The Great Timber Roof of Porta Nuova Railway Station in Turin: The Role of Assessment and Diagnosis for Sustainable Repair and Conservation

Clara Bertolini-Cestari, Giovanni Brino, Luciana Cestari, Alan Crivellaro, Tanja Marzi, Olivia Pignatelli, Steni Rolla, and Alberto Violante

Abstract

This article illustrates a wide multidisciplinary project carried out as part of recent restoration works of the great timber roof of Porta Nuova Railway Station in Turin (Italy). The station was built in 1861 (project by A. Mazzucchetti and A. Castigliano), when Turin was the first capital of Italy. In recent years, the roof needed important maintenance and restoration interventions due to water leaking which caused the decay of the timber structure. The original roof was under threat also because there was a proposal for the complete substitution of the timber elements (in a total of 2350 m²). However, after accurate assessment and diagnosis (following recent regulations) it was possible to save the original timber structure and to plan and realize sustainable interventions for repair and conservation with innovative technologies. This was carried out within a complex restoration site of the whole building.

Introduction

The present study started from a research collaboration between Politecnico di Torino and the company Grandi Stazioni S.p.A. to assess the state of conservation of timber elements and their connections in the roof structure of the railway station of Porta Nuova in Turin (Italy), and to propose interventions to support the function of the structure when needed. Particular attention was paid to the diagnosis phase and grading according to the wood mechanical resistance, as a base of knowledge to define the proper intervention proposals. This multidisciplinary scientific work was carried out with innovative technologies concerning the diagnosis and non-destructive inspection techniques. Innovative and traditional techniques were adopted for the repair and restoration works, always in respect of the original historic structure.

The Porta Nuova Station, an important site for its historical interest, was built in Turin 1860–1867. The roofs which were restored in 2015–2016, measuring about 2,500 m². The roof covering is made from stone tiles (“bargioline”), each of about 1 m² 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, which was mostly preserved during the restoration work of 1901 and 1908. This restoration work was a real practical “handbook of interventions”, still relevant today.

Porta Nuova railway station

The design of Porta Nuova railway station was conceived in 1860 by engineer Alessandro Mazzucchetti (1824–1894) from Biella (Mazzucchetti 1867b, 1867c). He had already designed the railway stations of Alessandria and Genova Principe, which relied 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 center of the 1851 urban plan by Carlo Promis, who also designed the houses that surround the station (Ballatore and Masi 1988b). The layout of the station is simple and monumental at the same time (Figure 1a): a central space 48 m wide and 142 m long, occupied by 7 railway tracks and their platforms, covered by a semi-cylindrical steel and glass vault, with a visible structure (built on the model of the Palais de l’Industrie of Paris of 1856). Services were located in two lateral buildings, with wide porticos covered with glass skylights open toward 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 colored glasses (Figure 1b). Polychromy, restored by Giovanni Brino (Brino 2015b), is achieved with different stones which are visible used for portions of the masonry walls and vaults: purplish grey granite of Balme, white granite of Montorfano, pink granite of Baveno, yellowish sandstone of Viggìu, the light ash color of sandstone of Saltrio, and the dark purplish pink color of Angera stone, which can be considered the main color of the railway station, following the Chevreul’s principle of harmony and contrast of colors 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 was completed in 1868, but opened at different stages (Figure 2).

**The timber roof structure**

The Porta Nuova Station has a hidden structure: the great timber roofs of the buildings belonging to the station complex (Figure 3). This hidden structure 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. Rather than replacing damaged parts, different types of consolidation and reinforcement were used. At the beginning of the recent restoration works, the roof was provisionally reinforced.

**Diagnosis**

Every single structural timber member composing the roof structure was inspected according to the guidelines described in the technical standard UNI 11119.2004 (Cultural Heritage – Wooden Artifacts – Load-bearing structures) on-site inspections for the diagnosis of timber members. According to this standard the objectives of the diagnosis were the identification of wood species, the estimation of the wood moisture content, the determination of the classes of biological attack risk (according to UNI EN 335.2006 Part 1 and UNI EN 335.2006 Part 2), the description of geometry and morphology of timber elements, including position and extension of the main defects, wood decay due to fungi and/or insects and possible damages, and eventually the grading according to the mechanical resistance of timber elements.

