ABSTRACT: The present paper illustrates a wide interdisciplinary project carried out in the frame of the restoration works of timber roof of Porta Nuova Railway Station in Torino (Italy). Torino, in 1861, was the first capital of the just unified Reign of Italy. In the same year, Eng. A. Mazzuchetti was in charge to design the railway station of Porta Nuova in Torino. The design and construction of the station deserved contributions from the most outstanding scientists of that time, including R. Sephenson who provided the details of the lateral roof structures of the station, and the young Eng. A. Castiglione who defended his thesis on the design of the great steel vault above the rails. In recent years, the roof structure needed important maintenance and restoration interventions due to the water leaking which caused the deterioration of the beneath timber structure. Due to the historical and cultural importance of the building that is protected by law the holders decided to start a conservative restoration of the great timber roof structures.

KEYWORDS: Timber Preservation, structural assessment, timber reinforcement, dendrochronology

1 INTRODUCTION

The present study started from research collaboration between Politecnico di Torino and the company Grandi Stazioni S.p.A. aiming to assess the state of conservation of timber elements and their connections belonging to the roof structure of the railway station of Porta Nuova in Torino, and to propose interventions to support the function of the structure when needed. Particular attention is paid to diagnosis phase and grading according to the wood mechanical resistance, as a base of knowledge to define the proper intervention proposals.

The Porta Nuova Station in Turin was built in 1860-1867, designed by the Eng. Alessandro Mazzucchetti (1824 – 1894) [1]. The roofs, subject to restoration in 2015-2016, measure about 2,500 square meters. The roof covering is made from stone tiles ("bargioline"), each of about 1 square meter and 2.5 cm. in thickness. Nowadays this material is no longer available and is only
replaceable with thicker, therefore heavier, “Luserna” stone tiles. The roof supporting timber structure consists of an interesting building typology, mostly preserved during the restorations works of 1901 and 1908, making it a real practical "handbook of interventions" still relevant today.

3 TIMBER ROOF STRUCTURE
The Porta Nuova Station has a hidden structure: the great timber roof structures of the buildings belonging to the station complex (Figure 3).

Figure 3: Plan of the restored roofs (top). Aerial view of the roofs before the restoration (bottom).

It is the original roof system of the lateral buildings and of the central vaulted part, consisting of a wide timber structure showing different typologies of trusses, with a roof covering of flagstones called “lose” of 1 m x 1 m, anchored to the timber structure through specifically designed steel elements. In addition, the roof structure presents the techniques used in the restoration works carried out in 1901 and in 1908, showing different types of consolidation based on the reinforcement, sometimes structural doubling, rather than replacement of damaged parts. At the beginning of the restoration works, the roof was provisionally reinforced (Figure 4).

Figure 4: Provisory shoring of a hip-and-valley rafter, made in 2013, before the permanent reinforcement work.

4 DIAGNOSIS
The methodology applied during the in situ inspection for the grading according to the mechanical 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). Every single structural timber member must be graded according to strength [5,6,7].

In the 4th paragraph of this UNI 11119 standard are listed the objectives of diagnosis whose final aim is to get information on:

- a) identification of wooden species.
- b) wood moisture content;
- c) classes of biological attack risk, according to UNI EN 335-1/2;

The design of Porta Nuova railway station is conceived in 1860 by engineer Alessandro Mazzucchetti (1824-1894) from Biella [2]. He was already author of the railway stations of Alessandria and Genova Principe, which relies on the collaboration of the architect Carlo Ceppi (1829-1921).

The station is located in front of the gardens of Carlo Felice Square, at the middle of the urban plan conceived in 1851 by Carlo Promis, who is also the author of the model of houses that surround the station [3].

The layout of the station is simple and monumental at the same time (Figure 1): a central space of 48 m. span for a length of 142 m., occupied by 7 railway tracks and their platforms, covered by a semi-cylindrical steel and glass vault, with visible structure (built on the model of the Palais de l’Industrie of Paris of 1856). Two lateral buildings were hosting services, with wide porches covered by glass skylights open towards the two lateral roads (2,000 m² towards Via Sacchi, for the arrivals side, and 1,800 m² towards Via Nizza, for the departures side).

The facades are characterized by two elements that were innovative at the time: transparency and polychromy. Transparency is achieved by the empty arches of the portico on the ground floor and by the arched windows on the upper floor with coloured glasses (Figure 2). Polychromy, restored by Giovanni Brino [4], is achieved with different and visible stones used for portions of the masonry walls and vaults: purplish gray granite of Balme, white granite of Montorfano, pink granite of Baveno, yellowish sandstone of Vighiù, the light ash colour of sandstone of Saltrio and the dark purplish pink colour of Angera stone, which can be considered the main colour of the Railway Station, following the Chevreul’s principle of harmony and contrast of colours in order “to give more visibility to the granites tints”.

