Restoration of historical timber structures – Criteria, innovative solutions and case studies

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ABSTRACT

The topic of the restoration of historical timber structures is actually very important and it is still susceptible to possible improvements and enhancements, especially considering the numerous mistakes that were made in the past years as a result of a certain superficiality and also of the enthusiasm created by the advancement of knowledge in the field of chemicals products such as epoxy resins or resin shotcretes. From an initial experimentalism, not properly governed by appropriate standards, specific rules have been created together with the definition of new concepts concerning wood restoration, especially with regard to the fields of reversibility and compatibility of materials. The designers, both as regards to the timber floors and roofs, now have several possibilities of intervention such as substitution, restoration, collaboration between existing structures, but specific rules and criteria are needed with the aim of satisfying modern structural safety requirements and conservative restoration principles.

KEYWORDS: RESTORATION, WOOD STRUCTURES, TIMBER TRUSSES, HISTORICAL MONUMENTS

1. INTRODUCTION

Problems related to the recovery of historical elements, buildings or parts of them, draw attention to which should be the main criteria to be taken as a basis for planning interventions. Is it correct to think of replacing parts with new ones, preserving or integrating them? And how could they relate the preexisting?
In the restoration of historical timber as in historical building, actually, the main criteria to follow should be the conservation. Some general values concerning the building such as the original design concept or the construction techniques are cultural values to be preserved especially for monument or building with recognized artistic value.
The maintenance of such values has become a topic of considerable interest, so much that the focus of the regulations has gradually moved towards this area. This also was made with the aim of putting a limit to the empirical experimentalism of the half of the last century that caused extensive damage, often associated with the use of inappropriate materials of which designers and contractors did not yet know the full extent of use.
Many damages have been done between the seventies and eighties by the use of resins on stones and sculptures without any prior verification or survey; resins that are now difficult or in some cases impossible to remove. These issues introduce concepts of reversibility and compatibility of materials that today cannot be underestimated.

The mandatory regulations have introduced the concepts of preservation following this direction and have formulated criteria for intervention that highlight the survey phases of the building, giving them the necessary importance.

It is worth pointing that the best recovery, for the purpose of durability, is not always that of the act if the necessary preliminary studies established the possibility of maintaining the "status quo" unchanged.

The issue of recovery of the wooden elements came back to this field and should be approached with the same premises. Even in this field the initial experimentalism led to interventions that in many cases caused the loss of the original signs of the historic building or element. Just think of the widespread use of implants made with epoxy resin to rebuild heads trusses or deteriorated head beams. In these cases we have lost not only the original formal identity but have also failed criteria of material compatibility and future reversibility. The issue of the recovery of timber structures is intrinsically linked to three factors: the material, the structure and the construction details. The joint of these three elements contributes to the creation of the work itself, which can be found used together in structural wooden floors or roof structures such as trusses.

While in many traditions of northern Europe and of overseas countries such as United States or Canada, wood fully contributes to the definition of the building as it is present both in vertical and horizontal structures, in Italy, where the traditional use of the masonries, beginning from the Roman period, is of prime importance; the wood has always been mainly used for horizontal structures as floors or roofs. This is especially true as one considers monumental buildings or with artistic value where significant structural capacity of wood, related to the specific weight, have always been used with success.

A frequent occasion for upgrading timber structures is now offered by the need of seismic strengthening. In case of wooden roofs, with or without wooden trusses, the problem of the intervention on the nodes is considerably complex, both from a structural and formal point of view especially considering the future reversibility. Even in the context of the recovery of wooden structures one may unfortunately notes that the above experimentalism of the seventies, eighties led to the loss of a significant cultural heritage due to complete replacement of deteriorated elements. The complete replacement of parts of the wooden elements was due to several factors: the shortcomings of laws, lower cost of operation due to substitution with respect to the restoration but especially the lack of knowledge, sensitivity and cultural heritage of designers and owners.