The identification of the wood species was carried out at first at a macroscopic level and then by anatomical observation through transmitted light microscope of the anatomical features of wood sections prepared from small samples collection on the roof elements (according to UNI 11118.2004). Wood moisture content was estimated via portable resistance type electrical moisture meter. Dimension and position of wood defects were recorded, because they can influence strength and stiffness characteristics as well as the mechanical performance of the timber member (Figure 4). Visual inspection was integrated with instrumental inspection using a resistographic drill. Such instrument allows the evaluation and quantification of decay of the timber elements parts that are enclosed inside the masonry. In fact, this type of non-destructive test completed the visual survey to detect alterations which are not visible on the surface of the timber member, but which may be present inside (Bertolini et al. 2016b; Bertolini Cestari 2000e, 2001b, 2004b, 2009b; Bertolini Cestari et al. 1997b, 2002b, 2004b; Kasal and Tannert 2010).

The results of the survey showed that all the inspected timber elements are made out of pine wood. In fact, at a macroscopic observations heartwood color is distinct from sapwood color and resin ducts are present. Anatomical analysis showed dentate radial tracheids and fenestriform-like pits on cross-fields classifying the pine species in *Pinus sylvestris* or *Pinus nigra* (which are anatomically identical). Wood moisture content was in equilibrium with the environmental conditions surrounding the timber elements. Insect decay was limited to the sapwood portion of the beams, and attacks were not active at the moment of inspection. The classification of wood elements according to their mechanical strength resulted in the three classes derived from UNI 11119.2004.

**Dendrochronological investigations**

Dendrochronology is a dating method frequently used in the study of historical architecture; thanks to the precision of its results, it offers a precious contribution to the reconstruction of the history of an ancient building, providing also useful indication for its restoration project (Figure 5).

Unfortunately, dendrochronology does not always allow the dating of an artefact; the chances of success are related to different aspects, such as the species, which in some cases may not be suitable for this type of investigation both for its growth behavior and for the lack of standard chronologies; the number of rings on the sample which may be insufficient to obtain a reliable result; the type of sequence with a markedly
<table>
<thead>
<tr>
<th>Element ID</th>
<th>Roof ID</th>
<th>T= Ridge beam</th>
<th>C= Corner beam</th>
<th>P= False rafter</th>
<th>Date of Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.01</td>
<td>1 x</td>
<td></td>
<td></td>
<td></td>
<td>July 7th, 2015</td>
</tr>
<tr>
<td></td>
<td>1A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size b x h [cm]</th>
<th>Wood moisture content [%]</th>
<th>Note</th>
<th>Residual section b x h [cm]</th>
<th>Strength category UNI 11119</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 X 29</td>
<td>9</td>
<td></td>
<td>26 x 27</td>
<td>III</td>
</tr>
</tbody>
</table>

Wood species: Larch
Biotic decay: Rotten
Defect: Knots 8cm/b
Ring shake
Grain direction
Geometry: Wane 6 x 6cm
Other

Resistographic profile
Date  ID  Direction  Distance from the top  Distance from the wall  Note

<table>
<thead>
<tr>
<th>Pictures</th>
</tr>
</thead>
</table>

Figure 4. Example of Technological Fiche showing how the characteristics of every single wood element of the roof were recoded during the diagnostic phase and stored for further analyses.

Figure 5. Construction of a standard chronology (by Schweingruber 1983b, modified).
individual growth behavior of difficult dating on the standard chronologies.

However, even in the absence of dating, the application of this discipline makes it possible to investigate some interesting aspects related to the timber assortment under study, such as the age of the trees used and their growth rate.

In the frame of the program of diagnostic investigations preliminary to the recent restoration of the timber roof of the Porta Nuova Station in Turin, a building of a known and relatively recent age, it was therefore considered appropriate to proceed with the dendrochronological investigations of some of the beams object of the intervention, in order to acquire further information on the timber (Figure 6).

The investigations involved a few number of timber elements: 11 beams belonging to the roofs 1, 2, and 3, selected on the basis of their dendrological characters, i.e., length of the tree-ring sequences and/or presence of the outermost rings of the parent tree. Generally, two or more cores with a diameter of about 0.5 cm were taken from each element by means of an increment borer.

In the only case of a collapsed cantonal of the roof 2, a cross section of a thickness of a few centimetres could be removed by hand saw.

Almost all of examined samples belong to pine wood (*Pinus* sp. Section *Sylvestris*), a single beam, the beam P29 of the roof 3, is made of larch wood (*Larix decidua* Mill.) (Table 1). These are species similar to a macroscopic level of observation with technological features that make them both suitable for structural uses (Giordano 1993b).

