

# **The use of steel in the conservation of timber structures (“Sustainable technologies in historical essay teachings”)**

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## **Abstract**

The aim of this paper is to study historical technical literature in order to analyse the theoretical approaches and work techniques that reflect a building tradition where a central role is played by maintenance, which used to be programmed in the building design by facilitating regular inspections and repairs. The re-interpretation of historic craftsmanship rules and traditions concerning in particular the use of steel devices, attempts to offer alternative design solutions to the current repertoire of work techniques. The study concludes with the analysis of a significant case study.

## **1 Introduction**

“Among the reasons for the negative results in the restoration of wooden structures are: the general inadequacy of our technical culture to cope with the structural problems of ancient buildings, designed and built according to empirical principles that are not connected with our culture, a particular difficulty in assessing the state of conservation of historic timbers and their actual structural performance and an inadequate knowledge of the structural behaviour and the physical, chemical and mechanical characteristics of this ancient material”<sup>1</sup>.

This study is based on the analysis of historical technical sources and intends to reconstruct ancient building methods with this material in order to establish alternative design solutions to the current repertoire of work techniques, stimulate “awareness” of the store of knowledge held by craftsmen and set up maintenance and/or restoration methods based on the conservation principles of historical buildings. This does not mean a “return to the past” but rather takes positive stimuli from the past to allow the sector to strike a favourable balance



between tradition and innovation, between theory and practice, and between skills handed down by experience and the most advanced results of scientific research, in compliance with general economic constraints and sustainable development of built-up areas.

The project covers the subject of the work carried out on the wooden roofs of historical buildings and attempts to shed light on the dividing line between routine maintenance, extraordinary maintenance and consolidation with steel devices.

The authors, starting from the study of historical treatises – codex's and practices of historic building culture, illustrate some emblematic cases of maintenance and consolidation work on the roofs of historical buildings using steel devices. The study includes a case analysis on a recent structural restoration carried out on an old wooden roof and illustrates the various analyses that were carried out: *in situ* diagnosis to determine the state of preservation of the material, dendrochronology, numerical modelling with finite elements of the structure and connections, and the consolidation techniques which respect the structural type.

## 2 What historical literature can tell us about maintenance and restoration projects

The work techniques used in the past basically reflect a building tradition from which, in spite of the differences deriving from the various periods and geographical areas, emerges the importance attributed to maintenance work and how this is provided for in the design of a building.

The importance of this is proved by the historical treatises that contain many technical suggestions on the subject which appear to be much more common than those envisaged by modern restoration methods.

In the past, maintenance, restoration and renovation work was often carried out by modifying the existing building: in many cases use was made of stone, wood or metal elements taken from other abandoned buildings.

This was achieved by dismantling and reassembling operations that were carried out by making clever use of resources according to their limited availability.

Among the various old building systems and the various materials used in the past (wood, stone, bricks), wood is the material that gives a perfect example of maintenance problems in relation to the different types of structure: floors, trusses and the overall organisation of construction work.

This type of maintenance work, therefore, is aimed at conserving the whole building and the continuity of transmission of ancient building techniques with a programme that entailed replacing deteriorated elements with sound ones.

The concept of replacement is clearly expressed by one of the most interesting nineteenth century treatise writers, Emy, the author of a work that perhaps has never been bettered as regards completeness and competence. In his "Treatise on the art of carpentry", Emy, talking about wooden elements, suggests that "...if an element of the building deteriorates, it must be replaced immediately".<sup>2</sup>

The system of periodically replacing and re-using wooden elements from other constructions, “recycling” we would say today, is often confirmed by accurate analyses, such as dendrochronology, that reveal the presence of parts that are older than the period in which the building was built. The solution lay in the way the building was constructed; replacement was an operation that had been envisaged right from the design stage of the construction in order to make it easy to replace a deteriorated element without complete dismantling the whole building.