At present, much remains to be done; assessment of existing wood is a big issue, and it's not completely solved especially with regard to reinforcement methods that are not purely aimed at obtaining the mere structural performance but also oriented to concepts of compatibility and reversibility. It's also necessary to include the possibility of a static downgrade of the structural element (floor or beam) if this contributes to the preservation of the same.

In conclusion, the assessment of existing wooden structures appears as a delicate search for a compromise among affordability, historical, artistic and technical.

In this paper, criteria that can be used as rules of interventions of assessment will be analyzed together with the main restoration systems of historic floors and roofs in full compliance with prior discussions.
2. NORMATIVE FRAMEWORK

In conservation, maintenance and restoration of historical timber as structures belonging to in historical buildings, actually, the main criteria to follow should include the topics of compatibility and reversibility: too many interventions have been executed in the past without any attention to the compatibility of materials and to the possibility of bringing back the element or restoring to its original aspect. Considering the history of the process of restoration, starting from the beginning of the twentieth century, we can find many connections to the modern concept of reversibility; the Athens Charter of 1931 [1], for example, established, for the first time, the fundamental principles of restoration. The contribution given to the development of a vast international movement has been remarkable. Consequently, specific documents have been developed in various countries, in which sensitivity and critical thinking have been applied to increasingly complex and multiple problems. From the fundamental principles of the Charter one can notice the need to preserve the evidence, avoiding total reconstructions and respecting the historical and artistic works of the past in its entirety. It is important to note that by this time the reversibility emerges as a constraint in the restoration, but it was with the publication of Brandi’s Theory of Restoration, in 1963 [2], which took place the first encoding of the concept of reversibility in the form of "singularity of the removal" Brandi claims that the work of art, the product of human activity, is the result of ingenuity and imagination of theoretical, practical and manual skills, and so it shows an historic, artistic and aesthetic message through its material nature that must be entirely respected.

A further application of these criteria to the historic buildings and structures in ruins were examined by Paul Philippot, particularly in his writings and in his lectures ICCROM (Philippot, 1976) [3]. Brandi, on the basis of this, formulated three principles:

1. The integration should always be easily recognizable, even if, observed from a distance, the integration must not disturb the unity that was intended to restore;
2. The material that forms the image is not replaceable only when it is a part of the appearance and not of the structure;
3. Restorations should not prevent future interventions for conservation, but rather facilitate them.

The last topic is significantly important, because confirms the need to think about a restoration compatible with the existing but also with what could be proposed in the future. In other words, it officially introduces the concept of reversibility of the conservation.

The fundamental concept of reversibility, which specifies that the restoration should not be definitive, but must permit, if necessary, further actions, is clearly set out in the subsequent Italian Charter for the Restoration (1972) [4]. This document lists historic and artistic buildings to preserve and underline the concept that the building has artistic value both as an object in itself and as an object in its context. In addition, it defines the first guidelines in the selection of products and methodologies to be used in restoration. A detailed analysis of the twelve articles of the Italian Charter for the Restoration, shows that the opinion of Brandi has been fully implemented. The article n° 8 declares: "Any intervention on the element or even near it (...) should be performed in such a manner and with such techniques and materials to be able to permit that the future will not make impossible a possible new intervention or restoration ". This statement contains implicitly the need for action to avoid changes that would result in irreversible changes of the product. The discussion relating to this requirement was further continued and developed together with the scientific research carried out in the field of physics and chemistry, however, making more progress in the field of preservation of materials.
Aware of the fact that the restoration project is based on a balance between use and conservation, the subsequent Restoration Charter of Krakow 2000 [5] widened the purposes and principles of the restoration by developing new conceptual tools for the transmission of cultural heritage respecting its authenticity and extending them to multidisciplinary fields. Section 10 of the Charter of Krakow reports: "The role of the techniques in the field of conservation and restoration is closely related to interdisciplinary scientific research on specific materials and technology specifications used in the construction" (...) The intervention selected must comply with the original function and ensure compatibility with the materials, textures and architectural values (...) When the application of new techniques in situ is particularly important for the preservation of the original element, it is necessary to provide a continuous monitoring of the results obtained, taking into account their behavior over time and the possibility of any subsequent reversibility".

