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RESTORATION OF HISTORIC TIMBER STRUCTURES: THE GREAT ROOF STRUCTURES OF THE CATHEDRAL OF VERCELLI

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ABSTRACT: The great timber roof structures of the Cathedral of Vercelli offer an extraordinary path of knowledge, diagnosis and conservation, through a collaboration between the architects of the Cultural Heritage Office of the Diocese of Vercelli – responsible for the restoration process – and experts in the field of timber structures.
The interest of the architectural complex is witnessed also by the contribution of renewed architects of Piedmont between the XVIth and XIXth centuries.
The paper goes beyond the diagnostic evaluation, giving an overview on the main consolidation interventions respectful of the conservation of the timber structure.

KEYWORDS: Restoration, timber roof, diagnosis, survey, monumental heritage, history

1 METHODOLOGICAL INTRODUCTION

In general, the conservation of historical timber structures requires the knowledge both of the overall static behaviour, and of its single elements, so that the task of who is involved in its restoration/maintenance can be based on reliable data for a proper project.

Of great importance is the constructive knowledge and understanding of the structure. It can be reached through an accurate geometric survey, both on the wood elements and their technological defects, both of the joints. The wood decay eventually present is also important, it has to be checked and quantified. On this survey is based the diagnosis for the evaluation and grading according to the resistance. The historical knowledge is fundamental for any kind of intervention.

2 THE CATHEDRAL OF VERCELLI

2.1 HISTORY AND DESCRIPTION

The present Cathedral of St. Eusebio of Vercelli was rebuilt after 1570, when cardinal Ferrero gave order to demolish the choir of the great and ancient paleochristian basilica probably dating back to VIth century, that was build on the primitive church built for the will of St. Eusebio, protobishop of Vercelli and of Piedmont around 355, on the place of the burial of St. Teonesto.
The Dome of Vercelli, also called the cathedral of San Eusebio, is a symmetrical, latin coss-shaped building. The ground floor has a size of 3634 m^2. It consists of 3 aisles, of these the much larger one in the middle overpasses the two side aisles. Where the extremely high dome covers the cathedral, the two transepts intersect the main aisle. At this crossing point are modern multi liturgical objects placed, like the ambo, the altar and the Episcopal seat. The two side aisles end with flat chapels,

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while the main aisle continues with semicircular apses after the transept. Along each of the two side aisles are three minor chapels before the transept. On the right side are: the altar of the feretory, the altar of S. Onorato and the altar of S. Giovanni Nepomuceno. On the left side are: the altar with the baptistery, the altar of S. Emiliano (now dedicated to S.Elena) and the altar of S. Guglielmo. At the two ends of the transept are the much larger octagonal chapels of S. Eusebio and Beato Amedeo. Besides these, there are little chapels on the right side the altar of the crucifixion, and on the smaller side of the aisle the altar of S. Ambrogio. On the left side is the altar of S. Filippo Neriand and at the end of the aisle is the altar of the Madonna.

Figure 1: *Nowadays image of the Cathedral's complex*

The five spans in divided aisles are covered with a ribbed vault, massive, quadratic posts and engaged columns. The two transepts on the other hand side are closed with barrel vaults. On the top of these vaults and the smaller cupolas are timber constructions mainly out of oak wood which carry a tile roof covering.
The dome and the larger cupolas are completely made of stone and covered with lead and copper.
The hipped roof is the part which has been retained nearly unchanged in the course of time (both structural technique and form). The form traces back to the four or more pitched roofs, with a primary structure out of trusses or beams and angle bars on the bisecting line. The main timber elements have been worked better and with more accuracy than the smaller elements with less importance for the structure. In other cases the different working techniques (for example sawn and not chopped) are indications that the elements have been replaced or added in later periods.
At the middle of the XXth century, the cathedral already showed big problems of moisture and rainwater leaking, so that several maintenance works started of the timber roof structure. These works were concluded in the 1960's. In 1992 were substituted the covering surface of the St. Eusebio chapel with new lid plates.
In the recent years, thanks to the interest of Bishop Masseroni, maintenance works have been carried out on the roof structures of the sacristy.
The increasing problems of the last years, mainly due to raising humidity and spread rainwater leaking, brought to a general state of decay inside and outside the complex that brought the bishop to consider an overall restoration intervention.

