INTERVENTION AND REPAIR TECHNIQUES IN WOODEN ANCIENT STRUCTURES

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Summary

At the present state of knowledge, the conservation and restoration of ancient timber structures has raised a series of problems that have not received sufficient attention at both a methodological and technical level. In particular they regard: the assessment of the real efficacy (and/or reliability) of the use of new diagnostic methods to evaluate the conservation status of the material, the forecast of the structural functionality of both their overall behaviour and that of the individual elements, the judgement of the durability of works performed using innovative type techniques.

The report illustrates studies, planning experience and knowledge acquired during several years of activity in the ancient timber floor and roof sector. The study - which is interdisciplinary - calls on the specific competences of various sectors: from history to construction technology, survey, wood technology, structural engineering and dendrochronology.

It also presents works on the restoration of ancient structures, starting from the construction survey through to numeric modelling, both to verify the structures in the presence of deterioration and to evaluate interventions realised using innovative construction procedures based on materials and techniques that differ from the originals.

Foreword

Objective of this paper is to contribute on the theme “Timber structure new methodologies for conservation and restoration” with a speculation on the opportunity and validity of interventions performed with recent techniques and new products. Advanced materials are provided with ever increasing frequency from technology to structural restoration, replacing and acting as alternatives for experimented materials and techniques.
The starting point of this analysis is essentially based on the hypothesis that medium- and long-term durability of these interventions, compatibility of diverse structural elements and the need to preserve the original technological principles should be the founding parameters of decision-making regarding the intervention techniques to be applied in structural repair projects.

These problems are beyond doubt the most indefinite and controversial of the many issues put forward today by who is called to intervene on these works with the objective of conserving historical value and structural efficacy in time. The uncertainty and the reservations regarding the application in various stages - from structural design to practical realisation - of several innovative technologies is still being debated, above with reference to the outcome of the interventions in time.

This paper outlines some observations conducted on concrete cases of interventions performed in recent times and aims at presenting guide-lines for a correct approach to the problem.

National state of art

Interest in Italy in the conservation and restoration of ancient timber structures, important aspects of our architectural heritage, represents a recently introduced sector of the Cultural Heritage Department, raising problems regarding diagnostic surveys and intervention techniques focused on conservation. Over the past few years, there has been growing firm conviction that these structures must - wherever possible - be conserved and restored in accordance with their static role, using interventions that are consistent not only with the original design but also with the material: the timber.

However, in practice, many recent interventions involving structural restoration have betrayed the idea of conservation: in extreme instances we have witnessed the unjustified demolition of century-old floors, coffer ceilings and roofs; more frequently, ancient buildings have been altered by the widespread use of new structures and new materials in replacement of the original ones.

These arbitrary and to say the least “heavy-handed” interventions are in the majority of cases induced by the difficulty of evaluating the state of the conservation of materials and the real load-bearing capacity of the structural elements, or by an incorrect evaluation of the overall structural function, or the

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1 This study refers to the results of a MURST 40% entitled “Historical Interest Timber Structures: Assessing Durability Consolidation Performed with Recent Technologies” (coordinated locally by C. Bertolini from the Polytechnic of Torino). Subsequent research addressed the theme “Diagnosis and Evaluation of the Loadbearing Capacity of Timber Structures: Optimising Structural Checks on Products Once Part of Historical Buildings” (U. O. Coordinator: C. Bertolini, in a strategic CNR-Cultural Wealth Supervising Agency, 1994). Further analysis was conducted during the writing of a dissertation presented at the Polytechnic of Torino entitled “Static Performance Analysis of Ancient Timber Structures in View of their Functional Restoration: Coupling and Connection Systems...”.

choice of summary and profitable procedures rather than procedures guided by the real needs of the timber components.

It is precisely their load-bearing capacity that is constantly debated today, in spite of the renewed interest in studies on wood, by operators who, clearly lacking the necessary know-how, demonstrate their complete distrust through their interventions on existing timber structures.

This distrust has been expressed and given tangible form through the development of consolidation techniques that foresee the extensive inclusion of every type of implant, made from "new" materials that, precisely because they are new, are regarded as superior from a short-sighted point of view that does not take account of medium and long-term behavior: this means problem of durability.

Many interventions - also those of an innovative type - currently appear to lag behind the conservative criterion which has spread not only in monumental restoration, but also in the restoration of historical or simply traditional buildings.

