for the strict space and for the its complexity.

It was decided to realise some laser scans setting up the instruments having care to not urge the wooden flooring to avoid any movements. Nine scans have been done surveying 10 milions points. Clouds were allinged using targerts to obtain one unique cloud. From the big cloud some "sub-clouds" of points have been extracted contained each one a truss, doing as matter of fact some thick trasversal sections. The sub-clouds have been employed in the 3D modelling of each wooden element applying the solid modelling tecniques based on primitives to better interpolate the laser points.

The choice was to realize a 3D model geometrically regular of each elements to represent the real complexity of the cover system.

This paper was founded on several considerations made on the wealth of the studies published on historic wooden structures. Our finding of only a small number of publications, though very important and holding scientific validity, has highlighted the need to develop research in these fairly little-explored settings.

The case of the roof of the Hall of the Great Council of Doge's Palace in Venice was found to be a piece of very important historic testimony of an uncommon construction procedure, whereby a span of 25 meters was crossed without the use of intermediate structures.

The general disinterest that architecture and restoration critics have demonstrated in horizontal wooden structures in our rich heritage is due to the major difficulties in reading these structures as part of the study presented here, whose objective is to describe a possible course to follow in order to define a product useful in terms of architectonic renovation. In addition to the material drawn from biochemical research into wooden materials and the structural investigations that are no longer sufficient, in the Italian technical literature, no specific works exist that focus major scientific attention on an investigation into wood structures from a purely architectonic perspective..

We believe that to protect this immense and previously little-known architectonic heritage, it is vital to engage many scientific sectors and begin identifying a possible design route to enact in the case of conservation of very valuable, historic wooden structures.

Therefore, this work departs from these assumptions and proposes to tackle the problem of conservation of structures by starting right from the root of the cognitive problem, i.e. from the geometric survey, a fundamental basis of all the subsequent investigations and product of great information complexity that requires the involvement of several spheres of learning for its creation.

Historic wooden structures engage in immediate communication with the observer: the clear geometry of the elements that occupy a limited portion of the space and their arrangement, the hierarchy of the elements of the structural units and the present systems, and the dimensional relationships reveal the organization given to the elements, in other words, the relationships imposed.
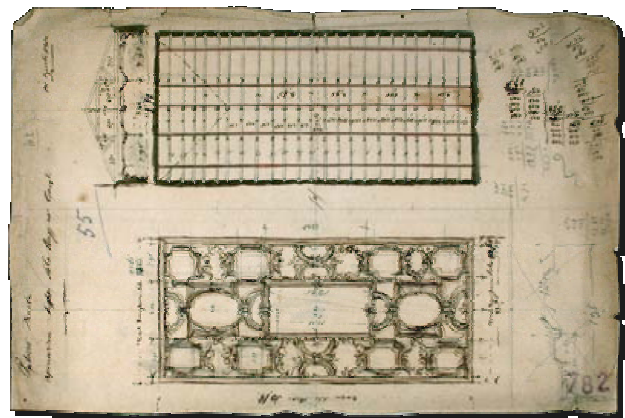

figure1: an old survey of the structure

The materials used in building the structures are left generally in view, partly for physiological reasons of conservation, therefore, it is possible to search for the particular characteristics, such as the species of wood used in the structure, the woodworking processes used, the degradation suffered, etc.

At times, however, larger wooden works, such as the roofs of large monuments, reveal extremely complicated and not immediately recognizable characteristics. In truth, this owes not so much to the elaborate organization of the structures as much as to the alterations, and more so to the repairs that were done on the structure over time and which considerably increased the number of axes and units present. Distinguishing the old from the new, the original structure from the additions and alterations, is done by the research of the ratio of the structural

complex and the hierarchical composition of the units present.

High warpings and lesions of the elements and structural units denote the presence of excessive internal tensions, certainly greater than those that stress elements which have retained their form. The presence of accentuated deformations in some sections allows us to make educated guesses about the regions of probable crisis and rupture.

