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SUSTAINABLE USE OF TIMBER IN CONSTRUCTION – SPECIFICATION, DETAILING, MAINTENANCE AND REPAIR FOR EXTENDED LIFE

SUMMARY

Timber is highly interesting from the point of view of sustainable construction and, besides most traditional uses it has received increasing attention in modern building industry. However, both the timber material and timber structures require particular attention, care and adequate strategies concern in materials specification, design, detailing, maintenance and repair for extended life.

Specific to timber as a raw material are its great variability, anisotropy, hygroscopic nature and the risk of biological degradation in adverse exposure conditions. Highly important or the performance and safety of timber structures are also the detailing of timber joints, dimensional variations and tensile stresses perpendicular to the wood grain, that often converge to cause malfunctions.

Keywords: timber structures, specification, detailing, problems, defects, degradation

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ОДРЖЛИВА УПОТРЕБА НА ДРВОТО ВО ГРАДЕЖНИШТВОТО – СПЕЦИФИКАЦИЈА, ОДРЖУВАЊЕ И ПОПРАВКА ЗА ПРОДОЛЖУВАЊЕ НА ВЕКОТ НА КОНСТРУКЦИЈАТА

РЕЗИМЕ

Дрвото претставува интересен материјал од аспект на одржлива градба, кое и покрај повеќето традиционални намени денес сè почесто наоѓа примена во модерната градежна индустрија. Сепак, и дрвото како материјал и дрвените конструкции бараат особено внимание, грижа, соодветен дизајн, одржување и поправка за подолг живот.

Карактеристично за дрвото како суров материјал се неговата анизотропност, хигроскопна природата и ризикот од биолошко разложување при изложеност на неповолни услови. Многу важно за ефикасноста и безбедноста на дрвените конструкции се деталите на врските, димензионалните варијации како и напрегањето на затегнување нормално на влакната, поради кои често се појавуваат дефекти во конструкцијата.

Клучни зборови: дрвени конструкции, спецификација, проблеми, дефекти, деградација

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1. INTRODUCTION

The use of timber in traditional construction has always depended from the local availability of timber as compared to alternative raw materials, from climatic conditions (as these may affect building construction through the year, determine different actions (loads) and risk of biological degradation and condition the human needs for shelter and thermal comfort), besides regional social and cultural issues.

Nowadays, dissemination of modern timber structures depends largely on their acceptance from the end users, on the confidence from financing and licensing entities and on sound scientific and technical skills of all professionals involved in their design, construction and maintenance.

Timber construction has changed in many countries in the last years, with large modern structures being built, mainly using glued laminated timber structures, of impressive shapes and sizes and great visual impact.

But such novelty and visibility bring with them an increasing responsibility to all intervenors, in order to guarantee the safety and a positive public image of timber structures.

The quality – adequate performance, safety and durability of timber structures – depends largely from good architectural options, sound structural design and correct constructive solutions, fabrication, assemblage and maintenance.

The insight experience gained from the assessment, inspection and maintenance of timber structures, including what past errors and accidents can tell us, are highly valuable to help reducing possible sources of errors in the future, thus increasing the safety and extending the life of our structures.

2. USE OF TIMBER IN CONSTRUCTION – THE PORTUGUESE EXPERIENCE

2.1. Traditional building construction

The construction of buildings-for-rent intended for a large number of families was already frequent in Lisbon in the beginning of the XVIII Century. Some of these buildings might have been as tall as 5 floors and presented remarkable spatial quality and surprising structural details for that time. Unfortunately, a big earthquake in 1755 (with magnitude 8.5, producing an intensity varying between VIII and X of Mercalli scale, lasting in total 9 min.), the associated tsunami and subsequent fires that went on for several days, severely damaged or even destroyed large areas of Lisbon.