The complete reversibility of the products applied or of the interventions are also reiterated in the latest standards of the Italian Ministry for Cultural Heritage "Risk Map of Cultural Heritage" in 1995 and Legislative Decree 22/11/2004 n ° 42, "Code of cultural heritage and landscape" which define guidelines, technical standards, criteria and intervention models for programmed maintenance of cultural heritage.

Summarizing, the objective of restoration is to operate on the historical building in such a way that what is done at a certain time for a recovery may be subsequently removed - avoiding as much as possible too innovative techniques and excessive changes - for further interventions. This concept of restoration and reversibility is indeed substantially similar to what was declared in the directives expressed by 'Institutional Council on Monuments and Sites (ICOMOS)[6] at the conference "Principles for the conservation of ancient wooden structures", which states that interventions should be or completely reversible or at least not such as to impair or prevent further action in the future when they become necessary again. From these principles it is clear the opportunity to define gradually reversibility in both the design phase as operational phases.

While it is true that the objective which you tend is not easily accessible, on the other hand it is essential to evaluate, for each action, the level of reversibility that is reasonably achievable [7]. Furthermore, the Italian Standard UNI 11138:04 [8], presents criteria for the preliminary evaluation, planning and possible execution of conservation, and maintenance and restoration of wood structures in buildings of cultural, historical, and artistic interest. In cases where we should not expect to get a total intervention of recovery or restoration, or also preliminary to the intervention itself, it is useful to consider the UNI 11119:04 [9] concerning structural diagnosis of the timber elements which gives information related to the assessment of the conservation status of the artifact and guidelines on how to achieve the necessary knowledge of the damaged or decayed elements.

Completing the context, also the other Italian Standards UNI 11118:04 [10] and UNI 11161:05 [11] should be considered. They establish, respectively the criteria for the classification of wood species and guidelines for the conservation, restoration and maintenance of wooden element. Moreover, with reference to the possible types of restoration available for a specific element or building, surely the designer must correlate the structural safety of the element together with it's historic value which usually is preserved by restrictions imposed by the supervisors for the cultural heritage.
3. IDENTIFYING POSSIBLE CRITERIA FOR INTERVENTIONS

A possible methodological approach to the problem of recovery is provided by the above mandatory regulations that summarize the basic steps that a designer should follow in order to reach a proper recovery of the wooden historical elements.

In particular, main criteria should be: preliminary evaluation of the state of conservation, planning of the intervention, criteria for controlling the efficiency of an intervention, methodology and techniques in the execution of an intervention and, finally, periodic inspections.

The phase of preliminary evaluation of the state of conservation establishes the importance of a correct phase of investigation in order to determine the characteristics of the elements as well as their state of preservation; the historical survey, the characterization of the material, the geometric survey, the detection of degradation, and the structural analysis are all essential steps through which can be achieved the preliminary knowledge of the element.

The historical survey is executed to permit the dating of the material as well as to provide knowledge of construction techniques used at that time in that specific geographical area. For the characterization of the material it may be useful to consider the additional codes such as Italian Standards UNI 11119:04 [12], comparing the measurements obtained among different survey methods necessary due to the high levels of uncertainty present.

The geometric survey should include the relief of degradation and structural deformations, both at a general and particular level of detail. Particular attention should be devoted to exactly highlight and distinguish wherever the level of deformations of materials are due to stresses applied to the structure or to inadequate static sections. These defects must be considered when one performs static analysis realizing a structural model that should consider defects and dimensional changes of the sections that in real cases are never constant.

