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Original article

State-of-the-art technology on conservation of ancient roofs with timber structure

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ABSTRACT

The timber load bearing structures of the roofs are organized as a hierarchic articulation of members and structural units connected by joints and auxiliary beams to form structural systems. The authors list, for everyone of the cited levels, the techniques that can be considered obsolete as the indiscriminate replacements of members and units or, worst, of the entire system, the application of heavy steel profiles placed at the exterior or at the interior of the members and of the units or the invasive prostheses that stiffen the nodes and destroy their ductility. Considerations on the lack of appropriateness of these techniques are exposed. Today are available new techniques that, both obtained as adjustment of the old ones or based on completely new approaches, are inspired by conservation and repair criteria. Since they are based on interventions of minimal extent, they are able to ensure, within certain limits, respect for the original structure with the values they carry and rescue of the original configuration, materials and bond. The authors non acceptance of the practice of dismantling the structure, to some extent or entirely, in order to replace its damaged parts demands for working *in situ* thus allowing also the rescue of the original assembly.

1. Research aims

- Reference to essential roof configurations that are commonly found in the European built heritage.
- Inventory, in relation to the more common causes of failure, of (past) present strengthening techniques of roofs, at the different levels of the components (Members, Units, System, Joints), specifying the general condition of the various settings (usual loads, seismic level, humidity, biological factors, etc.).
- Reference to theoretical and technical criteria of conservation.
- Examination of strengthening techniques.
- Critical evaluation of the effects of each examined technique in order to assess whether it is compliant or not, in any case to which extent, with the conservation criteria (efficacy; minimum intervention; respect of original configuration, authentic materials, original assembly, aesthetic values; reversibility; others). Furthermore, field of application, designed duration, (compliance with practice codes).
- Documentation and discussion of typical examples of application of the solutions cited in this essay.

2. Introduction

Historic roof structures are basically composed [1–3] of a system of portals, frames or trusses that directly support a secondary structural texture of scantlings lying in planes, the slopes of the roof, and the covering materials.

The members of a classical truss (a structural unit), directly inspired by the classical antiquity (see for instance the trusses of the St Catharina church in Sinai, 6th century [1]) are ties (tended and bent elements), posts (tended or, if they rest on the tie, compressed) and struts (compressed), false ties (compressed), rafters (compressed and bent), purlins and top ridge (bent, sometimes also tended), joists (bent), besides cleats, corbels, cantilevers, bracings, web members, etc. Nodes tie-rafter can rest on brackets fixed at the masonry support.

The scheme is almost statically determinate.

The roof trusses of Northern Europe countries are made with a set of horizontal and inclined members. Their schemes are generally several times statically redundant.

More complicate and sophisticated schemes are adopted by the English historic carpentry [2]. Barns represent a typical example.

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They are generally devised as a basic portal or frame that carries a superstructure of small size members arranged to accommodate a boarding or a plane of flat bricks and the covering elements.

Domes or polygonal vaults are often used to cover the transept of the churches. This is a rule in the byzantine architecture.

Posts, beams, struts and similar members, occasionally with cleats, are the members that make up the portals.

A roof pitch is generally composed, like a floor, by the purlins and the top ridge, longitudinally placed, and by the joists. A secondary network of scantling and a boarding (sometimes a layer of flat tiles) is also present to enable placing the covering elements as the lagging and the tiles.

Top ridge and purlins can be regarded [3,4], as well as auxiliary beams with the function, extremely important in seismic prone areas, of connecting the trusses or the portals to each other. If nailed to the main units, they can be tended and bent.

The cited members are subject to decay of material due to biologic agents, weathering, etc. (the ends are particularly hit by moisture especially if inserted into the masonry without ventilation, thus frequently damaged by beetles and fungi) and by failures caused by mechanical actions.

3. Conservation

3.1. General principles

The main aim is to conserve the function of the structure as well its authenticity, both ideal and material, in a condition of sufficient safety.

The principles [3–9] to be followed are:

- conserve the original conception. Repair the original pieces. Minimise the sacrifice of original material. Conserve the original assembly;
- conserve the functionality;
- make the intervention adjustable, reversible;
- conserve the evidence of the structural failures. Do not hide but show the repair interventions without disturbing the look and the perception of the original structure.

In order to follow the cited principles it is required to operate on the spot without dismantling the carpentry or any of its parts, start from the lower level, i.e. from members, going on with the upper levels of the hierarchic organization of every complex.

3.2. Preliminary operations

Careful inspection is needed in order to detect any failures caused by direct action of the roof (bulging of the internal facing, rotations, cracks, etc.) or other factors [10–12]. Maintenance and repair of the supports prior to repair of the roof are indispensable.

4. Repair technique

4.1. Measures aimed at preventing material decay

The first step to repair roof structures, anyway after propping, consists in strengthening the members; usually these measures are not sufficient and the structural units (frames, portals, trusses) and the same system of units as a whole need general strengthening and bracing (see overleaf). Wood decay development can be checked throughout its phases by means of treatments.

The material can be maintained intact. The affected wood (e.g. by fungi) can be re-aggregated by means of chemical products (e.g. acrylic resins) but the treated material does not recover its original mechanical strength.

4.2. Measures aimed at counteracting mechanical failures

A series of repair operations can be started taking into account at least four levels of intervention, hierarchically settled according to the building process and the different role the single components and the whole system play, i.e. that of Members, Connections, Structural units and Structural systems [3,13]. The mechanical problems of members of floors and roofs are generally tackled with similar techniques. Use of suitable and precise tools, especially saws and drills, is essential.

4.2.1. Members

4.2.1.1. A case record of the old fashioned solutions.. Operations currently carried out in the past or proposed by practice handbooks to recover the efficiency of damaged members of a timber carpentry appear today obsolete as far as conception, materials, execution is concerned.

Nevertheless, some of them are interesting due to their simplicity and reversibility. Just a few others are of historic value since they throw light on the understanding of failures of the timber structures and the strengthening conception at the time of their application.

A recurrent interesting example is constituted by the practice, mainly operated in the 18th and 19th century, of fastening the damaged sections of a broken member with several circles of continuous wrought iron strap (Fig. 1); the measure is ineffective and sometimes dangerous due to the high deformability in every direction of the iron ribbon and to its prompt rusting.

Severe hygro-thermal and aesthetic problems arise since the measure requires to hide a large extension of the member.

The strap can be removed but irreversible damage is brought to member surface by the very high number of nails to be removed. The application of plates at the lower edge of the members in order to increase the depth of the section and, at the same time, lend additional tensile strength to the member is an obsolete practice, moreover not effective if not integrated, as generally made, by the application of devices resisting compression at the upper edge. The application of resistant lamellas at the faces of the member, inserted in superficial horizontal slots made on purpose, is to be considered ineffective and not respectful of the mechanic peculiarities of the wood due to the tangential stresses that the lamellas exert on the wood.

Fig. 1. Absolutely useless fastening with iron strap of a truss tie affected with a check caused by shrinkage (Villa Demidoff, Florence. Photo Tampone).

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