The resulting chaos needed immediate intervention and a tremendous effort was put into planning the new quarters in a more rational way, with wider streets, lower buildings (up to 3 floors plus mansard-roof), better fire safety, sound structural details and a certain degree of pre-fabrication, all supported by official design rules being distributed to the builders. Some technical improvements were imposed with the new structural solution known as "Gaiola", like production and application of standardized prefabricated components, mainly timber pieces and facing stones (stonework), increase of height between consecutive floors, a more suitable design of the building stairs, raising up of stone separating walls above the roof level thus acting as fire-stop elements between buildings. In parallel, new equipment were systematically introduced, like chimneys and water sewage.

This type of construction - known as "Construção Pombalina" (named after Marquis of Pombal, who was prime minister of the ruling king and directly responsible for planning of the reconstruction) were most probably influenced by the empirical knowledge collected from the existing buildings surviving the earthquake, as a quick answer was required to reallocate the population and there was no time to import, assimilate and apply foreign solutions.

Intense building activity went on for about eighty years, generally following the imposed rules. After the mid XIX century, lost the memory of destruction, such building techniques became progressively altered and a poorer type of buildings appeared ("Gaioleiros"), where the sound structural principles, if not fully understood, were frequently forgotten. Concrete was introduced early this century, soon becoming the prime or even the only building material to be used.

It is nevertheless estimated that about 40% of the standing buildings in Lisbon were built before the “concrete age”, either dating from before the 1755 earthquake or being contemporary to the intensive reconstruction that followed it. Although the large majority suffered alterations, many of these buildings still rely on their original timber frame structures and some very fine examples of the original solutions can still be found and should be preserved.

“Pre-Pombalinos”	“Pombalinos”	“Gaioleiros”	“Placa” (concrete slab)	Concrete (no ductility)	Concrete (ductile)
 (<1755)	 (1755-1880)	 (1880-1930)	 (1930-1940)	 (1940-1960)	 (>1960)
Variable height	4 floors	5 - 8 floors	5 floors	6 - 8 floors	> 9 floors
20 820			12 196	15 809	4 345
39 %			23 %	30 %	8 %

Table1.Number of existing buildings in Lisbon city (53170 buildings, CENSUS 2001)

In recent years, the share of building rehabilitation in the building construction sector has been steadily increasing. According with Euroconstruct, from 2007 to 2015 buildings renovation percentage grew from about 27% to over 50%. This increased the attention of architects, engineers and contractors to the assessment, repair and strengthening of structures, from which timber structures are frequently the least well understood ones and still a major cause of concern.

In Portugal, as concerning traditional timber roof structures, which have long overpassed their expected service life, biological degradation represents the major problem, generally due to lack of maintenance of roofs and gutters. Quite frequent are also structural deficiencies, either original or resulting from later modifications, construction mistakes and joints deterioration.

Regarding timber floors, besides biological deterioration (most frequently affecting the beam ends), structural deficiencies are often present, most generally consisting in lack of transversal bracing and insufficient beam support length. Frequently their strength, stiffness, vibration response, fire or sound insulation performance fail to meet modern requirements.

Most critical problems generally present in these buildings derive from deterioration of building materials, especially due to local high humidity levels, as well as from modifications and conservation measures that have been incorrectly planned and executed.

One frequent cause of problems has been the increase in the number of floors without suitable structural verification and strengthening, and alteration of the ground level by creating wider windows and removing walls, sometimes without introducing adequate reinforcement elements or by placing them incorrectly. Further openings in the intermediate levels were also frequently done and sometimes they alienated load-bearing walls without proper consideration.

Another important modification concerned the introduction of electricity, gas, water and sewage pipes inside the buildings, as well as the implant of kitchens and bathrooms/toilets where ordinary rooms used to be. The need for such improvements is undeniable but they were often responsible for major errors like cutting floor beams to lay down a concrete slab or cutting load-bearing wall timber frames so that water pipes could be bedded in the wall thickness.

Highly deformed floors may have been originated just after construction as a consequence of unseasoned timber elements being used, but it often results from excessive loading of floors associated with modification of the building occupancy, when adapting it to offices for instance, with heavy archives being installed in the upper floors. Structural movements, associated with materials deterioration and creep of floor beams on their turn may be responsible for the original light partition walls becoming loaded.

