Wood structures: Acting before deterioration

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ABSTRACT: The present article presents conservation actions that can be taken to sustain the existing integrity and use of historic wood structures.

After complete inventory of the building to be conserved, minor modifications may be discussed between conservation professionals and conservation agencies in order to improve wood conditions by lowering moisture levels, provide physical and/or chemical barriers and applying wood preservatives. An inspection and conservation plan should be developed and personal should be assigned to apply the plan. Daily, routine, emergency and timely actions and inspections would be outlined and completed with a suitable methodology expressed by training and customised forms. Non-destructive essays and monitoring techniques that may help to ensure the wood structure health are briefly described.

Although much of the suggestions in this article can be applied to wood marine structures, it is recommended further reading before preparing an action plan to conserve those structures.

1 INTRODUCTION

Preservation is defined by the U.S. Secretary of the Interior Standard (Weeks, Grimmer, 1995) as the "act or process of applying measures necessary to sustain the existing form, integrity and materials of an historic property". More than the appearance shall be preserved: the same Standard proposes that "…construction techniques and examples of craftsmanship that characterise a property will be preserved".

Nearly every building in Brazil has used wood during its construction and most of them use wood structures. This picture is similar to most countries of the World because of wood's flexibility, machinability, light weight and once vast resources. Although the concern about preservation of forests is growing, wood is faced as a good ecological option for construction due to its low energy global life cycle and renewable character (Williamsome, Olwveny and Moosmayer, 2001, Trusty and Meil, 2001).

It is estimated by Avat et al. (1996) that 300 to 400 million of French Francs are spent yearly with wood biodeterioration. Freas et al. (1982) alerts that "1 billion worth (of US$) of wood products are lost each year due to poor construction practice and lack of maintenance". Unfortunately, Brazilian statistics were not available.

Several actions can be taken to lower the pressure on native forests. On the civil construction point of view the use of planted forest products, the re-use of construction timber and measures to extend timber service life are actions towards environmental conscious constructions.

Besides preserving native forests, extending timber service life of historic buildings is a must to preserve the cultural heritage. Even when not apparent, a timber structure is a testimony of an age's technology, culture and frequently protects other important features and content of a historic building, such as stuccoes, furniture and museum items.

Well preserved buildings also have a reflect on their neighbourhoods, keeping the economical and historic value of the surroundings and avoiding public resources to be applied on urban sprawl.

2 PREVENTION AND CONSERVATION

Several authors (Avat et al. , 1996, Freas et al.1982, Lepage et al., 1986, and Kropf, 1996) give important directions on how to design to prevent biodeterioration. Details such as specifying naturally resistant or treated wood, physical and/ or chemical barriers (Lewis, 1996, Révue du Bois, 1995) barriers to ground humidity (Kropf, 1996, Smulski, 1993, Weaver and Matero, 1993) design details to avoid water and dust accumulation (Kropf, 1996), just to cite a few.

Those prevention measures are very important to be followed, as long as possible. Many of the measures were included in some traditional building techniques, such as ventilating crawling spaces in Brazil (Lemos, 1999), but most of the techniques were not incorporated in the historical buildings and some changes are either impossible in erected buildings or might change the historic testimony. Pressure treating timber in service, for example, is impractical. Still there are actions that can be taken conserve timber structures in historical buildings, most of them dealing with controlling moisture, using barriers to biodeterioration agents and chemical treatments.

It is very understandable that in Europe the risk classes are based in the moisture levels (the higher the moisture, the higher is the risk). Water has a very important role in timber's service life and in wood's biodeterioration agent success.

As stated in an article from Cahiers Techniques du Batiment (1989) only treatments done in industrial sites can give wood an effective protection. Considering historic buildings, Singh (2001) states that "Eradication of dry rot spores or insect pests in a historic building and its contents is in practice, impossible. The volume of chemicals necessary and the toxicity required would be damaging for both the buildings and all its occupants." Even though pesticides evolve, environmental control and baiting should be first choice of control for building health.

3 DETERIORATION AGENTS

In order to understand better the measures proposed bellow, the most common causes of wood deterioration are briefly discussed. Detailed texts should be consulted to develop a deeper understanding of wood deterioration (Avat et alli, 1996, Lepage et alli, 1986 Weaver and Matero, 1996). Not all biodeterioration agents are present everywhere. For example, dry-wood termites are a treat in most parts of Brazil, but it is not very important in Europe.

3.1 Seasoning deformations and weathering

When humidity level increase, wood will increase its dimensions, especially in the tangential and radial plans. The different changes in each dimension might cause timber parts of a structure to distort. Member distortion causes internal stresses (Freas et alli, 1982) to the structure. Another problem caused by heavy timber drying is cracks that will appear when wood dries on its surface but its interior does not have the time to dry.

Wood weathering is caused by the alternation of sun (drying plus ultra violet) and water on the surface. Even if the checks or weather are not important to the structural performance they might damage surface protection (if applied), create ways to insects post their eggs or perforate into timber and/or create favourable places for fungus to develop when moisture is available. Ultra-violet rays alone have the power to degrade wood in shallow deepness, mostly in an aesthetic way.