2.2 THE TIMBER ROOF STRUCTURE

The great timber roof structure of Vercelli's Cathedral covers an area of around 3.800 sq. m. and present different typologies between presbytery-choir, central nave, lateral naves and transept. The typology of reference is the truss. In general terms, the examined trusses have the function to support the roof of the religious building and are composed by a tie-beam and two rafters connected with the help of a king-post. Each single element composing the truss derives from a single trunk that was squared by axe. King-post and rafters are connected by two struts. The span between the masonry walls on which lay the trusses is of approximately 15,50 m, the section of the timber elements is of approximately 30 x 30 cm or inferior: often the dimensions of the sections vary in the length of the element and between the elements within wide limits.

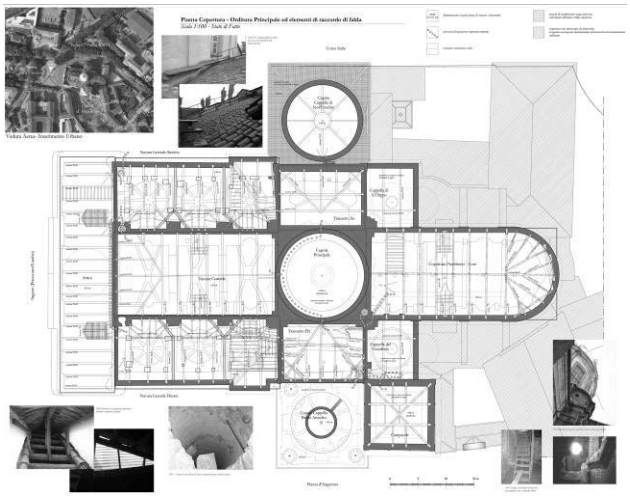

Figure 2: *Plan of the timber roof structure*

3 GEOMETRICAL SURVEY

The conservation project was carried out though a hand survey carried out by arch. D. De Luca in collaboration with the architects G. Corradino and R. Pasquino.

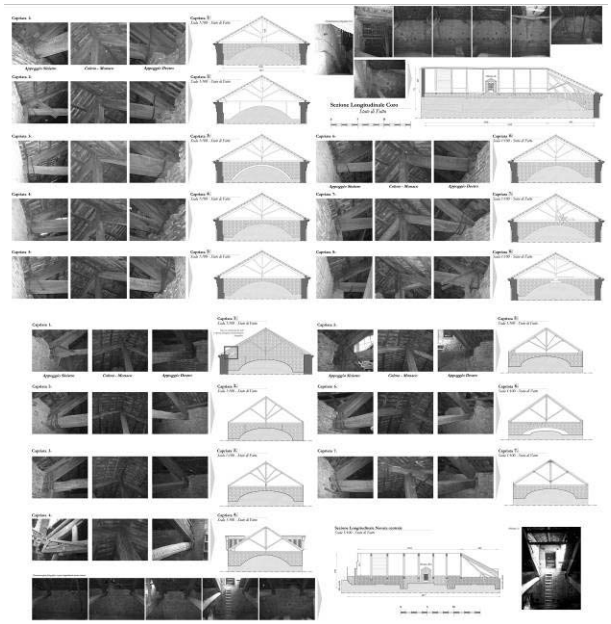

Figure 3: *Survey of the trusses of the transept-choir and of the central nave*

Each single element of the timber structure was surveyed in its dimensions, classified and evaluated under the technical profile and located in the overall structure. The survey was therefore translated into graphical drawings of plans and sections (executed for each truss).
The survey was also supported by an innovative survey technique through a "Laser Scanner" carried our by a Spin-off company of Politecnico di Torino. This work has allowed to located in the exact position all the hand survey without possibility of errors, if not minor ones. Afterwards, the work has been completed with the diagnostic survey on the main structure of the roof.

4 OPTIMISED STATIC MODEL RPLAN

The load bearing capacity of the truss has been modelled assuming an optimal condition of every single timber element. Because the forces in each of its two main girders are essentially planar, a truss has been modelled as a two-dimensional plane frame. A truss is a structure comprising a triangular unit constructed with straight members whose ends are connected at joints referred to as nodes. External forces and reactions to those forces are considered to act only at the nodes and result in forces in the timber elements which are either tensile or compressive forces. This means that torsional forces (moments) are excluded because, doing the calculations, all the joints in a truss are treated as revolutes.
The load cases which have been calculated are: the one for the permanent death load, a combination of death and snow load, death and wind load and for a combination of death, wind, snow and living load. The connections are assumed as hinge joints. The values (max. stress, modulo of Elasticity…) for oak timber have been taken out of table from standard UNI 11119:2004 on Maximum stresses of on site timber of the load bearing system.