The detection of damages and decays should consider the possible interaction between decays and environmental conditions such as microclimate that may have influenced the development of the same.

Finally, the general static conditions are assessed by mean of a structural analysis that should evaluate both the general static of the building and the details of the single timber elements and nodes.

Considerations, that could be performed planning interventions and possible criteria to be adopted, involve different topics that need to be considered. Specifically, the following ones could be mentioned:

I) Compatibility, traceability and reversibility; these three criteria should coexist in a recovery intervention; the compatibility should preliminary be related to material but also should refer to static structural models of computation which must be as close as possible to the original structural scheme, especially considering the security levels as defined by the standards; the traceability of the intervention is the need to not hide what designer has done, but to harmonize it with the existing context; the reversibility is a goal to be pursued knowing that it is intimately linked to concepts of permeability of the intervention with the existing one. The more new materials will be blended to existing elements, the less will be the level of reversibility expected for the intervention.

II) As far as possible the study of the stability of the building should join the new structural requirements with the original schemes. The study of joints has to be done maintaining as much as possible the original stiffness, unless it can be demonstrated that the stiffness values present are responsible for the failures detected. A typical case of wrong application
of this rule is the reinforcement of heads of trusses realized applying a metal cage with steel bars ad bolts that increases the stiffness and capacity but block rotations of the element.

III) The partial or total replacement of a deteriorated wooden element can be carried out if no artistic value is present. In this case designer should use wooden prosthesis of the same wood species as the existent one. The current practice of past years of using concrete and epoxy resins, as already indicated in the introduction, should be avoided. For this reason, the use of epoxy resins is to be expected only to allow the anchoring of the prosthesis to the existing wood with steel of fiber bars (Figure 1).

![Example of replacement of deteriorated wooden element](image)

Figure 1 – Example of replacement of deteriorated wooden element; (a) Resin prosthesis; (b) Steel bars ready for the wooden prosthesis.

IV) Complete replacement of the element should be performed only in cases of real structural inefficiency and realized using only materials compatible with the deteriorated ones, according to the results of the surveys and analysis carried out in previous actions.

4. ACTIONS FOR RECOVERY

The restoration works that could be performed on a wooden structure can be summarized as:
- Reinstatement of material;
- Restoration of structural continuity;
- Restoration of structural functionality;
- Strengthening of structures with mixed structures (timber-concrete or timber-timber).

Generally, the reintegration of material and structural continuity should be performed with materials similar to existing ones, restoring the original joints using traditional structural models. For this purpose, it is desirable to use, as much as possible and according to the static actions, simple connections using wooden or metal elements, as the traditional ones. The use of resins should be admitted specifically in seismic contexts and limited to specific adhesives for wood. In this area of intervention one of the most used technique is the replacement of decayed items with wooden prosthesis connected to the existing ones by means of fiber, carbon or steel bars. The types of interventions are the most varied: connections can be lateral sides, upper / lower sides, internal or external, all as regards to floor beams or trusses (Figure 2).
The bars are inserted into the wood in the same manner in which they are embedded in reinforced glulam. They usually are positioned at the upper and at the bottom side of the section, so as to fully restore it and delegating to the bars the function of restore the structural continuity of the element. Although the technique is widely used, there are aspects that still need to be investigated further. The behavior of the glue, for example, introduces a structural elastic-brittle in the ultimate behavior of the section whilst the reversibility and compatibility has yet to be studied at all.

With regard to the restoration of the functionality of the wooden structure, it is necessary to analyze it in the same original structural context, because it can considerably contributes to the overall static of the entire building. The analysis should define the contribution offered to the global static by the investigated element, both in the actual state but especially in the future arrangement, also considering the global actions that will be present in the future and defining appropriate interventions such as supplementary connection of the wooden structure to the perimeter walls with metal connections and wall-plates.