In order to underline how easy it was to replace elements, Emy says: “.... Whilst on this subject, I should point out that a large timber building will be perfect and the money required to build it will be well spent if its main elements are easy to replace in case they ever show signs of deterioration such as to compromise the solidity of the construction and the state of repair of the other wooden elements.”<sup>3</sup>

Another point about this maintenance system is the attention towards the possible damage caused to the wood by biotic micro-organisms (fungi and insects).

On this subject, Chevalley, in his treatise “Technical elements in architecture” suggests that “...when laying the roof beams, make sure they will last a long time by not closing them in the brickwork (especially the heads of the tie rods and struts) so as not to risk the rapid putrefaction of the reinforcements”.<sup>4</sup> Along with these suggestions, Chevalley indicates how to position the heads of beams so that they will last a long time.

### 3. Structural reinforcement work

Reinforcement work is intended to improve the structural performance of a building both in the design phase and in the work carried out on parts that have weakened due to phenomena connected with the characteristics of the material (rheological phenomena, movement of the geometry of the framework following cyclical movements of the wood) or to broken connections (caused by severe stress).

This type of work can be likened to maintenance for the frequency with which it was carried out in order to keep the structure in good condition: for example, the positioning of wedges between two connecting surfaces or the periodic tightening of reinforcing metal elements which were loosening due to the movement of the wood. The treatises provide us with an extremely rich variety of solutions.

Reinforcement work can be divided into two large groups that concern particular parts of the structure (a connection or a section) and work on the whole of the structure aimed at overall reinforcement or increase in resistance and/or rigidity.

The first category includes a series of devices such as *bolts*, *arrow-head bolts*, *stirrups*, *brackets* and *metal laminas*, the second category is dominated by the functional originality of reinforced beams.

### 3.1 Metal reinforcements

Up until the middle of the nineteenth century, wooden reinforcements were used a great deal; later, many treatise writers proposed metal reinforcements especially as regards connections. Emy gives a synthetic but accurate picture on the gradual introduction of metal elements in wooden structures “....iron is used in timber constructions in several cases: to join pieces of wood together, to increase their strength, to consolidate joints, to provide supports, to act as intermediate surfaces for wooden connections, and, finally, to replace some pieces of wood. At first, they were used to join pieces together and consolidate joints, but after a few years during which the use of iron frameworks for roofs became frequent, attempts were made to use them as supports or tie-rods for the timber framework ...”<sup>5</sup>. Some of his contemporaries such as Cavalieri di San Bertolo also hold that “...in order to ensure the heads of the rafters fit perfectly and that all play has been eliminated, a sheet of lead should be fitted between them ...”<sup>6</sup>, while Milizia advises “... placing small sheets of copper or brass between the teeth, so that wood doesn't wear on wood.”<sup>7</sup>

