Ancient Timber Structural Systems: An Attempt To Define The Main Components Of The Paradigm

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Introduction
When thinking to timber structural systems one is overwhelmed by the extremely wide variety of elements that this set includes, from bearing structures to framing devices, ..., to complex art objects (statues, carved or painted boards, retablos, works of marquetry and inlay), mobile and fixed furniture as libraries, choirs, in addition maquettes, musical instruments.

In this cosmos, a variegated universe is constituted by the set of the load bearing structures, with which this paper is mainly concerned.

Generalities
Witnesses of timber structures and constructions are documented since prehistory. In the lake areas of eastern France, northern Italy, southern Switzerland and Austria and close Regions, for instance, prehistoric or proto-historic palafitte (stilt houses) are brought to light, since half century, in great quantity in a large variety of types showing that construction techniques of dwellings and stores with timber were already suitable for that use. People who live today their constructive prehistory in lake areas in the periphery of the world still live in palafitte built by themselves or in huts in the forest. Study of primitive constructions is essential for the understanding of the origins and of the development lines of the timber structures.

The fundamental types and configurations as the truss, known in no more than two or three fundamental structural schemes, remained practically unchanged till present times though using sometimes different materials (steel cables in addition to timber, composites of wood, stainless steel, glue laminated timber etc.) and designed with slightly different details. In this sense an important role is played by the tradition and local craftsmanship. The same for the frames.

The importance of the timber structural systems comes from the fact that they have been, till the beginning of the XIX century, the only kind of mechanical device belonging to the field of the discrete in opposition to masonry, the field of continuous. This is due to the excellent mechanical characteristics of the timber that has been the only available material resistant to both compression and traction until the half of the XIX c., when steel became cheap enough and currently available to be progressively introduced in the building industry. Besides timber is available in considerable length, almost ready for use in carpentry except refinements which are anyway optional, in addition characterized by low weight, nice color, attractive look.

But wood has two more wonderful characteristics, the elastic deformability, read the flexibility, and the visco-elasticity. Both these properties occur in a beam, up to a certain extent, without breaking the member; in practice it is very difficult to break a beam of healthy wood dividing it in stumps.

The asset of timber structural systems is, therefore immense though the survival capacity of the material, limited in time by the quality of maintenance, causes a continuous reduction of the number of the ancient surviving specimens. Nevertheless the fossil specimens or the prehistoric surviving structures as well the structures still built nowadays by people living their constructive prehistory, the surviving ancient structures and some very ancient representation of timber structures offer a wide frame of types.

Besides painted panels ("tavole"), tritticos, retablos, maquettes, ..., *Furniture, Musical Instruments*, made of wood are to be considered wooden structures too, where the word structure means an articulated complex of joined members the function of which is to stand, suppor, keep together.

Existing high quality drawings and projects should be included in the asset as intellectual contributions.

**The Timber Load Bearing Structures**

A structural system is a complex device essentially designed to perform the function of bearing its own weight, the service loads as well the accidental ones and distribute the internal tensions caused by loads amongst the members, in a rational way, through various types of joints that act as internal constraints. Furthermore to transmit all the cited loads to the underlying structures (other structures made of whatever material or the ground) by means of external constraints.

A structural system is organized to provide strength, equilibrium and stability to the building. Generally speaking, it is conceived to work in the three-dimensional space and is hierarchically articulated.

The timber structural systems are generally composed by structural units (frames, trusses and similar, for instance) connected and stabilized by auxiliary members. The units in their turn are composed by timber members which are connected by joints.

The fortune of the timber over the ages as material suitable for construction of temporary or permanent structural systems are mainly due to its large availability, especially in certain areas, the easy workability and, as said, capacity of withstanding traction tensions in addition to compression, unlike natural or artificial stone. Tensile strength is essential in the performance of a beam, solicited to bending.