The dendrochronological investigations were conducted following the classical procedures (Baillie 1982; Fritts 1976b). The measurement of the tree-ring width was carried out with an accuracy of $10^{-3}$ mm with the LINTAB™ (Digital Linear TABle for Tree Ring Measure), while for the data processing the CATRAS© (Aniol 1983b) and TSAP-win © programs were used.

The sequences obtained for the different beams have a number of rings between 41 (in this case the sequence is restricted to the sapwood portion of sample n.2) and 244.

Despite the length of the available series and the fact that during the measurement no problems of tree-rings identification were found, only two pine series are well synchronized, confirming the difficulties of analyzing elements belonging to this type of wood, as also a recent research carried out in the French Alps highlighted (Shindo 2016b). Good optical and statistical agreement between the two mentioned pine series, the cantonal over the ladder of roof 1 (sample No. 5) and the collapsed cantonal of the roof 2 (sample No. 11), which gave a mean curve of 159 rings, suggests that they come from the same forest; the presence in both samples of at least part of the sapwood also suggests for belonging to the same cutting phase (Figure 7).

In the absence of local long chronologies comparisons were made with the chronology of the scotch pine of the Orgère (France) (Tessier 1986), a region near to the Piedmont Alps. Comparisons were also made with

![Figure 6. The samples and their dendrological features.](image)
other unpublished chronologies for the French Alps (thanks to the colleague Lisa Shindo, University of Aix en Provence, for the comparison made with the French chronologies) and with some unpublished chronologies created by colleagues for living populations of pine in Piedmont and Val d’Aosta (thanks to the colleague Paola Nola, University of Pavia, for the comparisons made with their chronologies). Since no dating has been detected, the research has also extended to other European areas up to the Scandinavian regions using the pine chronologies included in the ITRDB (International Tree Ring Data Bank) of Tucson, even in this case without reaching any definitive dating.

Even for the larch beam, species for which chronologies are available for the western Alps as well as local mean curves (Tessier 1986; Martinelli, Pignatelli unpublished data), it was not possible to reach the dating, despite the 168 ring length of the curve, probably due to the larch bud moth attacks, whose traces are detectable in the examined samples, that in case of particularly strong infestations can prevent the formation of the ring.

The investigations, however, have allowed to verify, although the samples, in general, do not reach the pith of the trunk, nor retain the last ring formed under the bark, the so called Waldkante, that the beams come from trunks of considerable age, generally above 150 years. This shows a careful selection of the timber, preferring large stems with slow growth, with generally narrow tree-ring widths.

The dendrological characteristics of the beams, obtained from large stems and characterized by slow growth, suggest that the wood refers to Pinus sylvestris L. or Pinus uncinata Mill. Both tree species grow in the Val Susa, a forested area nearby the station from where the timber could have been transported to the Torino

---

**Table 1. The samples and their dendrological features.**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Member type</th>
<th>Species</th>
<th>Pith</th>
<th>Length of the tree-ring sequence</th>
<th>Sapwood</th>
<th>Waldkante</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Roof 3 - “Lad” truss under the rafter P3.37</td>
<td>Rafter</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>108 tree-rings</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>Roof 3 - “Lad” truss under the rafter P3.37</td>
<td>Tie-beam</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>41 tree-rings</td>
<td>41 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>Roof 3</td>
<td>Beam T3.05</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>244 tree-rings</td>
<td>49 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>Roof 3</td>
<td>Rafter P29</td>
<td>Larix decidua Mill.</td>
<td>no</td>
<td>168 tree-rings</td>
<td>18 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>Roof 1</td>
<td>Corner Beam</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>110 tree-rings</td>
<td>uncertain</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>Roof 2</td>
<td>Rafter 10</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>156 tree-rings</td>
<td>74 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>Roof 2</td>
<td>Rafter 13</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>171 tree-rings</td>
<td>48 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>8</td>
<td>Roof 1</td>
<td>Rafter</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>214 tree-rings</td>
<td>128 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>9</td>
<td>Roof 1</td>
<td>Tie-beam</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>110 tree-rings</td>
<td>10 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>10</td>
<td>Roof 1</td>
<td>Corner beam</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>110 tree-rings</td>
<td>10 tree-rings</td>
<td>no</td>
</tr>
<tr>
<td>11</td>
<td>Roof 2</td>
<td>Quay beam</td>
<td>Pinus sp. Sectio Sylvestris</td>
<td>no</td>
<td>156 tree-rings</td>
<td>38 tree-rings</td>
<td>no</td>
</tr>
</tbody>
</table>

*Figure 7. Overlap of the tree-ring series of the samples nn. 5 e 11.*
Porta Nuova station. However, it should not be excluded that the wood assortments could have been transported from other European regions, such as Sweden and Norway and moved first to the port of Genova on the sea cost, and subsequently transported via the railway network to Torino.