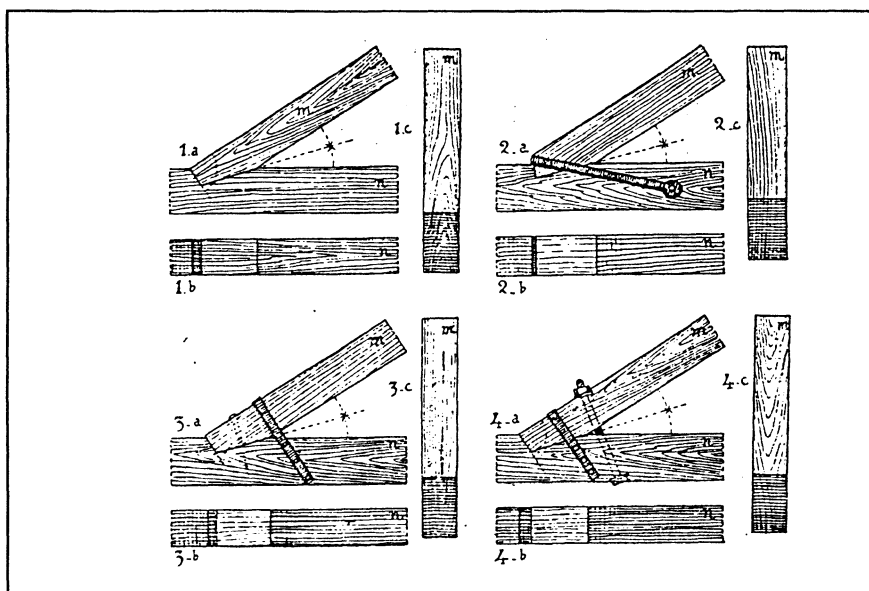


figure 1: Roof reinforcements - Tab. XVI Chevalley G., *Elementi di tecnica dell'Architettura*, published by Libreria editrice Carlo Pasta, Turin, 1924.

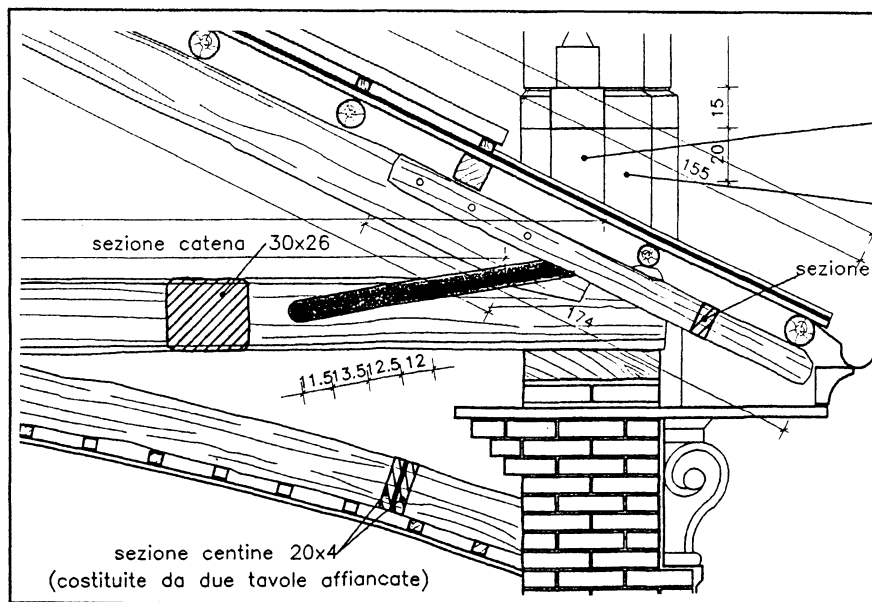


figure 2: The nineteenth century extension of the Castle of Valentino: detail of the strut-tie rod joint of the timber roof.

### 3.2 Metal devices for large-scale work: reinforced beams

The system of reinforced beams became popular mainly from the seventeenth and eighteenth centuries on and was adopted, as Rondelet says<sup>8</sup> "... because large pieces of timber are rare and very expensive, and generally of a lower quality due to the age of the trees ...". In its basic structure, the reinforced beam comprises an element with a length that is equal to the space to be covered, over which two counter struts are placed by means of various jointing, bolting and bracketing systems. An alternative method of reinforcing beams comprises placing two elements pushing towards the upperside, that is, two supports that decrease the free space of deflection, as can be deduced from the tables in Chevalley's treatise. The problem of reinforced beams, differentiated however from the previous solutions for the maturity of conception and the extraordinary correspondence between the geometric layout and the state of stress of the elements, is solved by Polonceau with the creation of a mixed structure in wood, iron and cast iron for pitch roofs with a structural layout comprising simple and clear grids with lower internal hyperstatic values.