Interventions that use mixed structures mainly concern the wooden floors [12]. In this area, the strengthening of timber structures is more documented. The reinforcement is normally reached adding a slab to the beams. The slab can be realized using concrete, wood or plywood that are joined to the underlying beams by means of metal connectors and epoxy resin (Figure 3).

Figure 2 – Example of interventions using connections; (a) Lateral side; (b) Inside the section.

Figure 3 – Example of interventions using mixed structures (slabs); (a) Concrete slab; (b) Plywood slab.
This strengthening intervention, widespread in the past, today must be carefully assessed if one consider the new mandatory regulations, as it induces increases in stiffness and suspended masses, especially in the case of reinforced concrete, which can be deleterious to the global static in the case of seismic actions. At present, research is evaluating alternative solutions of the mixed structure with particular regard to the compatibility of materials with existing structures even at the expense of the absolute performances technically achievable by the system.

5. CASE HISTORY: THE "PIEVE" IN CAVALESE: THE RECONSTRUCTION OF THE TIMBER ROOF AS A RESULT OF A FIRE.

5.1. History

The church of "Santa Maria Assunta", called "Pieve", is located in Cavalese (Trento) and is considered, from the local citizens one of the most important historic buildings of the region. The building has a symbolic role: it is the place that preserves the memory of the historical events of the community in the valley (Figure 4).

Figure 4 – External views of the Church.

The parish church is built in 1134. The church has been altered several times during the years, leading to the formation of an architectural complex in which individual elements reflect different styles. Everything comes from an original nucleus of the twelfth century, the remains of walls reveal the seniority of a rectangular room without apse and consists of three aisles by pillars. Between the fifteenth and sixteenth centuries were performed substantial interventions as a result of which the building took on the Gothic connotation still present. A polygonal apse with buttresses was added to the church. The Chapel of the Rosary is of late Gothic and is plastered with baroque stucco. In 1610 the fourth aisle was built on the north side. Of the same period is the sacristy, the volume of which protrudes from the northern prospect. The belfry was built later and is realized on a building dating back to previous centuries. The sacristy, located south, was built in the same period. The current plant is characterized by an important building. One can find a large hall, an apse, two chapels, one bell tower and two vestries.
The plant consists of a nave with cross-vaulted ceiling, two aisles symmetrical with acute ribbed vault and a span with additional vault. There are also two side chapels covered by a dome.

On the opposite side is located the choir with the organ. Of the same period is the minor sacristy, the volume of which protrudes from the northern prospect. The present apse was built in the eighteenth century, built to replace the old one. The belfry was built later and is built on a building dating back to previous centuries.

The sacristy, built in the same period, is located south (Figure 5).

![Figure 5 - Historical plan of the Church.](image)

### 5.2. The destructive event

On April 29, 2003 the church was affected by a disastrous event which resulted in the total destruction of the wooden roof. In addition to that, also the static and architectural arrangements of the building has been significantly altered consequently to a large fire. The original trusses, together with the roof structures such as tables and wooden mantle, went entirely destroyed, collapsing on the vaulted structures below. This fact has led to a considerable heating and consequent damage of the masonries. The structural stability of the building was altered, as well as the integrity of architectural elements such as paintings or frescoes (Figure 6).

![Figure 6 - The progression of the fire; (a) The roof; (b) Firemen in action.](image)
As usual in these events, it has been activated a set of preliminary investigation and surveys that highlighted the need to put in place temporary structures in order to avoid possible collapses of the walls. Simultaneously specific scaffolding and a provisional cover were prepared with the dual purpose, firstly to allow a thorough investigation and inspection of damaged elements and secondly to provide a shelter of the vaulted structure below the roof destroyed in order to avoid further damage due to the arrival of the winter season (Figure 7).