All too often we witness operations focused mainly on unjustified radical interventions: timber floors consolidated with heavy metal structures or capped in reinforced concrete, partial or total repair roofing with steel elements or reinforced epoxy conglomerates.

In these types of intervention, which reflect the distrust of this material and of traditional construction methods and the ancient master builders, it is often possible to note the lack of one of the characteristic phases of structural restoration project management: the diagnostic survey.

Dendrochronological analysis

The Dendrochronology represents an unpresentable support in the study of ancient timber structures and it is the single tool by which there is the agreement to the dating the structures with the calendar year accuracy of the last growth ring conserved in the timber manufactured. In the more favorable case, when there is the sapwood ring, this dating method is able to arrange, beyond the demolition year, also the season in which the tree matrix has been cut or has stopped to live.

For this reason, the Dendrochronology has been termed as the most exact existing calendar (fig. 1).

The principle on which Dendrochronology is based is linked to the vegetative cycle of trees living in the moderate climate: each year, in fact, there is a growth ring. During the spring there is the vegetative restart, in the more hot period there is the deceleration of wavaney-edge activity, in the sturdy summer and in the autumnal period there is the formation of belated wood until the coming of the coldly season in which the wavaney-edge activity stop and will start again during the afterward spring.

This cycle, during its phases, can give birth, relating the species, to the more or less diversified wood that depend from formation period and so we can mark a vernal or a belated wood, sometimes also differentiated for very evident morphological and anatomical characteristics.
Figures 1.1, 1.2, 1.3  Salbertrand Church. Relief of roofing timber structures and knowledge research. Dendrochronological mean curve. Dated elements (with black is showed the part of the existing sap)
The growth values of single contemporary of each arboreal species will be afterwards mediated between them to form the mean curve for that establish species. Several mean curves derived from lived trees in different epochs (living tree wood, timber structures of different period, fossil wood), can be linked between them for a number of years of the same age and will form standard curves (chronology) for the establish species with secular or thousand sequential. The comparison of dendrochronological curves of unknown age with this cross dating, will permit to recognize the existence of line with similar course, and so will permit to fix the period in which the tree matrix of the timber element to dating has lived. In this paper we present some examples in which it has been doing the dendrochronological analysis².

Structural restoration and survey: a difficult relationship

Specialists are well aware that there must be a close relationship between the execution of conservation work and the analytical surveys that "convey information" regarding the work itself (fig. 2). This relationship may throw light on the appropriateness of some technical choices and - indirectly - the overall methodological guidelines may become more credible: a correct cognitive basis forms the irreplaceable starting point for a structural restoration project. With this in mind, for the past few decades, technical and experimental research has developed survey methods involving various specialist areas, at times adapting knowledge from disciplines that do not belong to the construction sector (such as thermography, ultrasound, radiography, tomography) and at others using the technological refinement of procedures inherited from research into architecture and, in particular, into the technology of construction materials. In particular, non-destructive tests have become increasingly widespread, especially in more recent years, following the introduction of new methodologies and new diagnostic instruments. In the case of timber structures, however, it is worth recalling that the use of data obtained from these surveys has often proved difficult at a practical level. It is not uncommon for the restoration project manager to find himself with insufficient or - more often - superfluous information, and without knowing the benefits and disadvantages of each survey method, he is not able to use the results of the test. This is not all. Our culture, as architects and engineers with a polytechnical training, is largely inadequate to interpret the conception and materials of ancient timber structures since the latter were not signed using modern construction science and techniques: they are the result of empirical methods, the practical experience of master joiners and the application of "rules of art" for building in this material. This is true of all constructions, from the remote

² Bertolini Cestari C., Macchioni N., Pignatelli O., Investigation and project of restoration, in: Bressanone Meeting "To Project the restorations", 1998.
Figure 2  Timber structure of the roof Valentino Castle in Turin (17th Century): a complete investigation methodology on the emblematic case.
past to the middle of the past century. The other difficulty facing those intervening today is that of overcoming the contrast between the two aforesaid cultures, a contrast that is inevitable and constantly re-emerges during the structural restoration programme, from the diagnostic to the executive phase. Against this background, what indications can be given to orient a survey programme both at a methodological level and in practical terms for a correct structural restoration? What diagnostic tests are recommended as being the most effective and reliable for evaluating structural timber elements during interventions? And using what survey technologies? A programme of tests aimed at the restoration of timber structures must be based on the systematic collaboration of experts from different sectors: surveying, history, timber technology, dendrochronology, structural analysis and architectural restoration. With this in mind, the following pages focus on the main cognitive-diagnostic parameters involved in the choice of the survey project.