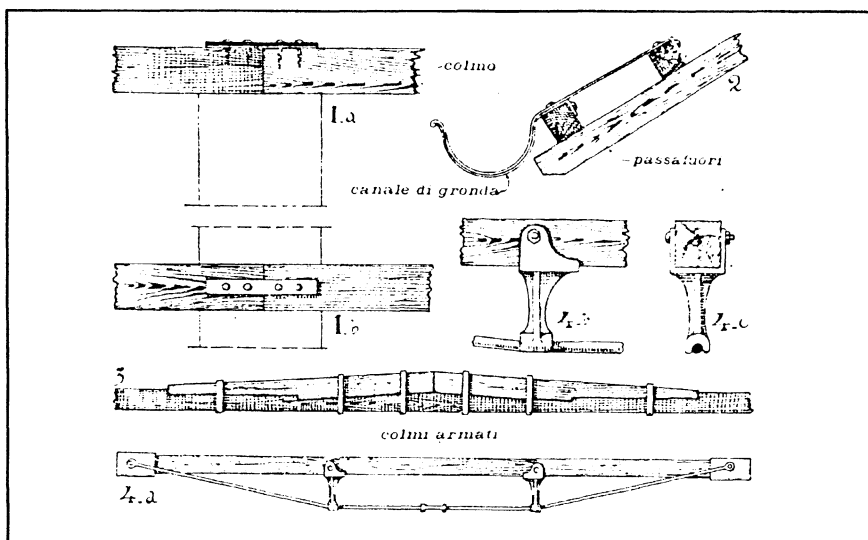


figure 3: Roofs - Tab. CLVI Chevalley G., *Elementi di tecnica dell'Architettura*, published by Libreria editrice Carlo Pasta, Turin, 1924.

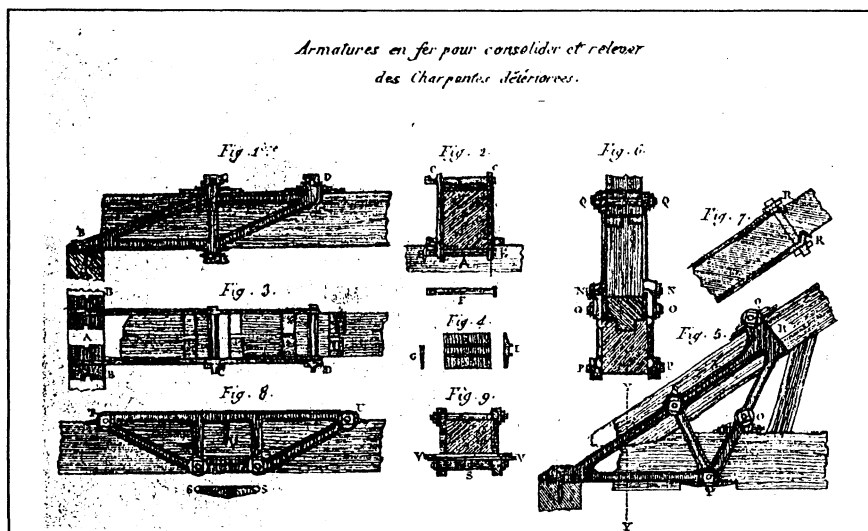


figure 4: Consolidation of roof structures according to Rondelet, from: Biston, Hanus, Boutereau & Gauché, *Encyclopédie Roret, Nouveau manuel complet du charpentier*, Paris, Inter-Livres, 1825.