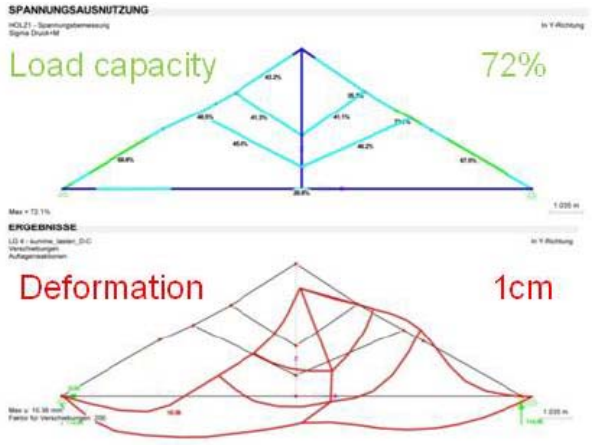

Figure 4: *Results for the load case D-C (highest loads)*

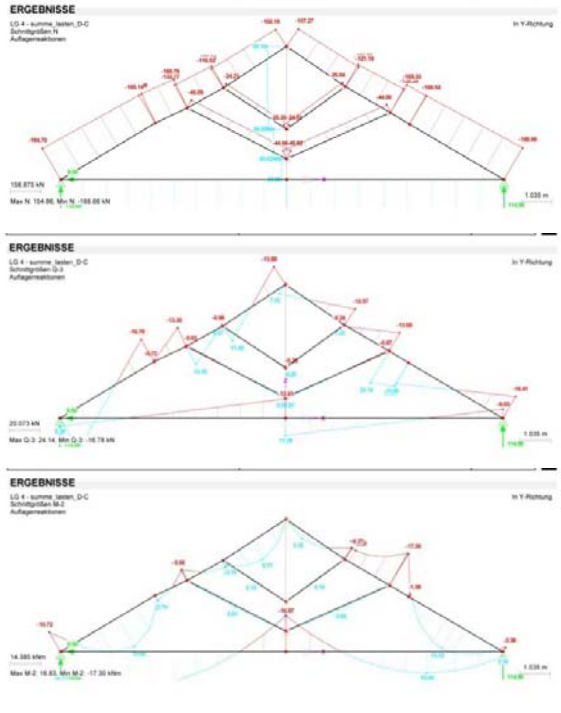

Figure 5: *Axial force working on the beams (a); shear force working on the beams (b); axial force working on the beams (c).*

4.1 STATIC MODEL RPLAN DEFECTS

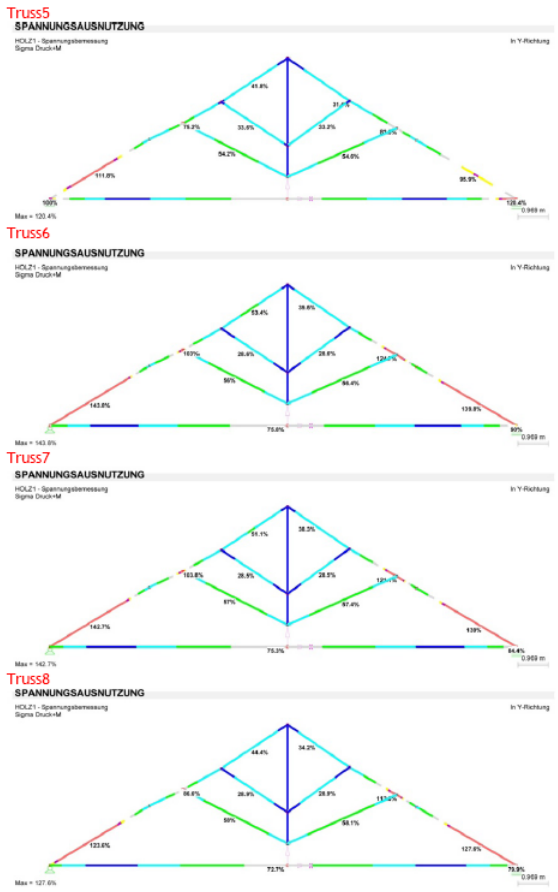

Figure 6: *Structural models reporting decays and defects of the components (stress in the lower part of the rafters is generally a too high)*

5 DIAGNOSIS

The methodology adopted during the *in situ* inspection for the grading according to the resistance, are the one foreseen by the standard UNI 11119 (*Cultural Heritage - Wooden Artefacts - Load-bearing structures - On site inspections for the diagnosis of timber members*).
In the 4th paragraph of this standard are listed the objectives of diagnosis whose final aim is to get informations on:

a) identification of wooden species. The identification had been carried out according to the criteria foressen by UNI 11118 (*Cultural Heritage - Wooden Artefacts – Criteria for the identification of wooden species*).
b) wood moisture content;
c) classes of biological attack risk, according to EN 335-1/2;
d) geometry and morphology of timber elements, including position and extension of the main defects, signs of decay and eventual damages;
e) position, form and dimension of the critical zone and critical section;
f) grading according to the resistance of timber elements as a whole structure and/or in single critical areas.