Therefore, the wooden structures can be interpreted by the peculiarity of their general characteristics (among which, the configuration is one of the most significant and particular elements) and be interpreted as to operations, efficiency, etc. by the warping and the lesions, which approximately and qualitatively show the distribution of the internal tensions for each individual membrane.

Surveys

The design of the survey of the roofing system of the Hall of the Great Council of Doge's Palace in Venice, has clearly shown a series of difficulties to surveying, based on the following reasons:

- the size of the room;
- poor visibility due to very poor lighting;
- absence of a suitable treadable floor level;
- a large number of objects present in the room;
- highly irregular geometry of the structures' membranes.

The room under the roof takes up a very large empty volume of the Hall, measuring 24.5 x 52 meters where there are seven meters between the suspended ceiling over the underlying Hall and the peak of the roof. Between the system of trusses and the ceiling, there is no slab with its own treadable floor level; therefore, the ceiling is suspended directly to the chains of the king-post trusses. A one-meter wide walkway, located along the central band, lain on the chains of the king-post trusses and passing alongside the upright trusses, permitted us to investigate only part of the room, making us absolutely unable to investigate the lateral parts and the rear part of the room in correspondence to the slant of the downward slope in the roof towards the square.

In light of these considerations, we were better able to understand the difficulties in applying traditional survey methods.

The lack of a sufficiently wide and rigid treadable floor level where we could move about easily prevented us from making direct measurements on all the structures, as well as complete the topographic measurements in the space under the roof in question. On the other hand, it was very difficult to carry out the measurements in a room both poorly lighted and difficult to illuminate.

The difficulties presented have led to the decision to carry out the entire survey by using laser scanner instruments for the following reasons:

- the fact that laser technology operates regardless of lighting levels;
- the capacity to uniformly acquire a great number of points for the definition of the geometry of structures without defining beforehand the elements to survey.
- the acquisition of a dense point-cloud would have enabled creation of a 3D model and, therefore, think of an innovative system of representation.

Use this instrument, not only to resolve some of the contingent problems, would have permitted experimentation into the potential of this instrument with a case of very complex wooden structures.

Application of this technology has simultaneously revealed both its potential and its limits in an architectonic setting of such greatly complex geometries.

This diagram briefly summarizes the phases of the survey carried out:

- Direct and viewable survey campaign [1 - 23 July 2002]
- First inspection of site with the photogrammetry laboratory [10 September 2002]
- Acquisition of the laser scanner data, supporting topographic grid and photographic campaign [30 October 2002]
- Data processing [November 2002 - March 2003]
- Acquisition of control measurements from topographic survey and direct survey [5 March 2003]

Rows of the 22 wooden structures located a intervals of 1.8 meters, one after the other, have caused the team to design a total of 8 scanning positions, located at about every three trusses (scannings no. 4, 5, 6, 7, 8); another two positions located on the section of the walkway that leads to the roof of the *Sala dello Scrutinio* (scannings no. 1 and 2) and still another on the section of the walkway that leads to the dormer window facing the bay, in an attempt to orient scannings to cover the entire room.