**Roof restoration**

According to the results obtained from the structural assessment, 51 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 m² 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 m² 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; and

2. The supporting timber structure 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 an alternative solution submitted by the Company BRA Italia, 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 “Soprintendenza” - National Board of Antiquities (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 their 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, war bombadments and decay due to water leaking 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, and Arch. A. Violante legitimized conservation and repair interventions, sometimes even risky. The structural verification conducted by Prof. C. Bertolini with Arch. A. Violante confirmed the validity of the reinforcing interventions, from a static point of view (Bertolini et al. 2016b; Bertolini Cestari et al. 2013b; Bertolini Cestari and Marzi 2018b).

The variant proposed to the executive project, submitted and approved by the Superintendence, consisted in reinforcing rather than replacing the 72 beams, through a series of “artifices” already mentioned and partially practiced in the two restorations of 1901/1908 and known through manuals and literature of the time, with the advantage of maintaining the original structures and historical “artifices” associated with extremely reduced costs and restoration times. Since the original “artifices” have guided the new interventions, even with some technological upgrades and the introduction of some new “artifices”, it is worth describing the various interventions in order of type of reinforcement, including those in which more “artifices” were used at the same time (Bertolini 2005b; Bertolini Cestari 1992b, 1994b, 1998b, 2000d; Bertolini Cestari et al. 2010b; Tampone 1996; Uzielli 2002b, 2004b).

**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 manuals or 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 (Figure 8) are the following ones:

1. Pendant post of “rompitratta” girder, ridges, common rafters and related “gattelli”;
2. Supporting pillars of common rafter, with related “gattelli”;
3. Beams and supporting transversal king post truss of hip-and-valley rafters with large span;
(4) supporting “rompitratta” girders to strengthen a series of common rafters with large span;
(5) “under-beams” to strengthen 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/without underbeam;
(8) horizontal tie beam that transforms 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; and
(18) angle iron used to reinforce damaged beams or considered at risk.

The historical mentioned interventions were all preserved and where necessary, further reinforced with similar but modern artifices. Such modern interventions are made out of fir wood glulam, “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 was introduced a new “artifice” derived from “tree surgery” of that period (Figure 9). This consisted in treating major gaps of two connecting angles (n.1 and n.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 had strong gaps. Some of these past interventions on living trees have survived until today and are preserved in protected environments (i.e. Gardens of the Villa Medici in Rome and the Racconigi Castle Park, etc.).

Present restoration interventions (2015–2016)

The reinforcement interventions on wooden structures were in total 51, each one identifiable by a special number plate showing the year of intervention and a progressive number (Figure 10). The labeling of the intervention will be useful for future inspections and maintenance. Hereafter are presented some of the intervention applied, selected among the most significant ones (Figure 11).

Struts for reinforcement of horizontal and inclined beams

Struts constitute a relatively simple “artifice”, which is often part of more complex “artifices” (reinforced beams, etc.). In the simplest forms, the metallic brackets have been adopted in the interventions nn.18,43,44, but many times the metallic brackets support the “underbeam” which support false rafters, as in the case of interventions nn.3,6,34,36,40,45.

In a more complex form, in intervention no. 35, two big metallic brackets, with tie beam and collar beam, carry out the task of supporting the continuation of a ridge. Some of the most significant images of the aforementioned interventions are presented.

Intervention n.3 was realized to reinforce the rafters for which replacement was planned. The reinforcement consisted of inserting a sub-beam supported by a pendant post (Figure 12). Intervention n.18 consisted in strengthening in...
the support of the roof ridge T2.03 of the tower towards Via Nizza, through a big strut (Figure 13).

Interventions n. 34 and 35 consisted in the strengthening of a connecting angle partly collapsed, through the support of the same ridge beam in the free end supported by a truss structure, formed by two struts, a double chain and king post, in addition to two other struts with underbeam (Figure 14). Interventions 36 and 40 are similar to the above mentioned (Figure 15).