**The Patrimony**

The PATRIMONY of the ancient load bearing timber structures is constituted by an enormous number of surviving specimens, mostly still performing their service. Just to quote some of the most ancient specimens, one should remember the roof carpentry (half of the 6th c. a.C.) of the Saint Catharina’s church in Sinai, constituted by the famous trusses of the roof of the church which are the most ancient known so far. The whole carpentry and the fortress including the church were designed by the Architect Stephan from Elisth. They are quoted by the Justinian Emperor’s historian Procopius from Cesarea as ordered by the same emperor. The dendrochronological analyses confirmed the temporal attribution.

The Buddha Sakiamuni (enlightened Buddha) timber impressive tower, tall 60 m, built in the 11th c. in internal Mongolia, China, is still safely standing. But carpentries of the XIV and following centuries are not extremely rare.

The latin writer Vitruvius (1 c. B.C.), deducing his considerations from Theophrastus, the greek philosopher of the IV – III c., who had written the works *Historia planatarum and Causae plantarum*, was already able to distinguish the main characteristics of the most used genera of the trees used in the constructions at his time.

But the choice of a given species is conditioned by availability, cost, size, length of the pieces of the stock etc.

**RESEARCHES**

The researches carried out on ancient or simply existing timber structures include survey, inventory, recording, classification, cataloguing with definition of the evolution lines. A specialized multilingual glossary and representation rules are requested to share their knowledge.

Object of interest are age, function, acting loads over the time (with specifications), structural scheme, geometry, span, bay, articulation of the components (members, connections, structural units), overall dimensions, size of the members, internal and external connections and constraints. Behaviour over the time, actual condition, serviceability, safety.

The general exterior look of a timber structure depends on a few elements such as geometry, finish, decoration...; shape, working, grain, texture, pattern, color; these elements can be casual or designed. Craftsmanship, assembly, patina (aging), symbolism. About the material, genus and species (assessment of the taxon) are matter of definite
interest; besides the characteristics (those related to the single species, grain, defects, ...; decay). The Ductility of a structure depends mainly on the nature of the joints.

An essential issue is the consideration of interaction between the structure and the other structures present in the building especially if the timber one and the others are directly connected as it happens for a timber roof resting on masonry walls. Stability of the support is hence a central matter of interest.

Durability of the timber structural systems largely depends on limitation and distribution of loads in relation to size of the members, span and bay as well protection of the material. They are affected by seismic perturbations though less than other structures made of different materials. Seismic events damage specially the joints of the timber structures: a large quantity of energy is dispersed through the connections and this prevents the members from being hit by high dynamic tensions. The members anyway are too light for being affected seriously by dynamic forces.

F. Milizia, 1784, was one of the first scholars to put the question of interaction between masonry supports for beams and trusses and floor and roof carpentries in the seism prone areas; he suggested to connect the end of the timber members to the walls in a rigid way by means of flat iron ties ("bandelloni") for cooperation of the two structural systems during seismic events, for instance to prevent outwards rotation of the walls, as well to prevent disastrous reciprocal hammering. Also the considerable deflection of a floor beam, for instance, can cause thrusts with the consequence of pushing forward the external wall.

The stability of the whole construction has always been a difficult task (especially with timber which does not allow to make perfectly rigid joints between members; the same problem of instability was, and still is, rather difficult to understand by intuition, as proved by the evolution lines of development of the fundamental types and as recorded by the introduction of new structural schemes.

Failures
The structure may be affected with failures that concern the single components or more of them. The course of the failures is a significant item.

The joints undergo malfunction and disconnections; in the nailed joints the effects of humidity on metal as rust and the alternating movements caused by shrinkage are responsible of the embedding of the holes in the wood, combined with the reduction of the nails size that result in their pulling out.

The failures of the structures manifest themselves by means of symptoms: loss of geometry of the whole system or of the structural units or of the single members, movements (translations, rotations etc.) of the structural units or of the members, deformations, cracks. Sign of the failures are very useful for recording the structural behaviour and shouldn't be wiped off.

The VALUES of the ancient timber structures are mainly of historic, aesthetic, scientific, technical, anthropological, symbolic kind.