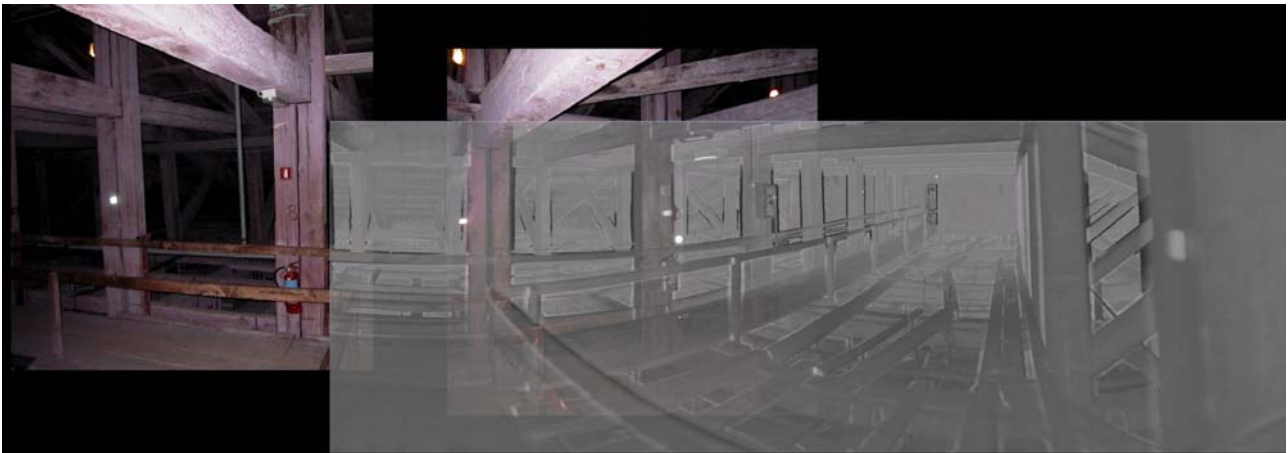figure 2: Laser scanner acquisition campaign

figure 3: elaboration of digital photos and intensity image to show the complexity of the place
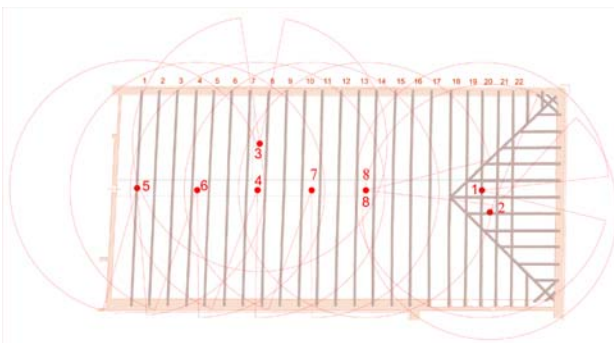

figure 4: scheme of the scans

In addition to positioning the scanning points, a small topographic grid was designed for placement of the control points (materialized on the structure of reflecting targets), necessary in phases of processing in order to orient the scannings and therefore, were set up along the entire longitudinal direction of the room; in this way, the team was able to see at least three necessary targets on all the scannings to carry out a rigid rototranslation.

While the team was not able to develop the grid over the entire room, we were able to create a triangle that ensured the rigidity of the support grid.

The scannings were made using the tried and true laser scanner instrument, LMS-Z 210 Rigl 3D, which presents an accuracy in measurement of ±2.5 cm

Other scannings were linked together and geo-referenced by using reflecting targets.

Absence of appropriate light has made it difficult to use the RGB images by Rigl LMS-Z210; therefore, the team executed a photographic campaign that compensate for this deficiency. With a series of photographs, we attempted to make the shots that covered the same visual cone of the laser, useful to making an easy reading of the numeric survey model.

Processing of point clouds

The processing phases of the point-clouds obtained came from a particularly long and complex operation for three main reasons:

1. The unique configuration of the room in the space under the roof

2. The raw data resulting from scans show signs of strong interference (noise) making a clear reading of the surface and surroundings difficult to achieve.

3. The large dimensions of the room and the great geometric complexity of the objects present in the room (kingpost trusses and structural truss system) have added to the production of an enormous mass of difficult-to-handle data from any and all of the standard posts.

Reconstructor by 3Dveritas was the process software used and deemed most appropriate to the case, whose advantages include the following:

- possibility of processing data from scanners, made using a variety of laser scanners (Rigl, Callidus, Cyrax…)

- flexible and intuitive structure of the controls, which allows the user to supervise with extreme facility the succession of processing phases

- display of the data in the form of 2D and 3D images

- LED display for a more rapid display of data

- automatic edge detection

- a range of useful tools for geometric operations

- ability to export data in DXF and VRML formats

- selection of portions of the point-cloud in a faster and more intuitive manner, by also selecting on the 3D cloud

The phases of data processing of the software are:

- *Preprocessing*:

to extract the information necessary for subsequent data processing.