![Figure 7 – Preliminary actions; (a) Provisional cover; (b) Suspended scaffolding.](image)

5.3. The reconstruction of the roof

As a result of the fire the entire wooden roof of the building has been lost, with the exception of the roof of the tower, too high to be affected by the flames. The operations of the reconstruction of the wooden roof, designed in a critical way, had to be aimed at the restoration of the identity of the building as well as to the initial impact of architectural figurative, restoring, as far as possible, the original core values. This meant, for example, a critical selection of possible technical solutions, trying to keep the distinctive historical and aesthetic characteristics and following the criteria of reversibility, compatibility and minimum intervention probable. All these things aimed at sustainability and conservation of wooden structures. Operating in this way it was possible to restore the original form of the old roof and ensure compatibility with the historical artifact.

5.4. Preliminary surveys

Most of the preliminary analysis has been devoted to the study of materials and their nature and deterioration, as well as the determination of the geometry of the roof construction that has been lost. Preliminarily the main characteristics of the wooden elements of the roof have been identified. The remaining original wooden beams of the trusses were analyzed by dendrochronological investigations according to UNI 11141:04 [13]. This survey, based on the study of the growth rings of wood, covered 19 wheels, chosen among the samples in better condition.
The wood species identified were three: Larch (Larix decidua), Spruce (Picea abies) and pine (Pinus sylvestris section). Using the analysis of the samples it was possible to determine the date of felling of trees which happens to be between 1544 and 1607 A.D. (Figure 8).

![Figure 8](image)

(a)  
(b)  
(c)  
(d)  

Figure 8 – Dendrochronological investigations; (a) The remaining original wooden beams after the fire; (b,c) Testing phases; (d) The result of the analysis.

5.5. The geometry

The next step involved the determination of the geometry of the original nave's trusses. There were no geometric surveys and the only sources were some photographs of the interior of the roof. An extensive geometrical and typological survey was conducted on the surrounding churches of the same period to identify similarities.

![Figure 9](image)

(a)  
(b)  
(c)  

Figure 9 – Different typologies of trusses analyzed in churches in the nearby areas; (a) “Nostra Signora” in Egna; (b) “Santi Martiri” in Sanzeno; (c) “San Giovanni” in Vigo di Fassa.
As different geometries have been found, the research did not exhaust the doubts, but, in spite of this, the survey allowed designers to verify the details of the structural nodes and the overall structural configuration.

Tree roofs of churches were analyzed: “Nostra Signora” in Egna (second half of the 15th century, first half of the 16th century), “Santi Martiri” in Sanzeno (15th century) and “San Giovanni” in Vigo di Fassa (latter half of the 15th century) (Figure 9). In Sanzeno and in Vigo di Fassa, scissors braced trusses are used to cover the vaulted nave, while in Egna the rafters are braced only by collar beams. All the trusses are closely spaced (about 90-100 cm). The spatial bracing system is provided either by boarding or by wind braces in the plane of the roof. In "Pieve di Cavalese" two type of trusses are designed: the first, called "type A", in which the rafters are connected with three horizontal beams in order to reduce the sagging. The structure is then completed by perimeter structures, in the form of triangles, providing support to the lateral walls. The second typological truss, called type ‘B’, is a scissor truss. Horizontal beams are also present at two levels. Scissor trusses were commonly used in roof framing to accommodate interior vaulting, domes and coves, or whenever the center of the ceiling beneath was designed to rise higher than the wall plates of the building (Figure 10).

![Figure 10](image1.png)

Figure 10 – Different typologies of trusses; (a) Type "A"; (b) Type "B".

A third truss completes the series of the main trusses. It rests on the horizontal beams and on wooden pillars and supports the longitudinal bracing system (Figure 11).

![Figure 11](image2.png)

Figure 11 – Roof schemes; (a) Assembly of three type of trusses; (b) General view of the roof.
Different scales of analysis were adopted to define such intervention. In particular, concerning the trusses of the nave, the static of the single element has been studied, and then, at a global scale, the interaction of many trusses with adjacent structures such as perimeter walls (Figures 12 & 13).