STUDY of existing structures is primarily directed to assess their efficiency. It is made by means of visual inspections, survey, analysis of the material such as taxonomic and dating assessments, grading (assignment of the members to a service class), detection and definition of the damage and decay of the material as well deformations and failures, dimensional measurements, detection of signs; furthermore with historic research, tests, trials. The dating process, one of the most difficult, needs to be carried out with several methods allowing cross assessments.

The collected data lead to the Acquaintance of the structural system and its identification (i.e. the understanding and interpretation of the general structural scheme).

Calculations are made both for verification and design (project, strengthening). Some modern calculation methods as the F.E.M. allow to simulate easily various loading conditions assessing the effects that are later compared with those really detected on the structure. They also allow to investigate the efficacy of several solutions in order to see, following a heuristic process, which one fits better the fixed parameters.

Compliance with present day practice codes with the aim of utilizing the ancient structure for practical use is always problematic because design concepts at the construction time were different by the
current ones. The most advanced codes anyway forbid the complete adequacy of the structures of the monumental buildings to modern requirements, since this would mean a substantial alteration of the ancient structural scheme.

The conservator has to make every effort to interpret the original concept and try to respect it.

The investigation means and instruments.

Diagnosis is the critical evaluation and interpretation of all the collected data, assessments, analyses, trials.

Most recurrent threats to patrimony are brought by biologic factors (the fungal attacks especially; termites or dead watch beetles infestations are able to cause structural failures too due to the reduction in surface of the resistant sections). It is essential in these cases to assess nature and extension of the infection and whether the damage jeopardizes the efficiency of the structure in a safe condition. Other causes of failure and collapse are natural catastrophes, fire, human carelessness and ignorance. Prevention and therapeutic treatments are often necessary. Composition, application modes, toxicity can be deduced by a set of Euroms.

Conservation
Reasons for the conservation of an existing structural system rest of course on philosophic and moral backgrounds (general purposes as well specific requirements as “istanza storica, artistica, tecnica, scientifica, pedagogica” etc.) as well on utilitarian and economic motivations; all these needs are generally expressed by “charters”, i.e. doctrinal documents concerning the Principles, and by guidelines containing the technical criteria to follow when operating (analysis methodology, reference to special practice codes, choice of the most appropriate techniques, characteristics of the added materials, their compatibility with the old system and materials etc.).

The material remains of the historic buildings and their structures deserve the maximum concern because they are the only authentic witness of the original specimen; once destroyed they will be lost forever. In particular it ought to be remembered that the history of the buildings is documented by their timber structures. Therefore, in spite of diversity of philosophic approach to architectural conservation in different Peoples, the conservation of the material remains is a general must.

Indirect and direct CONSERVATION of a timber structure should preserve the specimen (by means of the bureaucratic notification of the interest presented by the structure, f.i.) mainly carried out including the specimen in the official lists of the structures to be preserved (inventories and catalogues of eminent specimens, that anyway are generally missing separately for timber structures), respect and enhance its values considering, according to the most advanced theories, the historic, aesthetic, scientific, technical, pedagogic demands.

Doctrinal documents issued on ethics and philosophy of conservation should be discussed and updated frequently.

Operations of putting up and disseminating the documentation of an existing structural system are also to be considered a first step towards the conservation of the structure since the availability of records and their delivery to the public authorities concerned with the preservation of the historic buildings constitute a valid deterrent to any alteration or destruction of the specimen and, on the contrary, stimulate its protection and preservation without alterations.

Operative conservation of the structures includes the ordinary maintenance, the repairs, the temporary and permanent propping, the strengthening. Reinforcement, Upgrading and Retrofitting are activities in some way foreign to conservation.

The team appointed to plan or approve and supervise the conservation works of a building should always include a specialist in ancient timber structures (very rare to be found)

The systems to ensure sound condition and stability to the structure over the time by means of small repairs and adjustments deserve special attention both in the design and during the operative phase.
When reiterating the maintenance there is the danger of extensive replacements and substantial changes in the structure that could lead to replicas therefore only routine maintenance should be allowed, the extraordinary forbidden. Unnecessary replacements of material or members should be explicitly forbidden in the maintenance specifications; when replacements are considered necessary for future stability of the building a fully developed and technically documented plan should be proposed and discussed. The adjustments operated on the strengthening devices are, at the same time, an excellent way of checking the device efficacy and the occasion for possible operation of feedback.