Whenever continuous high moisture content of timber was present, either due to modifications of the building or to ageing of building components, severe decay is noted. As expected, materials kept dry remained basically unaffected, the exception being the possible attack of exposed timber (not enclosed in masonry walls) by wood boring beetles. Nevertheless, these are mainly responsible for surface damage and the attacks are usually not so severe as to risk the structural safety.

A particular problem in several areas of Lisbon, as in most other regions of Portugal, is subterranean termite infestation (*Reticulitermeslucifugus*) again linked with the presence of high moisture contents inside the buildings. Due to the special characteristics of their attack, their presence goes unnoticed until they are fully installed in the building, spreading from foundations to roof timbers. As the general public and even building contractors are not aware of the peculiarities of termites, sufficient corrective actions are rarely taken and the problem is bound to persist.

Humidity may have several origins, like roof or windows malfunction, damaged water systems and, less frequently, water penetration or rising water in the walls. Besides, renovation works may be also responsible for getting water in contact with old materials as when making new concrete slabs on top of unprotected timber floors, causing them to decay.

Although for decades, if not centuries, no problems were detected, it has been observed in recent demolitions that timber foundation poles may present severe decay, due to variations in the ground water level. The drainage of Lisbon ground water that has been conducted in the last decades, together with subterranean works in the vicinity of buildings, are likely to affect ground water level and therefore the moisture content of poles thus enabling fungal degradation.

A suitable strategy to recover or improve the structural behavior of these buildings includes the following steps:

- adoption of measures towards keeping moisture content of materials low;
- replacement of decayed timber elements, namely the ends of timber floor beams and some timber reinforcement elements from frontal walls;
- improvement of connections between walls and between these and the floors;
- removal of the extra upper floors introduced during the years, thus reducing dead loads and consequently seismic loads;
- replacement of the original design, correcting unsafe modifications associated with commercial use of the ground level (which included wider wall openings and even their removal).

2.2. Glued laminated timber structures

Glued laminated timber structures are quite new in Portugal. The first large glulam structure in Portugal was the Pavilhão Atlântico (now MEO ARENA), built for Lisbon Expo'1998, the World Exhibition. This very impressive roof structure consists of 17 glulam arches, reaching 47m above the arena and covering an oval area of 150m x 120m. This is also thought to be the very first large glulam structure designed according to Eurocode 5(EN 1995-1-1, 2004+A1, 2008).

Glued laminated timber was chosen for in many large modern structures due to its aesthetical appealing qualities – and timber is therefore exposed and visible to a large extent (which facilitates detection of possible anomalies or malfunctions of the material).

On the other hand, such structures correspond to structural solutions that were/are not familiar to most engineers, building owners and licensing authorities. Therefore, their structural design, fabrication and erection have been left under the responsibility of interveners that, as a rule, do not guarantee its follow up, maintenance or technical advisory work concerning use or required alterations.

Glued laminated timber became very popular in Portugal (Figure 1) for the new public buildings like sports and concert halls, shopping centers and swimming pools. A small number of refurbishment works have also been done using this material (mostly in the form of straight floor beams).

The available information regarding the quality and health of Portuguese glulam structures is still scarce, greatly as a result of the young age of most structures (less than 18 years old).