![Figure 12](image1.png)  ![Figure 13](image2.png)

**Figure 12** – Static analysis of the new roof; (a) Specific; (b) Global.

![Figure 13](image3.png)  ![Figure 13](image4.png)

**Figure 13** – Realizing the new roof: (a,b) Construction phases.

During the research concerning the realization of the wooden trusses, historical demands combined with current needs were considered. On one hand the new trusses should not modify the loads originating on the pre-existing walls and on the other hand they had to be adapted to the new building technologies in order to meet the safety criteria required by today's standards. New carpentry joints were chosen following this criteria and considering the historic survey previously mentioned. During the preliminary analysis of the roofs of the neighboring churches, nodes of the trusses were also studied. Elements common to all of them are precisely details of the nodes. In particular, the half laps are especially used at the diagonal crossing of in-plane continuous members. The dovetails and the birdsmouth joints are used when one of the two connected members terminates at the joint. The
traditional carpentry joints are always reinforced by double-threaded screws, in order to maintain the functionality of the joint in adverse and unpredictable conditions. In fact, the traditional internal joints generally work "at gravity". Stability is obtained by simple wood cavities, thanks to the correct positioning and the mutual clamping, relying on the action that each wooden element exerts on those with which it is in contact. For these reasons, these connections are not generally able to withstand reversals efforts, such as those caused by seismic events and so screws are used in order to avoid splitting along the grain in lapped joints (Figure 14 & 15).

![Designing the new joints](image1.png)

Figure 14 – Designing the new joints: (a,b) The traditional carpentry joints reinforced by double-threaded screws.

![Realizing the new joints](image2.png)

Figure 15 – Realizing the new joints; (a,b) Construction phases.

### 5.6. The material

The material used for the new trusses is ‘duo-glued timber’, that can be considered and graded as massive wood. This material is obtained using two or three sections of a wooden beam glued together as it is done with a glulam. Using this solution, the external part of the original beam, correctly dried (12% U.R.), is rotated and positioned inside the section of the new element permitting to the core of the beam, now positioned on the external side, to reach a correct drying as the internal one did. The advantages of this material are: stability against humidity variations, absence of cracks in time, general high quality due to a very
accurate production. The same species of the original timbers, that is Larch (*Larix decidua* Mill.), as proven by the dendrochronological analysis, has been used. The choice of this species, one of the ones with the higher mechanical properties and durability, has been realized also for the importance of the original roof of the building. The presence of some elements in spruce and pine, as some wall-plate beams, let assume that these species, less valuable, they were used for elements of "sacrifice", which precisely those in contact with the masonry and thus more easily perishable. The roof partly rests on the central pillars and partly on the external walls. In these areas a wall-plate is needed for static reasons and with the aim of connecting all structures together. Traditionally this element is made of wood but, in this case, it performs the only function of connecting element between the truss and the vertical wall and it is not able to react effectively to horizontal stresses due, for example, to an earthquake. For this reason, today, concrete castings are used (where permitted) or metal structures made of stainless steel profiles positioned so as to offer maximum strength in the direction perpendicular to the plane of the walls. The connection of these metallic elements with the underlying masonry is realized with metal connectors anchored with epoxy resins. In this recovery, a kind of innovative wall-plate has been experienced. It consists of wall-plates realized with Armalam ® trusses. Such material is made by inserting steel or carbon rods within a section of glulam arranging them at the sides of the reagent section so as to significantly increase the load bearing capacity of the element (Figure 16).

![Figure 16 – Armalam ® trusses: (a,b) Example of elements.](image1)

![Figure 17 – Wall-plates: (a) Use of Armalam ® trusses for wall-plates of the dome; (b) Use of Armalam ® trusses for wall-plates on the walls of the aisles.](image2)
The trusses rest on Armalam® wall-plates, placed on the top of the wall with their sections rotated by 90 degrees with respect to the classical use as floor beams and so as to offer maximum resistance to any static and seismic action with perpendicular direction to the masonry. Also in this case the wall-plate is connected to the underlying masonry by metal connectors and epoxy resin. As completion of the intervention, walls below the wall-plate are injected with natural lime to strengthen them and to permit a perfect contact each other (Figure 17).