Evaluation of the condition and serviceability of a structure, since it has important practical and bureaucratic repercussions, is necessarily formulated in accordance with procedures and values established in the current practice codes.

The calculation of the planned works should be elaborated according to the most advanced theories but recognizing the necessity of respecting the original structural scheme and the specific function that the structure had been designed to perform.

Relations with the environment and Interaction between the component materials are matters of interest, hence preservation of the site. To this purpose an essential issue is the consideration of all the structural systems producing interaction with the timber structures; special attention should be paid to malfunctions and failures caused by interaction of different systems.

Conservation Techniques

Compliance with the very restrictive requirements of current practice codes, generally studied for new constructions, is a hard task as already said.

The demand of some modern codes (Italian Technical Norms for building or restoring activity, for instance) when designing the measures for repair of ancient structures is only to limit the task of the intervention to a substantial improvement of the condition of the structure; in seism prone areas the same codes request a seismic improvement of the structure towards static and dynamic forces, i.e. repair and strengthening. The retrofitting with total adequacy of the structural scheme to the codes of practice general requirements on the contrary is explicitly forbidden for listed buildings. Reduction of the loading level is recommended instead.

A fundamental point is that the conservation techniques are essentially different from those applied in construction though using sometimes similar tools. Several modern building tools and techniques were adapted to be used for repair; a few were invented on the demand of the conservators, which makes the difference with the operational methods of let’s say fifty years ago, giving the right response to the strict requirements of the correct conservation.

Safety

Today there is an increasing awareness of need of safety (of the operators, of the users and of the same structure). The specific risks (Tampone, 2015) when operating on an existing timber structure are those connected with insufficient knowledge of the structure, especially of the severity of its decay and failures, insufficient understanding of the aims of the conservation project, contemporaneous presence of several contractors in the same worksite, slippery wooden surfaces covered by biologic patina or simply wet, lack of skill of the workers, insufficient skill in the use of new tools available today, freehand use of dangerous tools as saws and drills.

Education

It should be carried out for conservation designers and workers but courses on doctrine and practice as well training are practically missing. On the other hand, it is a matter of question who should be the teachers? In the few courses actually held at local and international level, in general the replacements of worn pieces and the working of new ones with traditional crafts are thought, local repairs, which have very long tradition too, being almost unknown. These courses are, mostly, mainly concerned with the saving of the traditional skills.

One more important aspect of the education is the didactic function of the restoration works. The repairs and strengthening works carried out on an ancient (timber) structure as well the signs of the failures, should be visible though not affecting the general look of the structure and be clearly put in semiotic relation.
Dissemination of results (case stories) is overabundant but most interventions are questionable. What is missing is a constant dialogue with private or public owners in order to get them acquainted with the aims of conservation and the most appropriate ways to achieve satisfying results with not very expensive works. Specific price lists are totally missing and it is therefore difficult to set up reasonable priced bills of quantities. Registers of specializing contractor's are inexistent since the category of general restoration undertakers is reputed sufficient (and it is not).

Apposite Specifications are totally missing. The conservative nature of the works should be clearly declared. They should prescribe in primis that demolitions of any part of the structure or even removal of any member and disassembling the structure are, as general criterion, not allowed. This kind of debilitating operations should be the last chance when no other means are possible, in any case the proposals to operate demolitions and replacements should be largely justified in advance and the related intervention only made after formal approval of the relevant authorities. Specifications should also prescribe that, in general, repairs should be made in situ without disassembling the structure. Great attention should be paid to the connectors; quality of steel, especially the nuts of the bolts, always needs accurate definition.

The offices concerned for preservation should include some specialists in ancient timber structures in the team entrusted to examine the general conservation plans of a historic building.

Other important components of the paradigm are financing, fiscal exemptions, contributions by public bodies.

The bibliography on conservation is absolutely redundant; nevertheless the works dealing with the conservation philosophy of structures combined with the conservation techniques, are rather rare.

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