We followed this objectives. The visual inspection was integrated with instrumental inspection through resistographic drill. This instrument is necessary for the evaluation of the state of conservation of parts of the element that are enclosed inside the masonry.

Identification of wooden species
All the examined elements of the trusses presented the following characteristics useful for the wood species identification::
- growth-rings easily recognisable by naked eye.
- brownish colour of the heartwood differs from the colour of the sapwood.
- timber vessels are particularly evident and have a ring porous distribution.

All the elements constituting the trusses are in oak wood (*Quercus* sp.p.). The oak wood is very heavy, with volume mass of around 800 kg/m^3. This wood is traditionally used for historical monumental structures in the Padana plain of northern Italy, where there were wide forests of oaks.

Climatic conditions under the roof
Wood assumes a different equilibrium moisture content according to different *in situ* conditions. Some climatic conditions are favourable for biological decay of wood.
To be able to define the classes of risk of biological attack, the standard EN 335 identifies 5 classes of risk. For each class are defined the situation of service and the moisture conditions of wood in those situations.
In the specific case of the Cathedral of Vercelli, the temperature during the days of the survey was of 3-5°C and the air relative humidity was 80%. In these thermo-hygrometric conditions, wood assumes an equilibrium moisture of approximately 16%. Furthermore, the high value of environmental moisture content has to be connected with the water leaking that are clearly observable due to traces and spots visible on some elements.

Figure 7: *Elements of the roof timber structure over the apse of the Cathedral of Vercelli*

Overall state of conservation

Concerning the trusses object of the survey, an overall good state of conservation is present, except for some fungis and insects attack limited to portions of sapwood in some timber elements.

In any case the insects attack had ended since a lot of time.

In general, tie-beams are more decayed than rafters. This is probably due to material (i.e. concrete, pieces of tiles and bricks) that fills the space between the heads of the trusses and the masonry. This material becomes wet after rainwater leaking and provokes a high moisture content in wood that is therefore more subject to xilofagus fungis attack.

Figure 7: *Elements of the roof timber structure over the apse of the Cathedral of Vercelli*

Grading according to resistance

Each timber element of the trusses was classified according to resistance.

None of the end transversal section of the classified elements was visible at the monent of inspection. Tie-beams have been inspected on 4 sides. Rafters have been evaluated on 3 sides, excluding the upper one that was not directly visible. King-posts were evaluated on 4 sides. The state of conservation on some tie-beams was critical in the parts inside the masonry.

The grading procedure we followed (UNI 11119) permit to get to each wood element a mechanical profile.

The result were proposed in a table were, for each truss element, this information were reported:

- minimal effective section of the element;
- wood moisture content;
- notes about geometry, position e nature of wood defects and decay;
- position of critical zones;
- residual section (effective section minus the degraded parts)
- strength category.

This results permit the calculation of the structure on the base of the residual sections. The survey carried out has brought to consolidation procedures with punctual character (i.e. joints rafter/tie-beam) and of overall character (i.e. the longitudinal reinforcement with the addiction of new structures).

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), Dl. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	N. 8	Choir	
Tie-beam			
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	See rafter	
	Ring-shakes	Nothing observed	
	Twist		
Wooden species	Oak		
Humidity	According to the surrounding air about 16%		
Average dimensions of the element	27 x 30 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Absent
		Deformations	Absent
Other characteristics	There is a problem at the joint tie beam- rafter, because of the heavy degrade, the tie beam seemed to be flattened (crushed) by the weight of the slightly moved and curved rafter. A group of knots is visible.		

Resistographic profiles				
Data	Profile N°	from	Direction	Observations
3.12.08	R 15	front end south side	perpendicular to grain	Drill 15 (executed on soft timber): the test has been taken perpendicular to grain on the tie beam. There are only 6cm of good timber, after that there is nearly no resistance. The result couldn't have been much worse.

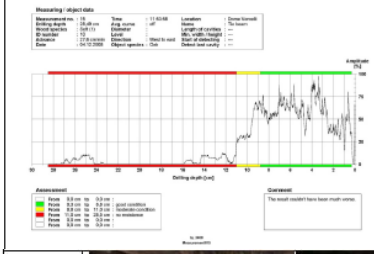

PHOTO		
n. Photo	IMG_7034 Truss 8	IMG_7344 Knot (king post - rafter)

Figure 8: *Example of Thematic Fiche*

Intervention proposals

The results of the visual grading of the timber elements of the examined trusses have been integrated with the instrumental analysis carried on in the timber parts included inside the masonry walls.