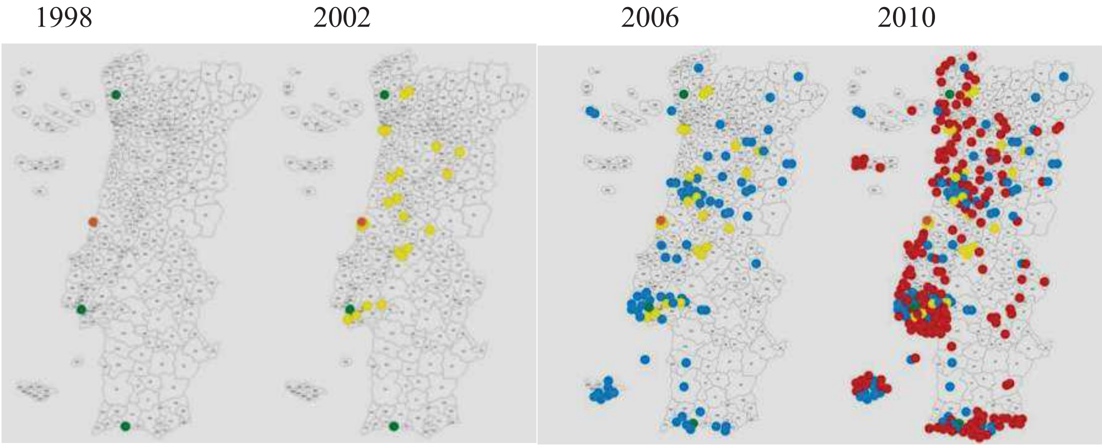

Figure 1. Glued laminated timber structures in Portugal (Negrão, 2011)

However, deficiencies detected so far include: poor specification of the adhesives used regarding the exposure conditions, particularly experienced during erection of the structure (when timber intended for indoor exposure stays fully exposure to weather); poor design or assemblage leading to "unexpected" tensile stresses perpendicular to grain; lack of bracing leading to collapse during erection; poor detailing of the envelope leading to water intake and subsequent timber decay; poor joints design, detailing or execution – frequently associated with restrained shrinkage of timber leading to timber splitting or joint failure.

2.3. Timber building frame houses

There is no tradition of integral timber houses in Portugal. This is due to the high summer temperatures, the significant risk of biological attack to timber and the little availability of timber of high quality as opposed to the large availability of other materials e.g. stone and cement. The preference of traditional building methods, the lack of trained workmanship and timber educated engineers and the lack of suitable codes of practice contribute to keep low the timber share of the house building market.

Timber building construction registered a great impulse in the 70's of last century when industrialized timber building systems were used to respond quickly to the need of new schools for an increasing student population.

Although designed as temporary buildings, some of them are still in use. The poor quality and durability of such buildings, though acceptable in temporary solutions, led to many conservation problems along the years that contributed to a bad image of timber construction.

Recent concerns with the environment and sustainable use of natural resources brought a new impulse to the timber housing market. A varied offer of timber building industrialised systems, some of which of excellent performance and good durability, is available nowadays in the Portuguese market.

Besides (second) houses, the target market includes restaurants and other touristic facilities, especially in protected landscape and in the most expensive segment.

Some non-industrialized timber houses have also been built, but the lack of building codes applicable to timber is hindering progress in this field.

Structural design of timber is covered in Europe by Eurocode 5. However, in quite complex structural systems like buildings, detailing and assembling procedures are of utmost importance for good global performance and durability and, as not fully covered by European standards, they are normally left to the choice of the architect or the building contractor. Also the fire, thermal and acoustic performance require specific technical knowledge, sensibility and experience from all intervenors regarding calculation, detailing, materials specification and building methods that are more complex and are more important in this case than in the case of traditional masonry construction.

3. LEARNING FROM THE EXPERIENCE

Research conducted in other countries on structural failures and malfunctions affecting concrete, steel and timber structures (not necessarily involving casualties) point out to data that that deserves attention. It should be stressed that there is no evidence of the risk associated to timber structures be higher than the risk associated with steel or reinforced concrete structures. However, factors responsible for structural failures or malfunctions vary according with the material. Knowledge on such factors may therefore help anticipate and even avoid future problems and failures.