The lateral building towards Via Nizza, has a monumental hall 33 m long, 16 m wide, 20 m high, used as ticket office. The station is completed in 1868, even if opened in different stages.

2 PORTA NUOVA RAILWAY STATION
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d) geometry and morphology of timber elements, including position and extension of the main defects, wood decay and possible damages;

e) position, shape and size of the critical zone and critical section;

f) grading according to the mechanical resistance of timber elements as a whole structure and/or in single critical areas.

The identification had been carried out according to the criteria foresee by UNI 11118 (Cultural Heritage - Wooden Artefacts – Criteria for the identification of wooden species). Through wood identification is possible to collect a lot of information about wood technological characteristics such as e.g. natural durability, mean physical-mechanical characteristics, geographical origin and typical employs.

Wood moisture content was determined through a portable resistance type electrical moisture meter. The knowledge of wood moisture content is important because it is a limiting factor for the development of fungi and wood boring insects able to damaging wood. Dimension and position of wood defects, which may influence mechanical performance of the timber member were recorded.

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 timber elements that are enclosed inside the masonry. In fact, non-destructive tests complete the survey in case of alterations which are not visible on the surface of the timber member, but which are supposed to be present inside.

The results of the visual grading of the timber elements of the examined trusses have been integrated with the instrumental analysis carried out on in the timber parts included inside the masonry walls. The assessment was carried out on 70% of the total roof structures.

4.1 IDENTIFICATION OF WOODEN SPECIES AND DENDROCHRONOLOGY

All the examined pieces of the trusses presented the following characteristics useful for the wood species identification:
- growth-rings easily distinguishable with the naked eye,
- heartwood colour distinct from sapwood colour,
- resin ducts present.

We also performed an anatomical analysis to more precisely identify the wood species [8]. The elements constituting the trusses were made out of Pine (Pinus nigra or Pinus sylvestris, which are anatomically the same).

Dendrochronological analysis has also been carried out to date some timber elements.

5 ROOF RESTORATION

According to the results obtained from the structural assessment, reinforcement interventions have been carried out. These interventions have been conducted both considering the traditional reinforcing methods dating back to the beginning of 20th century, and proposing innovative solutions respectful of the original structures.

The roofs, subject to restoration in 2015-2016, measure about 2,500 square meters, and they are characterized by two elements which make them original and worthy of being preserved:
1. the roof covering is made from flagstones called (“bargioline”), of 1 square meter of surface and 2.5 cm. in thickness. Nowadays this material is no longer available and is only replaceable with thicker “Luserna” stone tiles, therefore heavier, than the original ones;
2. the supporting structure of larch wood is constituted by an interesting building typology, but mostly preserves the “artifices” used during the restorations works of 1901 and 1908, making it a real practical “handbook” still relevant today.

A first executive project included the “replacement” of 72 main beams that would have caused the complete dismantling of the roof, with the consequent loss of a high percentage of the original stone tiles, too thin to be removed with massive displacement, and the loss of great part of the wooden structures and “artifices” put in place in 1901/1908 to strengthen them, without counting the cost and the time used to achieve this intervention.

Given the risks, costs and execution times, the owner (Grandi Stazioni), accepted a variant solution submitted by the Company BRA Italy, according to the design and direction of Prof. G. Brino, with the control of the General Director of the restoration works of the station (before Eng. M. Antonelli and then Arch. A. Betta), and the Project Manager S. Rolla, under the aegis of the Superintendency (before Arch. L. Moro and then Arch. G. Scalva), that approved the project. The variant proposed the preservation and reinforcement of the beams, alternatively to replacement, following precisely those same “artifices” (although with the necessary technology upgrades) that allowed the roof to remain for nearly 150 years, despite severe traumas caused by fires, bombardments and degradation due to water infiltration caused by severe lack of maintenance.

The diagnostic investigation team directed by Prof. C. Bertolini, L. Cestari, Dr. A. Crivellaro, Arch. T. Marzi, Dr. O. Pignatelli, Arch. A. Violante, legitimized recovery interventions, sometimes even risky, to which the structural verification conducted by the same professor. C. Bertolini with Arch. A. Violante confirmed the validity of the reinforcing interventions, from a static point of view.

5.1 PAST RESTORATION INTERVENTIONS (1901-1908)

The interventions carried out in 1901-1908 on the timber roof structure applied specifically designed artifices. Many of them are not even present in the handbooks of restoration of timber structures. A catalogue of these artifices was compiled to list the recurring reinforcement systems applied in Italy during the same period.