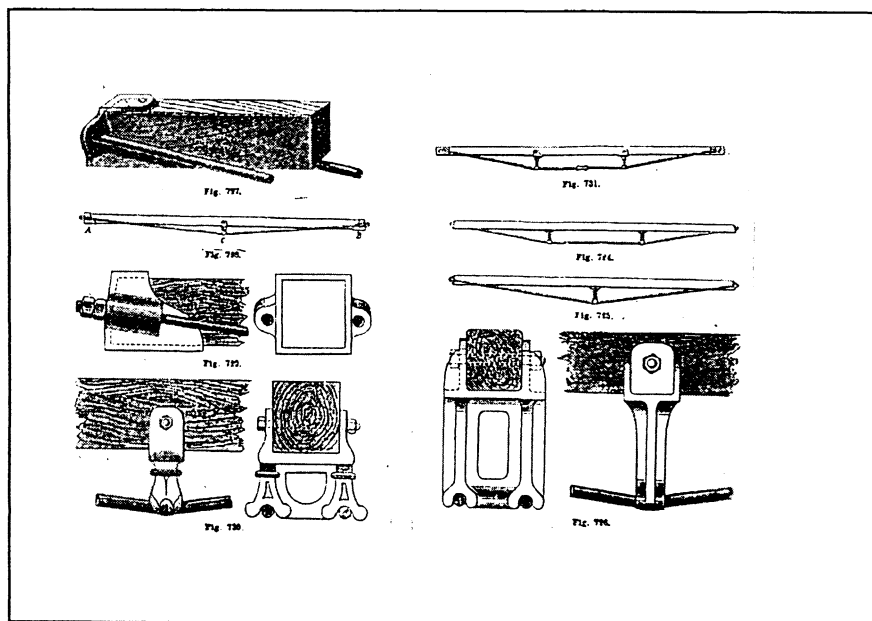


figure 5: Polonceau, trussed-beams, from Pareto, R. and Sacheri, G., Enciclopedia delle Arti e Industrie, V. 5, Torino, UTET, 1865.

#### 4. The repair of ancient wooden structures using the suggestions contained in the treatises

A case analysis of restoration work carried out following the original methods is the parish church of St John the Baptist in Salbertrand (X-XI century): For this Gothic building of great architectural and structural interest, in agreement with the local Office for Cultural Heritage and in the light of a functional restoration of the timber roofing of the whole church, a detailed historical analysis and archive investigation was made into the documentation of the church and the work carried out over the centuries. An accurate investigation was then carried out on the structure: 1<sup>st</sup> level investigations into the state of preservation of the wooden elements, from large pieces to small frames, and 2<sup>nd</sup> level investigations with equipment and instruments, such as ultrasounds (Silvatest, Pundit), microdrillings (Resistograph and DDD2000), endoscopies and dendrochronology.

The two levels of investigation mainly concerned the properties of the material and the state of preservation of the structure with *in situ* execution of the above-mentioned investigations. A careful assessment was then carried out on the results obtained from the single investigations, illustrated in theme cards, and executed on the basis of the geometrical and structural surveys, that show the various species of wood identified, the defects in the material, the presence of

shrinkage fissures, breaking, rotting and cavities caused by wood-eating agents, etc.. The first structural model of the behaviour of the building was then made and structural consolidation work was carried out on the elements that had been compromised by the deterioration.