Regarding timber structures, the following mistakes have been identified (COST Action E55, 2011):

- poor timber performance (e.g. timber grade lower than the one assumed in structural design);
- deficient production (e.g. poor gluing of lamellas or finger-joints);
- wrong fabrication principles (e.g. use of inadequate adhesives for the intended use);
- alterations (e.g. cuts or holes done onsite for practical reasons);
- design errors concerning actions (e.g. incorrect estimate of actions, incorrect structural model);
- design errors associated with environmental conditions (e.g. loading associated with environmental conditions causing drying fissures, restrained shrinkage, or biological degradation);
- deficient assemblage/erection;
- exceeding code design actions;

Forensic engineering has shown that the primary cause of an accident is not always easy to establish. First of all, many failures originate from association of errors. Moreover, judgement may be influenced by the experience and subjective assessment by the expert, who may be more aware to design, fabrication or erection of timber structures and therefore more promptly will detect related aspects.

It has also been acknowledged that certain errors are more likely on certain structural types or more common in certain societies. This may be linked to different knowledge and skills of designers and contractors, implementation of mandatory project review, product certification, inspection and quality control of the building process.

Another interesting conclusion of that study concerns the age of structures at the time of failure: from 87 investigated cases, in 19% of the structures failure occurred during construction and in about 34% occurred in the first 3 years. Such early stage failures are mainly due to design and assemblage errors.

The same study points out the following often neglected or misunderstood aspects – some of which are specific to timber and timber structures:

- structural lateral bracing to avoid instability of structures in the various stages of the building process;

- tension stresses perpendicular to the wood grain;
- moisture and shrinkage related effects;
- design and detailing of structural timber joints;

Inappropriate or missing bracing may be a design or planning error. The last three problems frequently appear associated. These are of utmost importance but are also particular to timber structures, thus requiring from the various people involved (in design, assemblage and follow up of the structure) sound knowledge on timber and its peculiarities.

Off course that only a few part of structural failures come to the public knowledge, thus leading to biased conclusions. Nevertheless, it seems that human errors command the list of primary causes for timber structural failures, alike for steel and concrete structures.

4. SOME STRATEGIES TO EXTEND THE LIFE OF TIMBER IN CONSTRUCTION

Biological deterioration is one major concern regarding timber structures and a major cause of damage and structural failures in the case of traditional construction.

The service life of the material is linked to its natural durability, understood as the natural resistance of wood to the attacks by living organisms (fungi, insects and marine borers) and to its impregnability, to the extent that it determines the viability of giving it added protection.

Susceptibility to the attack of the various organisms varies with timber species, being normally higher in heartwood than in sapwood. The European standard EN 350-2 (1994) lists the durability and treatability of most important timber species used in Europe.

But the probability of deterioration depends not only on the biological agents known, but also on the location of the piece of timber in construction. It should be noted that certain living organisms like fungi and subterranean termites require the timber to have and maintain for some time relatively high moisture content (generally above 20%) to install and attack it.

The moisture content of wood is therefore at the base of the use classes of application laid down in EN 335-2 (2013). This standard sets several use classes that are function of the probability of timber to retain water and develop high moisture content.

Life extension of timber structures may be obtained in several ways. A good strategy consists in the selection of forest species with sufficient natural durability regarding the biological agents (fungi or insects) likely to feed from timber applied in the expected service conditions, i.e. adequate to the risk class.

Bad choices made in the design stage will reflect negatively in the whole life of the structure as protection of timber in service is neither easy nor as effective as preventive treatment prior to application.

It is generally accepted that some building components may be less durable than the expected life of the structure, if they are not essential to safety and can be replaced at acceptable costs. This should be agreed by all intervenors and that replacement be considered both in the maintenance program and maintenance costs.

However, most timber species currently available in Europe have low or moderate durability. When less durable species have to be used, these may also be preservative treated with chemical products. Preservative treatments should be specified to the target biological agent (fungi, boring beetles or termites) likely to attack that particular part of the structure ("surgical" treatment, instead of extensive treatment). A possible alternative to preservative treated timber is modified wood (by thermal treatment, acetylation or furfurylation, for instance), that may have enough durability for the job.

An even better strategy to improve durability is the reduction of the risk class of the most critical parts of the structure by adopting suitable architecture and construction details, able to avoid water intake and its long-term retention by the timber members. Detailing should prevent timber from ground and water contact, allow quick drying and unrestrained swelling and shrinkage, in case of accidental moisture absorption.