**Intervention Issues**

In the restoration of buildings, ancient timber structure complexes represent a specific class of manufactures with special importance and acknowledged interest in the rich cultural wealth of historical buildings and tradition due to territorial diffusion, typological articulation, technological characteristics, artistic and formal value, etc (figs. 3-4). In order of priority, we wish to mention that these manufactures are before all structure and for this reason, especially in the past and in Italy, they did not receive the same attention or consideration granted to the building they are part of. Consequently, they were not treated with the same respect. In many cases, the structures were demolished, replaced or altered. In recent times, in the matter of conservation, the conviction that as far as possible these structures should be kept, restored and conserved in the static role they perform took root. According to this idea, interventions should respect the nature of these manufactures and be coherent to their original conception and to the material they are made of: wood.

However, in practice, many structural restoration interventions performed in recent times betrayed the idea of conservation. In extreme cases, we assisted to the unjustified demolition of ancient ceilings and roofs. In other cases, certainly more frequent, there were ancient loadbearing organisms extensively tampered with by a generalised replacement with new structures and new materials. Consequently, the arbitrary or - if only - considerable interventions were induced most of the time either by problems in assessing the state of conservation of the material and its actual structural loadbearing capacity or the incorrect evaluation of its structural performance. In other cases, the interventions were caused by excessive adhesion to safety criteria valid for new structures only or by the choice...
Figure 3  Typical example of timber roofing structure of Italian architecture of 17th Century
Figure 4  Typical example of timber floor of Italian architecture of 17th Century
of quick and profitable procedures instead of procedures guided by the real requirements of timber products.

In fact, current discussions still address the loadbearing performance of these structures notwithstanding the renewed interest and the diffusion of studies on timber. Operators, evidently not equipped with adequate knowledge, demonstrate their total mistrust towards existing timber structures with the interventions they perform. This mistrust is expressed and concretised by defining and developing consolidation techniques which include the extensive application of various types of "prostheses" made with "new" materials which - because new - are considered winning in a short-sighted vision which does not consider duration and medium-to-long-term effects of the interventions.

The static function performed for centuries by individual components and global structures is thus subtracted, modified and distorted and, in some cases, limited to a purely aesthetic covering function by those who believe in the greater reliability of bolts, reinforcements, fibreglass bars or steel sheets and various types of conglomerates which "devastate" the structure from the inside. Thus, cutting out a timber structure to introduce rigid bars or plates which inhibit coupling play reflects the mistrust towards this material, towards tradition and towards the ancient craft of timber building.

Techniques and technologies of interventions: General Criteria

In current technical literature, certain interventions - included those with innovative features - appear strongly delayed with respect to the conservative criteria which are being imposed for monumental and historical building restoration or more simply, by tradition. Too often we witness operative practices which prevalently address radical interventions: timber ceilings consolidated with reinforced concrete mantles replacing all or part of the structure, total or partial reconstruction of roofs with steel or glued wood laminate. The introduction of materials extraneous to the timber restoration tradition indicates a wide-spread loss of building know-how on behalf of designers and sector workmen.

With these premises, which techniques and technologies and which materials can be usefully recommended today for consolidation interventions?

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\[^{iii}\] One example for all: F Sironi, "Timber and Imagination", in "Modulo", no. 204, September 1994 suggests an intervention on a timber beam ceiling with incredible proportions for an ancient structure. The base-to-height ratio (8 x 20 cm) is closer to that of a laminar beam structures than that of solid wood and the cut resistance bolts lead to perplexity on the possibility of insertion without breaking the timber beam extrados. Moreover, the intervention prescribes L-brackets, stands and suspending brackets... Is all this imagination actually necessary?
Currently, a designer involved in a structural intervention on ancient manufactures cannot avoid being stricken - and even intimidated or bewildered - by the great variety of recently performed structural interventions on a wide range of structures which include ceilings, frames, pillars, and trusses only to quote the most common. Moreover, the design suggestions emerging from the flourishing technical literature in this sector too often represent very particular cases and are treated as unique. The proliferating of various consolidation technique "patents" - consisting of steel sheets and wires placed in the core of the beam, multiple layer techniques, epoxy resin applications, etc. - appear to provide the catalogue of solutions and techniques to be adopted to solve the problem. In this scenario, is providing indications to address the choices on methodological and practical level still meaningful? On the other hand, the conviction that no suggestions in principle and in practice can be offered would fatally lead to restoration interventions being conceived one at a time or even - for the most complex cases - step-by-step, with unplanned consequences in execution and decisional adaptation. This paper certainly does not intend to treat the complete, complex and delicate issue of structural consolidation of timber manufactures neither does it intent to offer final solutions to problems which underwent complex and sometimes contradictory evolutions and appear to be tending to more mature and balanced insertions in the picture of wider general structural restoration. The starting point, however, is understanding the existence of many shortcomings and the conviction that much can still be done to eliminate the problems on methodological and practical level. With this reference, this paper aims at offering a contribution regarding the main parameters which take play in choosing from the most common intervention techniques.