With the aim of bringing back thermo-hygrometric conditions of wood below the limit that is favourable to fungis attack, is indicated to facilitate air circulation around the wooden parts inside the masonry, so that it will be possible to reach better moisture conditions.

It is also advisable an accurate cleaning of the horizontal timber elements with the removal of dust and various deposits.

The project of the proposed interventions follows the guide-lines of UNI 11138 (*Cultural Heritage - Wooden Artefacts – Building load-bearing structures: criteria for the preliminary evaluation, the design and the execution of works*).

At present the rehabilitation and restoration site has already seen the first phases of the activity, from the scaffoldings until the cleaning phases.

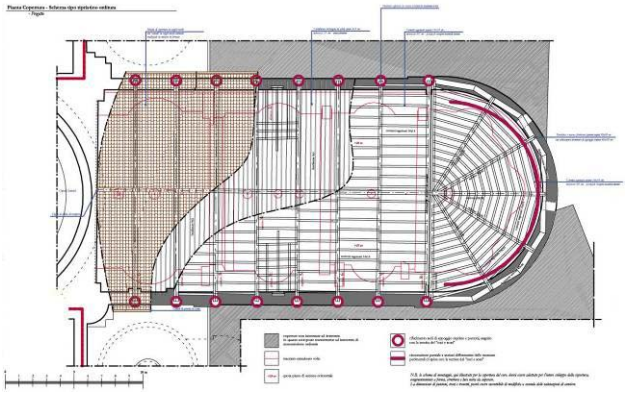

Figure 9: *Plan of the presbytery-choir. Scheme of the restoration project for the roof structure.*

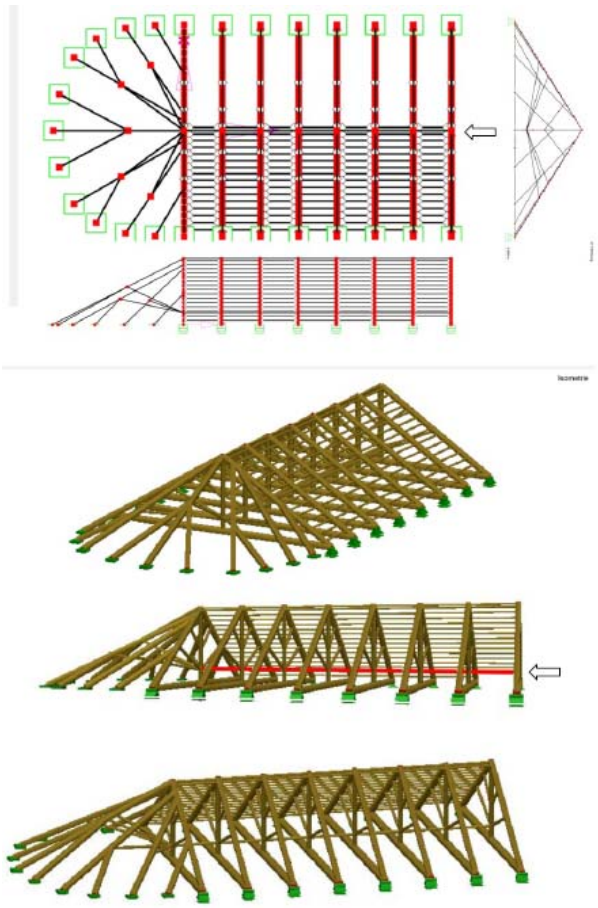

Figure 10: *Sketches of intervention proposal*

6 CONCLUSIONS

The great timber roof structure of the Cathedral constitute the first part of restoration works of the whole architectural complex. The works are followed directly by the Cultural Heritage Office of the Diocese of Vercelli, and are aimed at the conservation and restoration of the timber roof structure, adopting techniques that are very few invasive and suitable to give back structural consistency to the whole structure, without loosing the important characteristics of the building: its impressive structure, also considering the skilled carpenters, the importance of royal architects and the traditional rules of the art that those structures still preserve.

The intervention foresees the rehabilitation of all the great trusses and the relative metallic elements; also the secondary structure, where possible, will be preserved. While it is foreseen the only substitution of the covering. Part of the tiles will be preserved and an accurate maintenance will be carried out also on the copper and lid cupolas.

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