**Beams side by side**

The reinforcement by joining new beams to those considered weakened, correctly connected, is one of the “artifices” most applied in the past historic restorations of these roofs. Double-sided doubling is not limited to beams, but is also applied to weakened joists that connect cross-beams that carry the vault and even to the laths to which are attached the “hooks” that carry the “bargioline” stone tiles. This technique was applied in the interventions nn.4, 5 (Figure 16), 13, 14 (Figure 17), 15, 42, 48.

**Underbeam**

A variation of the “artifice” of the associated beams is constituted by the “underbeam”, which consist of reinforcing the weakened beams by new beams put in place below them. This “artifice” was applied in the interventions n.7, 37, 46, 47. Intervention n.7 represents a first case of “underbeam” with a new beam duly connected to a rafter (Figure 18).

**“Rompitratta” girder**

This “artifice” has been adopted as an alternative to substitution in interventions nn.12, 16, 41, 50, and 51. Intervention No.16 was adopted in the “Via Sacchi Tower” to avoid the replacement of six beams. Intervention No. 41 was adopted to support common rafters of roof 1A instead of replacing them (Figure 19).

**Reinforced beams**

The reinforced beams consist of reinforcing an important beam (a ridge, a “rompitratta” beam, etc.) by means of an underbeam placed in the central part and two “hangers” that start at the ends of the underbeam grafted in the two walls on which the beam is to be reinforced. This “artifice” was adopted in the interventions nn.17, 19–34, 39. Interventions nn.19–34-39 (Figure 20) transform the cross beams of central vault into reinforced beams.

**Tie beam transforming false rafters into truss rafters**

A special “artifice” consists in transforming two false rafters convergent on a ridge, by means of timber tie-beams into truss rafters (see interventions nn. 8, 9, 10, 11, 38), reinforcing them properly, without replacing them (Figure 21).
Figure 11. Plan of roof 1 and roof 2 with indication of the reinforcement interventions.
Metallic belts reinforcing single beams (ridges, tie beams etc.)

In some cases (i.e. intervention n.49), similarly with reinforcements carried out in the past, the long beams that were considered weakened were reinforced only with metal ties. Intervention n.49 consisted only in the installation of stiffening metal ties (Figure 22).

“Jupiter” joints

Another intervention involved the use of a “Jupiter” joint which is based on a particular geometric construction that permits the connection of two elements with a profile very similar to a thunderbolt. This artifice was traditionally used to extend tie beams of trusses or rafters (even with different sections).

Although no new interventions were made with these “artifices”, it was possible to save from destruction the four joints of this type present in roof n. 3. These “artifices” are absolutely original, as they are joints designed to create “prostheses” of existing beams damaged perhaps by a fire and not to create new “composite beams” as one might suppose according to historical manuals (Figure 23).

“Tree surgery”

In Interventions 1 and 2, a particular “artifice” was applied, as in the case of the other “artifices” (rivets, “underbeams”, “side beams”, and metal belts) based on an intervention in reinforced concrete gaps in very long rafters. This “artifice” comes from a traditional
Figure 14. Intervention n. 35. (Up) Before the intervention and reinforcement project. (In center) Project as built. (A below) Photo during and after the Intervention.

Figure 15. Intervention n. 36. (Top) and Intervention n. 40 (Bottom). (Left) Before the intervention. (In center) Reinforcement project. (Right) Photo after the intervention.

Figure 16. (Left) - Intervention n. 5. Before the intervention. (In center) Reinforcement design as built. (Right) After the intervention.
reinforcement system adopted for gaps in living trees, which was used until World War II. Intervention n.1 (Figure 24) and n. 2 (Figure 25) consisted in the rehabilitation of rafters located in roof n.1.

**Figure 17.** Intervention n. 14 represents another case of joining a new beam from one side. (Left) - Before the intervention. (In center) Reinforcement and as built project. (Right) Photo after the intervention.

**Figure 18.** Intervention n. 7 (Top) and Intervention n. 3 (Bottom). (Left) Before the intervention. (In center) Reinforcement and as built project. (Right) Photo after the intervention.

**Figure 19.** Intervention n. 16 (Top) and Intervention n. 41 (Bottom). (Left) Before the intervention. (In center) Reinforcement and as built project. (Right) Photo after the intervention.