6. CONCLUSION

The knowledge of techniques and materials, today, allow the definition of restoration and conservation projects oriented to maintain and preserve the original characters of the historic building, whether architectural or structural. The recovery, indifferently directed to the building or to the single element, should use techniques and methods representative of the highest level of technological knowledge available in the temporal context in which the intervention is made. High levels of compatibility and reversibility are permitted by evolution and technological innovation in this particular field of interest and in the light of criteria and guidelines provided by mandatory regulations aimed at safeguarding and preserving the historic heritage. The recovery of timber structures, analyzed in this context, must not be considered only a simple act of restoring the original structural features, but also a re-appropriation of the evidences and of the common knowledge related to typological and constructive traditions.

Floors and especially wooden roofs are built not only to fulfill practical needs, but also to summarize, in themselves, the specific characteristics related to the shape and to the final image of the entire building. The recovery of them must, as far as possible, consider these characteristics and allow to point out the proper meanings and the original values, as well as give shape again to what is visible but especially to what it is not, because concealed by architectural harness; all must contribute to the recreation of the identity of the primitive artefact.

Very often one can see restorations that cannot be considered philologically correct as they do not use techniques consistent with the historical ones. This, although such techniques propose solutions for recovery or reconstruction of deteriorated elements that visually and aesthetically return a semblance of the original element.

Of course it would be wrong to propose the reuse of historic building techniques "tout court", without a critical analysis looking at the modern wealth of scientific and technological experiences. One can think of a joint of a truss that, if repeated using traditional techniques, would not be able to meet the static and dynamic performances required by mandatory regulations; it is more correct to propose, instead, a formal approach to the topic that includes the search for synergy between old constructive methodology and contemporary manufacturing techniques.

(...) “the use of technologies that may be considerably different from those present in the building to be recovered, requires the verification of the features offered and of the executive logics in order to avoid creating incompatibility with the Technological System of the building” [14].

In the context of the joints of timber elements, for example, it is correct to assume their execution using traditional carpenters techniques, such as "halfwood" or scarf joints, but improving their static performances by the use of the most advanced current techniques, such as double tpered screws, metal bars with epoxy resin of fish plates and through bolts.
The project for the recovery of "Pieve di Cavalese" follows this conceptual methodology. Designers reproduced the architecture of the past, now lost due to the fire, providing the necessary formal completion of the building together the stereotyped image, historically established; at the same time, the project has allowed the achievement of the required parameters of the new static regulations. The synergy between traditional techniques and new technologies can meet conditions required by institutions responsible for preservation of monuments; this synergy recovers, although not entirely, traditional and cultural architectural values as well as traditional constructive knowledge of the site. Not least, the issue concerning the building site is noticeably affected by the contribution given by new construction techniques; manual skill and accuracy of the carpenter regain strength in the execution of the joints by the use of the most advanced technologies which also considerably influence the phases of building site. The wooden elements, which historically were assembled on site, or directly built "in place" for the lack of sophisticated lifting systems, can now be directly assembled outside the work site or "at ground", near it. The building site changes as a result of modern technological developments. In this context, it is clear that the construction technique, when applied to contemporary architecture, could offer benefits unimaginable until a few years ago. But no one can refrain from reflecting on the role of technology in the world of contemporary buildings and on the role of recovery in topics where more and more frequently technique is replaced by unnecessary technicalities. This fact, forgetting that one can hide a bad picture but a wrong restoration may impair centuries of history that no one can ever give back.

7. REFERENCES


8. BIBLIOGRAPHICAL SYNTHESIS

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