Proprocessing includes the following phases:

- Hole Filling
- Normal Computation
- Confidence computation
- Edge detection
- Noise Reduction
- Build LOD

These parameters were set after having first carefully analysed the scans and the quality of the rough figures. Every single choice of the parameters to enter in the control chart derives from considerations made on the quality of the raw data and the settings of the instrument.
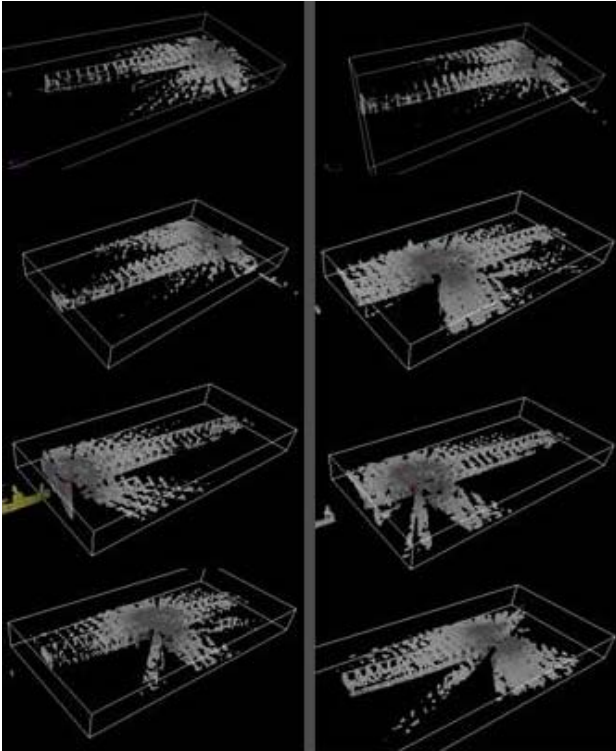

figure 5: edge detection
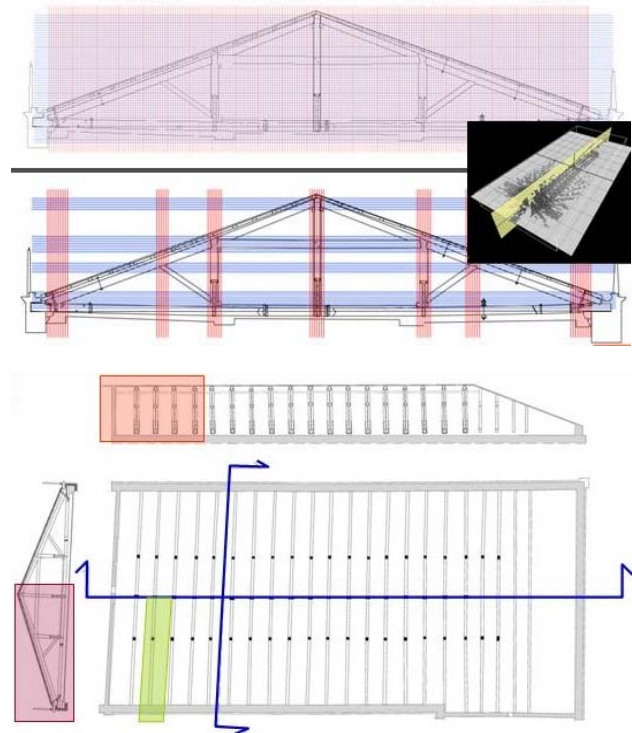
figure 6: registration

figure 7: sections extraction and data restitution

The preprocessing operations have been done simultaneously on all the scannings, since all presented the same characteristics of the raw data and all have been made with the same parameters of acquisition

- *Registration*:

Consists in aligning the various scannings, each with its own reference system, assigning a new and unique one to each (reference frame). This operation is based on recognition of the control points materialized from reflecting targets, detected by topographic means. Pursuant to rigid rototranslation, the s.q.m. obtained on the control points varied between 0.005 to 0.024m.