**Restoring renforcement and consolidation techniques**

In the wide and articulated case study of current carpentry restoration-consolidation, a schematic subdivision can provide an initial orientation. Timber structure consolidation can be classified by type according to the interventions required and to the instability found. Schematically, two major types can be identified: localised interventions and interventions on the global structure.

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V A specific UNI committee on "Recommendations for the Structural Restoration of Civil Buildings and Architectural Wealth" co-ordinated by Prof. G. Croci (the section on timber is co-ordinated by C. Bertolini) is preparing a long and articulated paper on the technical analysis, the intervention technologies and the materials to be used to restore ancient buildings.
The first is the consequence of existing deterioration on single mouldings or more commonly near panel points with other mouldings (internal connections) or at coupling points with surrounding walls (external connections) where conditions of moisture and poor ventilation at beam headers caused biotic attacks on materials.

The latter type of intervention prevalently involve on the needs to adapt to changed conditions of service and consequently address structural safety issues.

This schematic organisation highlights the different purposes of the two types of intervention and specifically:

- Restoring or rebuilding interventions on material considerably altered or damaged by external factors (biotic attacks, fire, demolition, etc.). Localised re-constructive techniques include in situ fitted wood prostheses, glued sheets, epoxy cement.

- Reinforcement interventions with substantial changes to the existing system tending to increase the resistant capacity of the original structure. This category of interventions on trusses includes positioning metal tie-rods, adding steel ribbing and inserting fibreglass bars to consolidate connections.

It is important to note how these two types of interventions referred to panel points and trusses stiffen couplings. Essentially, the interventions change the structural arrangement of the truss with reference to stiffness ratio at local and complex level. From a static point of view, these alterations can produce qualitative and quantitative tensional alterations which cannot be neglected.

The following paragraph illustrates and discusses an intervention technique which causes alterations and changes to the structural arrangement.

**A “Sub-ludice” Intervention Technique**

Recent intervention maintenance, consolidation and seismic upgrading techniques on ancient timber structures have highlighted an increasing and diffused use of a recent technology which consists of applying glass or fibreglass rod reinforced epoxy conglomerate. The idea of using synthetic material with mechanical resistance features very different from that of wood (such as epoxy concrete, for example) in structural restoration interventions dates back to approximately thirty years ago, while the technique has only been applied in Italy for the past twenty years.

The success and the diffusion of this technology can be re-conducted both to the possibility to return unity and compactness to strongly corroded or non-existent moulding parts and to intervene in correcting the static arrangement thanks to the application of epoxy prosthesis and suitably anchored fibreglass rods.

It is important to note that this “therapy” is irreversible. The reservations towards the application of this technology arise from the problem of compatibility with the material (timber), the reversibility required for some interventions and the uncertain durability. In particular, durability is the theme this paper aims to focus on,
considering that the technique and the medium- to long-term material performance and reliability have not yet been demonstrated (i.e. approximately twenty years). Consequently, this paper aims at illustrating a survey conducted on approximately thirty roof reinforcement interventions performed by applying this technology during the last fifteen years in Italy.

It is worth outlining the operations which this consolidation technique consists of:

The moulding part to be removed is defined by evaluating the instability and extension of the rotting or wood-wormed area. The healthy parts of the timber are then drilled and fibreglass rods are inserted in the holes. These are bound to the mechanically resistant timber parts with epoxy paste. The entirely missing parts are reconstructed with epoxy concrete after constructing a suitable provisional or disposable formwork.