**Structural analysis**

The artifices used in this intervention, already widely used successfully in the past and validated by the test of
time, refer to the historical constructive tradition based on the rules of good construction and tradition. The procedure commonly used in the past was completely different from the design criteria used nowadays, which often leads to the choice of the type of intervention from a preliminary calculation or from results of laboratory tests.

In the case of Porta Nuova timber roof structure, the idea was to verify if these repair interventions were also correct from the point of view of the calculation using the classification introduced by the UNI 11119.2004 standards, based on the resistance of the wood species and their category, in order to evaluate the resistance of wood components.

The interest was focused on the overall behavior of the structure which was the purpose of these artifices. For this reason it was considered not appropriate to investigate the local interactions between the artifices implemented and the existing structure, since, according to the historical constructive tradition, the purpose was to reach the result.
It was also neglected the friction generated by metal tie-rods on the contact areas between solid wood and glulam, which involves the lack of cooperation of the two superimposed elements in case of bending (Figure 26).

In the sections subject to verification, in the case of simultaneous presence of glulam and solid wood, where it had been sufficient for the verification, the sole contribution of glulam wood was considered; otherwise, both sections

Figure 23. Intervention n. 39. (Left and Center) Jupiter joint on the tie beam of a truss. Angle irons employed at intervention n.1. (In center and right) Angle irons used on false rafter.

Figure 24. Intervention n. 1. (Up, left, and center) Before the intervention. (Top, Right) Survey, project and as build of intervention No. 1. (Bottom, left) Axonometry of intervention n.1. (Bottom, Right) Photograph after the intervention, with the plate and angle irons and the metal belts.
were considered, but referring to the minor design strength between the two elements, which corresponds to the third category of solid wood.

In the same way and for these reasons it was decided to face the numerical verification using simple calculation tools that can be easily replaced by a manual calculation that was the tool available to designers who worked between the 19th and 20th century.

**Figure 25.** Intervention n. 2. (Top, Left) Photos and axonometry before the intervention. (Top, Right, and Center) Survey, project and as build of intervention No. 2. (Bottom, Left) Removing the cover for concrete casting. (Bottom, right) Photos after the intervention.

**Conclusions**

The great timber roof structure of Porta Nuova Railway Station was an important part of the restoration works of the whole architectural complex. The multidisciplinary scientific works were carried out in accordance with the “Soprintendenza” (National Board of Antiquities).

Accurate diagnosis of the timber elements allowed the conservation and restoration of the timber roof...
structure, and techniques almost non-invasive were adopted, suitable to give back structural consistency to the whole structure, without losing the important characteristics of the building. The intervention included repair of all the great trusses; the secondary structure was also preserved with the same philosophy. Furthermore, the study conducted on the “artifices” realized during past interventions constituted an important suggestion for the restoration of the timber roof structures.

Presentation of the original sketches, which preceded the AutoCad drawings, provies the article with an original way of explaining the techniques adopted in the recent works. Added value of the present research is given by the multi-disciplinary work carried out in the restoration site.

For the future there are plans to make a kind of “open path” for guided tours under the roof, as a kind of living exhibition of construction and restoration techniques of timber structures. This could be also an added value to enhance cultural heritage tourism linked to the history of the development of railways.

**Acknowledgments**

Grandi Stazioni Rail S.p.A. (Managing Director Eng. Silvio Gizzi, Technical Director Eng. Pietro Panzavecchia,
Construction Manager Arch. Alessandro Betta), and BRA Italia S.r.l. (Arch. Raffaele Sceral) are gratefully acknowledged.

**References**


Bertolini Cestari, C., M. Brunetti, and N. Macchioni 1997b. Le lacune nel legno. Indagini sul degrado e metodologie diagnostiche in situ su antiche strutture lignee per la valutazione della capacità portante. In *Lacune in architettura*, 259–70. 10.1016/S1081-1206(10)63012-8


doctorale 355: Espaces, Cultures, Sociétés; Ecole doctorale 251: Sciences de l’Environnement; Centre Camille Jullian, UMR 7299, Institut Méditerranéen de Biodiversité et d’Ecologie marine et continentale, UMR 7263.


UNI EN 335. 2006c. Durabilità del legno e dei prodotti a base di legno - Definizione delle classi di utilizzo - Parte 1: Generalità

UNI EN 335. 2006d. Durabilità del legno e dei prodotti a base di legno - Definizione delle classi di utilizzo - Parte 2: Applicazione al legno massiccio