- *Integration*:

Automatic process that identifies the overlap areas between the different scannings based on the confidence values calculated during the phases of pre-processing and which precedes triangulation.

- *Triangulation*:

Converts the point-clouds acquired by the scanner into a surface representation. The mesh phase transforms the set of raw 3D points into a continuous surface and therefore produces a more intuitive visual representation (especially if mapped with the reflecting or with texture data), while at the same time, reduces the mass of data. Reconstructor uses a 2.5D-Meshing algorithm that uses proximity information inherent to the 2D-image range image and then triangulates the point clouds on a basic scanner. Every scan is first transformed into an initial low-resolution mesh and then refined until reaching a definite accuracy. This approach results in a multi-resolution mesh, using larger triangles where the surface of the object has a smaller curvature and smaller triangles in the areas with a higher curvature.

- *Texture Mapping*:

In mapping above the mesh or above the point cloud in the RGB image acquired during scanning. In the case of this application, texture mapping has not been done since it is not necessary with respect to the purposes of research.

Construction of the model

It was possible to find a series of 2D graphics by performing a series of surveying tools present in Reconstructor, that allow automatic extrapolation of the sections, according to a plan defined beforehand on the point cloud. Overall, 220 sections were extracted. The enormous volume of files derived has not permitted us to create a single file with all the sections; however, since all are in the same global reference system, we worked on small groups of sections. Once the meticulous work of editing on each section was complete, the processed and significantly lightened sections - selected for creation of the final model - were imported into a new file.

The cloud was sectioned with a horizontal plane perpendicular to the vertical of the Laser Scanner, i.e. orthogonal to the Z-axis of the global reference system. Once identified, the longitudinal plane was extrapolated in the horizontal sections already extrapolated. In fact, once we deduced the angle between the plan and the line of section desired, we set this angular value with respect to the section plane set in the software, thereby obtaining a section plane in the desired point.

The concept at the basis of the choice of the sections to use for composition of the 3D model is definition of the position of the nodes of the structures, the fact that the sections become more dense in correspondence with the nodes has enabled us to determine the position in the space of the structures. The horizontal sections have allowed us to define the section of the vertical elements (such as small columns), the vertical sections of the horizontal elements (such as the chain and the counter-chain). The inclined elements, such as struts and knee rafters, were defined by both types of section. We obtained a Wireframe model which was then used to extrapolate the solid 3D model of the entire room.

Conclusions: reading the model

The scheme obtained has shed light on the process of simplification that leads to its representation from the measured

reality. The transition from the point cloud to representation evidently leads to an approximation or simplification of the data surveyed by filtering operations, integration, triangulation and data editing.

The work of creating a "cognitive model" in the survey, as part of the contemporary culture, today consists in defining which parameters can be described with an adequate cognitive model of the object, that in addition to being understandable, communicable, useful and able to be manipulated, also adheres to the interests, needs and desires that man expresses in relation to his environment.

It seems evident that the group of information gathered around an object is increasingly more vast than any individual representation, graphic, analytical, or alpha-numeric it may be, can ever explain.

According to an operating approach, the work of survey entails, in a new meaning, the construction of the cognitive model of the object, perceived as a mental logical construction, based on conjecture that meet the observations, to the extent that these are made. Surveying means transferring observations from the real object to the model, reaching its increasingly more general formulation.

As a result, the characteristics of the forms of representation adopted to establish the data observed are much less important. On the contrary, it is important to recognize that each image produced constitutes only a partial representation of the model, as well as not being a traditional graphic representation of the survey than periodic representations, not of the object, but of its cognitive model.