With this system, most of the traction stress is absorbed by the rods which are suitably dimensioned to calculations, as refers position, diameter and length. The glue pastes are used (epoxy resin at a ratio of 2/1 and 60% weight; inert quartz 0.15-0.30 mm and 40% weight). Conglomerates are used to replace the missing parts of the wood and usually consist of inert quartz with variable granulometry from 1.15 to 10 mm and epoxy resin at a ratio of 2/1, 14% weight.

The success and the wide diffusion of this technique is due to its simplicity and rapidity of execution (the intervention is quick and the parts directly addressed by the instability do not need to the dismantled), to the opportunity to return unity and functionality to strongly degraded moulding, and to the possibility to correct static arrangement with the effect of reinforcing the structure. The increased stiffness resulting from this technique (and consequently, the increase in applicable load) depends on the elastic module of the reinforcement materials, the area and the moment of inertia of the reinforcement elements and - significantly - by the stiffness in adjacent element couplings. With reference to this matter, it is important to note that a mixed wood, concrete or steel reinforced beam deforms with the sliding of the contingent surfaces (sliding is lower when the joint stiffness is higher). On the other hand, deformation and sliding are completely different in beams reinforced with epoxy concrete (fig.5).

We will not face this matter in great detail in this paper as the reader can refer to specific literature for details. This paper intends to recall some structural considerations and some technological aspects finalised to our purpose.

Remarks on Examined Cases

The examined cases (approximately fifty) show two distinct categories of intervention with this technique. The first category concerns consolidation of supporting areas while the second regards interventions on the truss structure panel points.

It is important to note that the matter of static arrangement is elementary for interventions on the supporting areas and mainly addresses resistance to cutting stress. Consequently, the dimensioning is simple and - from a purely theoretical
point of view, since the load borne by rod reinforced epoxy conglomerate is surely much greater than that of wood - this intervention should ensure optimal results. However, inspections conducted on structures with this technique - such as beam headers and truss chains fastened to the perimeter walls - showed degradation by rotting and decay, which reduces mechanical resistance to annul it completely. We noticed that, in some cases, the contact surfaces between the two materials (resin and wood) were not solid. In these cases, the mechanical effectiveness of the intervention did not seem reduced (at least at the time of inspection) but durability could be compromised by subsequent biotic attacks in the timber section exposed by the shrinking of the material due to thermal-hygrometry variations. This phenomenon can be re-conducted to the different performance of the two materials to thermal-hygrometry stress (epoxy concrete is much more stable than wood). The loss of adherence between the surfaces is the result of warping or deformation caused by shrinking above all in presence of helicoid fibre moulding.

It is important to note that attacks or degrading in wood can severely weaken even only a small area of a structural element (e.g. the detachment section). The greatest hazard is that of fungi which can occur when the local moisture exceeds 20%. This can occur due not all but rare events, such as filtration of moisture, condense, leaks from pipes. Moreover, as mentioned above, the section where the attack risk is higher is near the critical area of the walls where the fungi attacked timber looses its mechanical resistance properties to a considerable extent and even totally, in the most severe cases. The hazard is made severer by the transverse location of the section, i.e. perpendicular with respect to the direction of the fibre. Consequently, in these cases, a preserving treatment is required in situ according to the timber risk class.

The problem of durability appears extremely important in interventions on carpentry spatial panel points where several wood elements converge and addresses both technological and structural issues. In this situation, the structural interpretation of the system cannot be referred to the usual reticular arrangement. The stiffening of panel points, in fact, appears as a “unique arrangement” where the re-distribution of the stress in the moulding is qualitatively and quantitatively very different from the original arrangement. The conducted surveys highlight the difficulty in choosing a mathematical model suited to validly interpret stress in noticeably inhomogeneous structures due to alterations following the interventions on panel points, to geometric configuration and to the mechanical features of the materials (resin, rods, wood) forming the moulding (fig.6).

In actual fact, for joint stiffened timber and simple trusses the common definition of reticular structure arrangement used in the science of construction is inexact and approximate. This complex of rods can hardly adhere to exactly defined static arrangements with their complicated geometrical arrangements caused by the panel point stiffness. Consequently, these systems are characterised by strong static

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VI. L. Uzielli, “Evaluating the Loadbearing Capacity of Timber Structures”, in L’Edilizia, no. 12, December 1992
Figure 6.1 Finite element numerical model of traditional Italian carpentry: representation of the deformation relating y axis.