Moisture absorption can cause timber swelling and its attack by termites and fungi. The application of too wet timber regarding the expected service conditions, as well as varying environmental conditions, cause timber moisture content variation on site, leading to distortions and drying fissures.

Although large cross sections subjected to mild weathering will suffer less increase of moisture content than small cross sections, it should be noted that massive cross sections, once have gained moisture content will take much longer to dry out, thus facing a higher risk of biological attack.

Similarly, surface protection by “impermeable” paints or vanishes may retard water absorption in timber but they will also retard its subsequent drying (if water managed to get in through fissures or contact surfaces). This is why “breathing” surface protection against UV radiation, are likely to last longer and protect more effectively the timber surfaces than “impermeable” products.

Another point to take into account is that longer and wider elements are likely to develop more impressive distortion when subjected to environmental variations. From this point of view, length and width of timber pieces should be limited, whenever possible, as for instance in flooring, where swelling in tangential direction and twist distortion may be critical.

As far as possible, direct contact of timber with ground should be avoided, by fixing it on top of concrete or masonry foundations, keeping timber members apart from the ground at least 30cm. Care should be taken to avoid water accumulation in contact surfaces and promote ventilation especially in all end-grain surfaces and butt-joints.

In ground floors and basements, with raising humidity, impermeable layers or membrane materials should be placed between timber and concrete or masonry surfaces, to prevent the highly hygroscopic timber from absorbing moisture.

End grain surfaces must be carefully protected from direct rain in outdoor uses as this is the preference entering way of water in timber. The use of metal caps (Figure 2), preservative treated timber layer or sacrificial (to be replaced when needed) timber layer, are several ways of doing it. Detailing should include ventilation gaps and dripping-pans, to prevent water retention. Repeated application of sealants or water repellents on the end grain surfaces may limit water exchanges with the exterior environment, thus limiting moisture variations.

Contact surfaces between timber elements are prone to water adsorption and uptake by capillarity, especially severe in large contact surfaces. In places subjected to the accumulation of dust and rubbish a gap larger than 5mm between adjoining surfaces is recommended; otherwise, a gap about 2mm is sufficient. Metal washers or similar simple devices may be used for that purpose (Figure 2).Horizontal contact surfaces may be more difficult to protect, requiring for instance the use of dripping-pans to drive water away, water repellent paints to reduce absorption), and in certain cases preservative treatment may be advisable to locally increase the durability.

Figure 2. Timber resting on a concrete column to avoid contact with ground water; metal cap of the column end-grain surface; washers to space contact surfaces (top view)

Since human errors have been the origin of the majority of problematic situations, it is essential to invest in the education of designers, producers, building and inspection contractors concerning the particular behavior of timber and issues that are particular to timber structures.

5. INSPECTION, ASSESSMENT AND MAINTENANCE

Interventions in timber structures are generally motivated by detection of deficiencies like degradation of materials or joints, or deficient structural performance. Frequent sources of concern are fungal or insects attack (which are often difficult to tackle by most practitioners), fissures, cracks or rupture of members, delamination of glued laminated timber, failure of mechanical joints, as well as perception of excessive deformation, sagging or vibration, to quote some examples. Health and safety assessment may also be required when a new use is intended for the building or when its structural system has been or is to be modified intentionally.

Inspection and maintenance of timber structures have to be designed for each specific situation (structural type, specific materials and type of joints, age, environment and use conditions) that may determine specific conservation problems. Nevertheless, past experience from inspection and monitoring timber structures allow calling the attention to a number of critical aspects and establishing priorities.

Timber elements fully or partially exposed to outdoor environment and in ground contact are naturally at risk. Exceedingly humid environmental conditions, condensation, rising ground water or water leakage of any source also create conditions for potential timber degradation.