The work of survey is therefore a transfer of information from the object to the model by a breaking down technique that, with different methods, enables us to reach the desired degree of analysis.

In this sense, therefore, the geometric survey is part of a more complex and differentiated cognitive model.

Thus, conceiving a cognitive model or "infographic" model of an architectonic object means making sub-groups within it, if all the surveys executed and seek to pursue in a far-sighted line that tends to add information rather than to the research in creating a new and more detailed and precise model. Only when we make comparisons between them can we add constructively to our knowledge of an object.

These considerations have induced us to conceive the final model as the basis of successive elaborations, in order to add to it even more. In this light, the research of historic sources and their integration with the metric knowledge of the structure have attempted not only to learn more about the evolutionary process of the building, but also the gather as much critical material as possible on this structure over time, as a basic preliminary cognitive system to each intervention.

References

Bornaz L., Lingua A., Rinaudo F., *A New Software for the Automatic Registration of 3D Digital Models Acquired Using Laser Scanner Devices,* in CIPA WG 6 International Warkshop on Scanning For Cultural Heritage Recording, Greece, Corfu, 1-2 september 2002.

Sgrenzaroli M., Wolfart E. , *Accurate texture mapped 3D models for documentation, surveying and presentation purposes*, in CIPA WG 6 International Warkshop on Scanning For Cultural Heritage Recording, Greece, Corfu, 1-2 september 2002.

G.Bitelli., *Rilievo di beni architettonici,* in 6° Confereza Nazionale ASITA Geomatica per lìambiente, il territorio e il patrimonio culturale, Perugia, 5 – 8 novembre 2002.
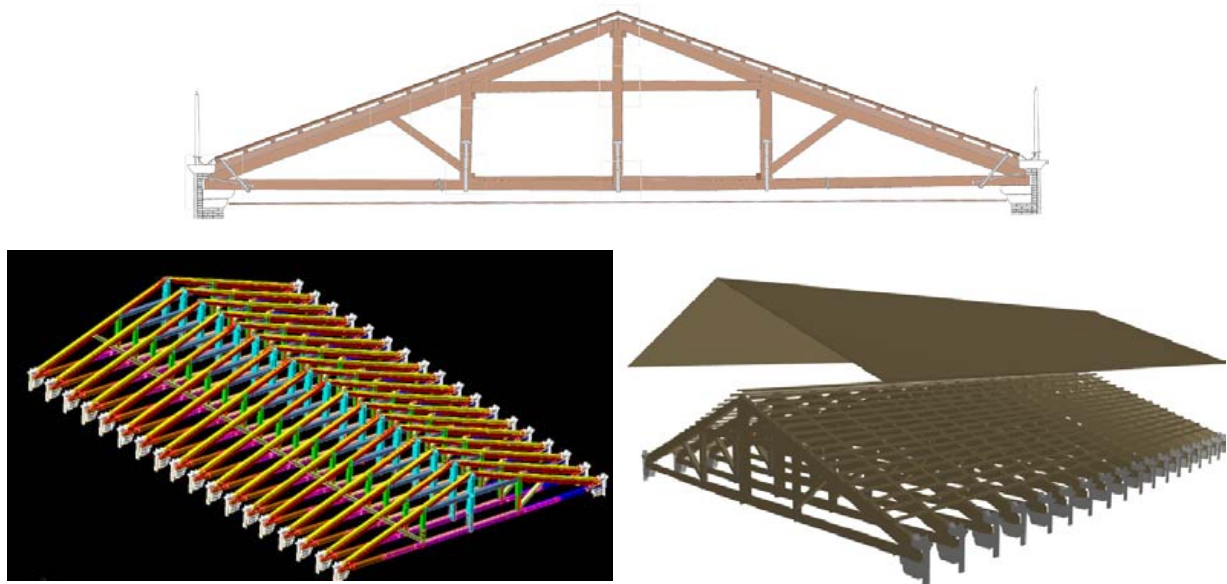
figure 8: structure model and 3D elaboration