The main artifices found in the Station roofs are the following:
1. Pendant post of "rompitratta" girder, ridges, common rafters and related "gattelli".
2. Supporting pillars of common rafter, with related "gattelli".
4. Supporting "rompitratta" girders to strengthen of a series of common rafters with large span.
5. "Under-beams" to strengthen of weakened beams, connected with hangers and drift bolt.
6. Side by side beam with beams considered at risk, connected together with through-bolts.
7. "Rompitratta" girder or common rafters, by means of pendant post, with or without under-beam.
8. Horizontal tie beam that transform the common rafters in the king post trusses.
9. Collar beams applied to king post trusses to support "rompitratta" girders or ridge pole.
10. Scarfed joint " to replace parts of the tie beam or common rafters damaged.
11. Hangers with drift bolt to enhance individual beams.
12. Hangers with drift bolt to connect different beams.
13. Climbing iron or hooks to connect different beams between them.
14. Flat iron attached with roofing nails to connect the rafters to tie beams or ridges.
15. Bolts to connect the rafters to tie beams or collar beam and queen post of king post truss.
16. Climbing iron anchoring of stone slabs covering the ledges to the wooden roof.
17. Hooks or climbing iron (Y-shaped) or slate to roof support.
18. Angle iron used to reinforce damaged beams or considered at risk.

The historical mentioned interventions (Figure 5) were all preserved and where necessary, further reinforced with similar but modern artifices. Such modern interventions are made out of glue-laminated fir wood, "anchor bolts" of appropriate size instead of the original forged nails, to connect medium-sized wood and metal belts formed by plates with slotted holes and threaded rods to replace brackets with fishbolts or through-bolts, to interconnect their different beams.

In addition to these technological updates of the traditional "tricks", it introduced a new "artifice" derived from "tree surgery" of that period (Figure 6). This consists of treating major gaps of two connecting angles (# 1 and # 2 Intervention) and minor gaps of "rompitratta" girder (Intervention n.39A) and of a rafter (40 Intervention) through a special metal reinforcement and concrete casting (in addition to and in connection with other traditional "artifices", according to a technique used in the same years in the treatment of the trees that have strong gaps, which have survived now few specimens preserved in protected environments (Gardens of the Villa Medici in Rome and the Racconigi Castle Park etc.).

5.2 PRESENT RESTORATION INTERVENTIONS (2015-16)

The reinforcement interventions on wooden structures were in total fifty-one, each one is identifiable by a special license plate showing the year of intervention and a progressive number. The labelling of the intervention will be useful for the program of future inspections and maintenance.

Here we detail some of the intervention applied, selected among the most significant.

5.2.1 Intervention n. 1 (Roof 1)

Reinforcement of a "connecting angle" (1) large with serious gaps, already propped up in 2013 and intended to be replaced. The intervention consisted in combining two beams in the connecting angle over the transverse trusses (2) and place a underbeam (3) reinforced with iron to form "L" throughout the cantonal, with a strut (4). Both the combined beams that underbeam are connected with the metallic belts (5). The gap (6) has been restructured with reinforcing steel rods, which included the iron anchor bolts of the combined beams connection, and concrete casting (Figure 7).
5.2.2 Interventions n. 8, 9, 10, 11, 12 (Roof 1)
Reinforcement of 13 struts destined to be replaced and that have been preserved using a "rompitratta" girder (1) into two segments, and with the realization of four wooden tie-beams (2) connecting the struts (3-4) converging in the ridge beam (5), transforming them into strong struts of trusses which support the two segments of "rompitratta" girder. The connections between the various beams have been realized using the metallic belts described (6) (Figure 8).

5.2.3 Interventions n. 16, 17 (Roof 2)
Reinforcement of the ridge beam (1) of the "Via Sacchi tower", intended to be replaced, with the formation of an "armed beam" similar to that already realized in 1901 in the "Tower Via Nizza", with struts (2), underbeam (3) and its "gattello" and creation of a "rompitratta" girder (4) reinforcement of the six rafters (5) to be replaced, with the aid of the usual "metallic belts" (Figure 9).
5.2.4 Interventions n. 19-20-21-22-23-24-25-26-27-28-29-30-31-32-33 e 34-35-36 (Roof 2)
The interventions n.19-33, relating to the 15 cross beams of the central vault, consisted in the laying of a underbeam (1) with two struts (2-3) and 5 "metal belts" (4) for each of the beams, while the interventions n.34-35-36 consisted in strengthening of a connecting angle (5) partly collapsed, through the support of the same booby ridge beam (6) in the free end supported by a truss structure, formed by two struts (7-8), a double chain (9-10) and king post (11), in addition to two other struts with underbeam (12-13) (Figure 10).