Figure 6.2 Finite element numerical model of traditional Italian carpentry: representation for half carpentry of tension relating x axis. It is evident the increase of the tensions in the inferior edge of chain.
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Figure 6.3  Strut-chain connection. Tensions Sigma xy; concentration of traction tensions in the yellow area.

Figure 6.5  Strut-chain connection. Tensions Sigma xy; in the external part of the chain the blue area presents a great cut tension, very dangerous because it is parallel to the wood fibres.

Figure 6.4  Strut-chain connection. Tensions Sigma y; in the blue area it is evident the vertical compression with the squashing of the squashing of the material.

Figure 6.6  Strut-chain connection. Three principal tensions. There are represented the areas of the most elevate compression stress.

Figure 6.7  King post-strut connection. Tensions Sigma y

Figure 6.9  King post-knee rafter connection. Vertical movements relating y axis.

Figure 6.8  King post-strut connection. Three principal Tensions.

Figure 6.10  King post-knee rafter connection. Tensions Sigma x.
hybridism which results in a compromise between the structure ratios with panel point hinges and stiff or semirigid panel point structures. In this picture, timber as a material plays a fundamental role due to the known "movements" which characterise its performance in variable ambient situations. In actual fact, we have noted how roof structures with stiffened panel points can be effected in time by cracks along the some moulding where the internal bondage is reduced to allow those rotation movements impeded by the end sections. Finally, the concern regarding the outcome of these interventions can be identified by the locked panel points which alter the structural arrangement and annul the possibility of cyclic movements in the timber which were foreseen by the original constructive technology.

Restoration: what the treatises teach us

Examining past interventions on timber structures by re-reading source material from treatises and manuals calls for an effort to reconstruct a type of experience to which we are no longer accustomed: right from the preparation of its component elements and connectors, the conception of the timber structural complex is defined using criteria that allow subsequent maintenance operations - destined to improve their structural function - and the possibility replacement of decayed frameworks.

The concept of replaceability is clearly expressed by one of the most precise treatise writers of the 19th century, Emy, who in his Trattato dell'arte del carpentiere, suggests .... if decay should be noted in any part of a construction, it must hastily be replaced with good materials .... In the organisation of the traditional building site, replacement was an operation that was planned right from the outset of the structure, in order to ensure the easy replacement of a severely decayed part without having to pull down the entire building. Owing to this ease of replacement, Emy states ... and on this subject I will draw attention to the fact that a joinery work that is a very large in size, will be perfect and the cost of its construction well invested if, in addition to the conditions imposed by the purpose which has to be satisfied, it also presents the facility of replacing any one of its parts which might show such deterioration as might compromise the soundness of the building and the conservation of the other timbers ...

In some seventeenth-century joinery work it has been observed that thin parts present half-timber joints using dovetailing between contiguous joists, and the joint was realised using wooden dowels in wood that was more resistant and more durable than the joists, but at the same time could be extracted to allow the part to be replaced from the joint (fig. 7).

Among the numerous procedures proposed by the treatises it is still possible to find the positioning devices consisting of timber shelves inserted in the masonry under the headpieces of beams and tie rods. This procedure served the dual

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Figure 7  Examples of metallic devices to reinforce degraded carpentries, relating literature: 1 - Emy, 2 - Pareto-Sacheri, 3,4 - Rondelet.
purpose of maintenance, namely to ensure the replaceability of an element in direct contact with masonry to protect the headpieces from deterioration, and structural reinforcement of the beams, by reducing the deflection free span VIII.

**Intervention techniques between tradition and innovation**

In the wide panorama of intervention techniques now used in the restoration of timber structures, those of a "traditional" or even historical nature present an undoubted advantage: durability (fig. 8-9-10-11). On the contrary current operating practice predominantly tends towards radical interventions: timber floors consolidated with slabs of reinforced concrete, often in replacement of the structures or part of them, or partial or total reconstructions using steel or bonded laminboard. Following the introduction of additional elements, realised using materials that are extraneous to the tradition of maintenance and the restoration of timber structures, there has been a widespread loss of knowledge of traditional construction techniques, both among building designers and specialised workers. This has led to the problem now faced in conservative consolidation and restoration works: what techniques, what technologies may be usefully proposed today and using what materials?