Moisture problems are most common in roofs near the eaves, chimneys and openings where water leakage is more likely to occur. Roof trusses and rafters, as well as floor beam ends sitting in exterior walls and generally basement or ground timber floors especially in the presence of rising capillary water from the ground, damaged window frames, blocked gutters, missing or displaced roof tiles, damaged mortar and plaster covers are therefore potential sources of wood wetting and subsequent degradation and should be considered and repaired.

The structural behavior and detailing should also be analyzed. Even old structures without obvious signals of failures or bad performance may have inherited original design errors or deficiencies that can and should be corrected to improve its structural safety and robustness. Besides, multiple intentional modifications made during the life of the structure and damage suffered by joints or timber members are likely to have altered the functioning of the structural system and should be taken into consideration.

Fissures and cracks are a common source of concern (though not always justified). First of all it is important to distinguish between drying fissures and mechanical failure cracks of members. While the first ones develop parallel to and split apart the wood fibers, result from moisture content variations and are normal to a certain extent, the latest may sometimes cross perpendicular to the wood grain (show broken wood fibers) or cause the wood fibers to slip along each other and mean that the member was overloaded.

Furthermore, the influence of fissures (or delamination) in timber members depends on the type of member and its loading situation. Of particular concern are fissures affecting joints, members with high shear loads or cross sections where tensile perpendicular to the grain is likely to develop. Even in the absence of fissures, one should pay special attention to all situations prone to introduce tensile stresses perpendicular to the grain as the corresponding timber strength is very week and sudden failure may occur.

The following structural deficiencies are quite common and should also be investigated.

- In flooring systems: insufficient bearing of beams on walls; nonexistent or loosebracing; missing supports (e.g. walls removed from lower floors); introduction of partition walls (mid span extra loading); main elements cut (e.g. to accommodate water pipes or electric wires).
- In roofs structures: wrong design of trusses; wrong design of joints; eccentric loads at supports; trusses with loads applied out of the truss nodes (e.g. by the roof rafters); no bracing;

missing parts (due to construction mistakes or subsequent interventions, e.g. to facilitate access or to install equipment).

- In joints: missing plates and bolts; lack of contact between timber elements where this is required (e.g. due to construction errors or to structural deformation); too small or missing bolt washers; corrosion of metal fasteners or plates; loose bolts (e.g. due to shrinkage or to local crushing of timber); timber fissures or biological damage in the joint area; insufficient spacing, end or edge distances of fasteners.

Monitoring is essential in any type of structure to allow the early detection of possible degradation processes and to remedy deficiencies by establishing suitable maintenance routines and so extend the life and enhance the performance of the structure.

Inspection and maintenance are particularly important in the case of timber structures, due to the highly hygroscopic nature of timber and its susceptibility to biological deterioration specially when exposed in moist environments and or contact with water, or frequently wet materials.

Maintenance plays a fundamental role in the guarantee of the long term performance, safety and durability of buildings. Inspection, monitoring and maintenance plans should be carefully designed regarding the structure characteristics and use, to prevent, detect and correct in due time possible problems.

REFERENCES

[1] Negrão, J.H.: 2011 – Estruturas de madeira em Portugal, Presente e passado. CIMAD 11 – 1stIbero-Latin-American Congress of Timber in Construction, June 2011, Coimbra, Portugal

[2] EN 350-2: 1994 – Durability of Wood and Wood-based Products. Natural Durability of Solid Wood. Part 2: Guide to Natural Durability and Treatability of Selected Wood Species of Importance in Europe. CEN, Brussels

[3] EN 335: 2013 – Durability of Wood and Wood-based Products. Use Classes: definitions, application to solid wood and wood-based products. CEN, Brussels

[4] COST Action E55: 2011 – Assessment of failures and malfunctions. Publication on failures and guidelines for quality control.Ed. Kohler, J; Fink, G.; Torati, T. Shaker Verlag

[5] EN 1995-1-1:2004/A1:2008: Eurocode 5 – Design of timber structures. Part 1-1: General - Common rules and rules for buildings.CEN, Brussels