5.2.5 Interventions n. 39A-B-40 (Roof 3)
Rehabilitation and reinforcement of a "rompitratta" girder (1), with a minor damage, but not negligible, which supports the struts with original joints to "dart of Jupiter" (2). The intervention has led to the transformation of the "rompitratta" girder into an "armed beam" with underbeam (3) and the double strut (4-5) and the reinforcement of two rafters with a underbeam (6) and one of which with a strut (7) (Figure 11).
5.2.6 Interventions n. 41–42 (Roof 3)
Reinforcement "rompitratta" girder (1) with two "struts" (2) and a "underbeam" (3), which transform it into an "armed beam", and reinforcement of the two "rafters" with combined beams (4). The connections between the "rompitratta" girder and the "underbeam" on and between the struts and beams combined have been realized using "metallic belts" (5) vertical and horizontal (Figure 12).

5.2.7 Intervention n.48 (Roof 3)
The intervention of 1901 was the reinforcement with two beams (2-3) combined with a strongly damaged rafter (1). The intervention consisted in inserting wedges in the spaces between the existing beams (4) and two thin beams outside of the original reinforcement beams (5-6), to regularize everything that was connected with 4 metallic belts (7). The original rafter degraded and intervention subject of the original reinforcement was kept as a witness (Figure 13).

5.2.8 Interventions n. 50-51 (Roof 1A)
The theme of the first intervention n.50 was the reinforcement of 10 rafters destined to be replaced completely, with the creation of a "rompitratta" girder (1), supported by two trusses formed by new rafters (2) connected to two of the 10 false original rafters, with a double chain (3), king post (4) and relative struts (5). The theme of the second intervention n.51 was the reinforcement of 14 rafters destined to be replaced, using another "rompitratta" girder (6), supported by two
wooden columns (7-8) placed corresponding of the underlying walls, armed with rafters (9) and underbeams (10) equipped with special "metal belts" (11). This intervention was the only one made of larch beams, recovered from work carried out in other roofs other than those covered by this report (Figure 14).

5.2.9 External interventions (Roofs 1-3)
In addition to actions that summarize the most significant types of reinforcements made in the under roof, is worth conclude the report with a systematic presentation regarding the restoration and verification of the anchoring system of heavy roofing sheets of the ledge side Corso Vittorio (1) and that involves the terminal part of the cover and the anchoring system of the stone roof tiles (2) (Figure 15).

6 STRUCTURAL ANALYSIS
Static analysis focused on some consolidation works considered more significant. In particular reference is made to the classification according to the resistance of the wood species and their category in work, in order to evaluate the resistance of the wooden components, according to the specifications introduced by the UNI 11119: 2004.
Verifications were conducted in accordance with the precautionary principle, placed its focus on structural safety. In particular in the case of contemporary presence of laminated wood and solid wood, it is considered, in case it was sufficient for the verification, the only contribution of the laminated wood; otherwise they have been considered both sections, referring to the lower resistance between the two elements, which in the case under consideration concerns the solid wood of III category. It has also been neglected the friction generated by metal ties on the contact areas between solid wood and glulam, which involves the lack of cooperation of the two superimposed elements in case of bending.
The calculation method used is the limit states with analysis of static and linear, as shown in the Italian Technical Standards for Construction, D.M. January 14, 2008. For the solution of these simple static patterns it
was used the calculation software SDC.

**Figure 16:** Examples of static schemes with the relative elastic deformation (Roofs 1-3)

### 7 CONCLUSIONS

The great timber roof structure of the Porta Nuova Railway Station is an important part of the restoration works of the whole architectural complex. The works are followed directly by Grandi Stazioni S.p.A. in accordance with the National Board of Antiquities (“Soprintendenza”).

An accurate diagnosis on timber elements allowed 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. The intervention has seen the rehabilitation of all the great trusses; also the secondary structure has been preserved with the same philosophy.

Furthermore, the study conducted on the “artifices” realised during past interventions constitutes an important suggestion for the restoration of the timber roof structures.

The originality of the paper is given also by the presentation of the original sketches, which preceded the AutoCad drawings, that explain in an effective way the adopted techniques.

Added value of the present research is represented by the multi-disciplinary work carried out in the restoration site. For the extent and variety of passages under the roof, including the vaulted passage in correspondence to the central arch, it is planned in the future a kind of “open path” to allow guided visit tours, as a kind of living exhibition of construction and restoration techniques of timber structures.

### ACKNOWLEDGEMENT

Grandi Stazioni S.p.A. (Managing Director Eng. P. Gallo, Technical Director Arch. S. Bernardini and Responsible of Procedures Arch. R. Furlani) and Bra Italia S.r.l. (Arch. R. Sceral) are gratefully acknowledged.

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