The planning proposals that emerge from the flourishing technical literature in the sector all too often represent very special cases, treated as genuine unicum. The proliferation of various "patents" for consolidation techniques using steel lamina and latticework positioned in the core of the beam, using epoxy grouts reinforced with glass fibre bars, etc. appear to be provide a catalogue of solutions to the problem of planning choices regarding the technique to use. In this situation it is increasingly important to provide indications to guide choices in both methodological and practical terms.

The present contribution certainly makes no attempt to provide a full discussion of the complex and delicate subject of the structural consolidation of timber structures, nor does it offer definitive solutions to problems that have undergone difficult and sometimes contradictory evolutions and which are now moving towards a more mature and well-balanced insertion in the conservation sector. The last two decades have seen the growing and widespread use of the recent technology that uses grafts in epoxy conglomerate reinforced with steel, glass or glass fibre bars.

The idea of using synthetic materials with characteristics of mechanical resistance that are completely different to those of timber (such as grout) in structural restoration work dates back some thirty years, and its realisation to only twenty years ago. The success and widespread use of this technique may be attributed to the possibility of restoring unity and compactness to strongly corroded or non-

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Figure 8  Timber roofing structure of Salbertrand Church; reinforced with metallic system
Figure 9 Timber roofing structure of Salbertrand Church: consolidation of ridge beam.
Figure 10  Timber roofing structure of Salbertrand Church: detail of metallic carpentry.
Figure 11  Timber roofing structure of Saibertrand Church: phase of consolidation.
existent joists, and the possibility of intervening at a corrective level on the static regime through the use of grafts and appropriately anchored bars.

It is worth stressing that this "therapy" forms part of the class of interventions defined irreversible. This has generated concern regarding the use of this technique, because the question of its compatibility with timber and the occasional need for reversibility are compounded by the inscrutability of its durability.

The study has focused in particular on this topic, bearing in mind that the materials used have not yet been finally tested in terms of their behaviour and structural reliability in the medium-long term.

From the analysis of the tests performed it was found that for trusses stiffened at joints using this technique, the presence of breaks along some joists."x.R.

Conclusions

Some indications addressed to the people in charge of managing consolidation projects can result from these brief speculations: the application of an intervention of the type herein described must be faced with care. The points to which most attention should be devoted are the following.

The degraded area of wood affected by fungi or insect attacks is never clearly delimited with respect to the healthy wood. Consequently, it is not easy to identify which part of the wood to remove. Removing the wood from the areas where it is totally inconsistent, in fact, is not enough. Removal must go well beyond and a powerful antiseptic must penetrate in the wood.

Drilling fibreglass rods in the wood can provide good resistance, from a static point of view, but in order to ensure this effect, resin to cement the rods to the body of the beams must be applied with extreme care in the holes drilled in the healthy wood. Given the viscosity of the glue, in fact, it is very difficult to make it penetrate in the hole and totally fill the space between rod and wood. Moreover, the bond must be performed in complete safety to ensure effecting connection because, as described, it is not possible to totally rely on the perfect adhesion with the block of resin poured on the rod end.

Finally, for interventions on timber truss panel points, for the reasons mentioned above, we wish to note that not excessively stiff consolidations are to be preferred as to not alter the general distribution of stiffness with sometimes very negative effects on diminished energy dissipation, especially noticeable in the event of earthquakes.

Durability and reliability of this and other consolidation techniques presenting innovative features needs to be evaluated by means of surveys conducted on the

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"x.Cfr.: BERTOLINI CESTARI C., Tecniche di consolidamento e loro durabilità: problemi di intervento e aspetti progettuali, in Timber: a structural material from the past to the future, Workshop 48th General Council RILEM, Trento, 1994"
widest possible statistic sample. These surveys will allow to better address and plan consolidation and to study the actions required to prevent the medium- to long-term negative effects of these interventions.

This contribution follows within the research “Analysis of the condition of preservation and methods of intervention - heritage”, as part of aimed project “Cultural Heritage. Ancient timber structures: structural functionality, constructive technologies and methods of intervention” (Target 2.5.1.) promoted by CNR, where Clara Bertolini Cestari is in charge as head of scientific research.

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Figure 5  
Detail of 17th century truss with hybrid static performance and diffused consolidation interventions on most of the carpentry panel points with the epoxy cement and fibreglass reinforcement technique and Consolidated panel points. The grey areas are resin.