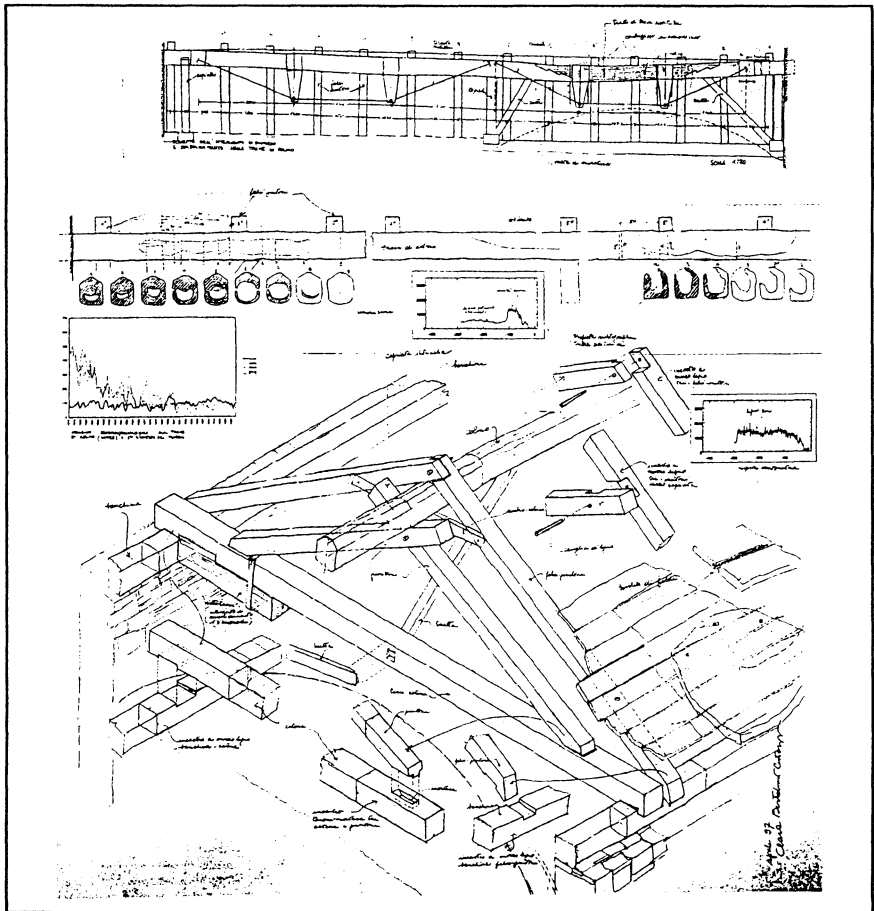


figure 6: Structural consolidation work on the Church of St John in Salbertrand – detail of reinforced beam.

This type of work, with the use of two reinforced beams to increase the resistance and rigidity of the ridge beam, partially replaced with a wooden structure, proves that the teachings of Polonceau are still applicable today, a light, transparent and reversible restoration in which the combination of steel and wood guarantees the preservation in conditions of safety.

## 5. Conclusions

The short notes in this study contain some indications taken from the works of the treatise writers and illustrate how the application of the ancient rules of workmanship can reach the aims of preservation and structural efficiency with overall cost-effectiveness in recent restoration work.

The introduction of these criteria in new projects increases the quality of the work compared with that achieved with "innovative" technologies that still leave some doubt as to their durability and reliability.

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(All quotations are translated by the authors only for use in this paper)

<sup>1</sup> BERTOLINI CESTARI, C., New methodologies for the conservation and restoration of ancient timber structures. In: *Conservation of monuments in the Mediterranean basin – New concepts, technologies and materials for the conservation and management of historic cities, sites and complexes*, Proceedings of the 4<sup>th</sup> International Symposium, Rhodes, 6–11/5, 1997.

<sup>2</sup> EMY, A.R., *Trattato dell'Arte del carpentiere*, Venezia, Antonelli, (ed. translated into Italian in 1856, orig. ed.: *Traité de l'art de la charpenterie*, Paris, 1837-1841), V. I, p. 92.

<sup>3</sup> Ibid., p. 92.

<sup>4</sup> CHEVALLEY, G., *Elementi di tecnica dell'Architettura*, Torino, Carlo Pasta, 1924, p. 382-384.

<sup>5</sup> EMY, op. cit., V. II, p. 253.

<sup>6</sup> CAVALIERI DI SAN BERTOLO, N., *Isituzioni di architettura, statica e idraulica*, 5<sup>th</sup> edition, Mantova, Negretti, 1855.

<sup>7</sup> MILIZIA, F., *Principi di Architettura civile*; Bassano, 1785, anastatic print, Rome, Angelo Ruggeri, 1991, V. III, p. 170.

<sup>8</sup> RONDELET, G., *Trattato teorico e pratico dell'arte di edificare*, 1<sup>st</sup> Italian translation on the 6<sup>th</sup> orig.; Napoli, Tipografia Del Gallo, V. III, part 1, book 5, p. 41.

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  6. BERTOLINI CESTARI, C., *Il Castello del Valentino. Analisi strutturale. I modelli di comportamento strutturale delle incavallature lignee*, *Recuperare*, n° 36/1988.
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