The weathered appearance and deflections of wood may be considered as a natural feature of the building and its conservation may be desired. Discussion must then be held between the professionals about the maintenance of the weathered appearance (and sometimes its natural path) while preserving of wood itself.

3.2 *Chemicals*

Wood is generally resistant to acid or alkaline chemicals within reasonable levels (Freas, 1982). On the other hand, the hardware used in wood structures is not always designed to resist chemicals and might get corroded, especially when moisture is available.

3.3 *Fungi*

There is an infinity of fungi species worldwide. Most fungal attacks are in fact a succession of different fungi and bacteria. Five conditions are needed to for fungi to develop (Weaver and Matero, 1996):

- source of infestation - fungi spores are generally available in virtually any place;
- food supply (non toxic wood);
- wood moisture content higher than 20 (Smulski, 1993), 25% (Weaver and Matero, 1996) or even 30% (Lepage et al. 1986), depending on the information source. Most woods within 90% air relative humidity will be below 20% of wood moisture content (Cruz, Machado and Nunes, 1994).
- Source of oxygen;
- Suitable temperature, 25 to 32°C for most fungi. Fungi will be killed if submitted to 65°C, but will only go dormant in subfreezing temperatures.

Considering buildings, it will be very difficult to control oxygen source, stop infestation sources or control temperature beyond fungi requirements. One of the options of control left would be moisture control and, when not possible, spoil food supply by poisoning wood that is not naturally resistant.

In cold habitats, fungi decay may take years to significantly damage timber. In tropical countries favourable conditions, depending on the fungi and wood kind, 3 to 6 months might be enough to severe decay.

3.4 *Termites (Isopteres)*

There are many species of those insects, whose colony living habits ensure attack power equivalent of a 330 million of US Dollars yearly in the U.S. only, according to Smulski (1992). There are two main practical groups of termites: subterranean termites and Drywood termites

3.4.1 *Subterranean Termites*

Responsible for most of the damage in Europe, U.S. and some important Brazilian cities as Salvador (Bahia State, Brazil), those insects live in nests independent of the wood attacked by them, but sometimes may be hidden inside unfrequented areas of the building itself. One nest may forage for food 30 meters hidden from light, mostly underground, hidden in structural gaps, settlement cracks, electrical, plumbing, sidings or building shelter tubes made of soil and digested cellulose. These termites are especially attracted cellulose materials under moisture, preferring fungi altered wood, but can attack wood with as low as 8% of moisture content.

Poisoning the attacked wood itself does not eliminate subterranean Termites, as their colony will survive forage other sources of food. After the residual effect of the biocide applied to wood is lost, the colony may come back.

The Subterranean Termites has faster and bigger impact than Drywood Termites. If during springtime clouds of their winged reproductive Subterranean termite individuals can be seen nearby of inside the building, this is a indicative of infestation.

3.4.2 *Drywood termites*

Those species of termites live in smaller colonies, nesting inside wood itself, without any other source of water. Even though a Drywood Termite colony has slower impact in wood structure, the individuals may transit by all the wooden structure parts in contact with each other, making their nest difficult to find. Drywood Termites are apparently the most common source of timber damage in Florianópolis (Santa Catarina State, Brazil), along with fungi.

The infestation of timber occurs in their winged reproductive form, after what they are rarely seem. The mating fly happens in summer night, frequently after rain or wet day, and is a strong indicative infestation when in closed buildings. Another indicative is the presence of fecal pellets expelled by the termite right down from 1mm hole from wood.

3.5 Coleoptera

Well known wood eating insects like the *Old House Borer*, *Powderpost Beetles* and *Anobiid Bettles* have something in common: although they are mostly known as beetles, the damage in wood is done by its larvae. In fact, as explained by Avat et al. (1996), the beetles (perfect insects) of those xylophages have their utility limited to sexual reproduction and do not even feed themselves during their several week life. After copulation, the perfect insect will post eggs in the wood end grain or on small holes or cracks. From the eggs the larvae emerge and will feed from wood during their life, which may range from several months to several years. Many larvae will attack only the sapwood, but some may attack even core wood.

After the last stage, when larvae turn into nymphae and then in a perfect insect, a exit hole will be made in the wood. Sometimes the exit hole is the only evidence of attack noticed, when the larvae have already done damage. If the insect is dry wood apt, it may re-infect the wood. If the attack is from a green wood insect, it will not re-infect dry wood – this last case will be rare in historical buildings, where most wood is already dry.

Acting before biodeterioration in an historic building

3.6 Knowing the building

The axiom "Identify, Retain and Preserve" has been frequently applied to cultural heritage with success. Diagnosis should be the first step toward preservation, specially considering that cleaning and restoration works might cover up important indicatives of deterioration.

A wide inspection and inventory will identify:

- building history, modifications and changes in use;
- important characteristics to be preserved;
- previous repairs;
- construction techniques originally employed;
- biodeterioration taking place, if any, and their extent;
- biodeteriorators history within the building's region;
- the risk areas (p.e. high humidity) and the probable treats to materials;;
- damp material that attract biodeterioration agents;
- areas to be inspected routinely and areas without inspection access.

As stated by Freas et al. (1982), "records on buildings and other structures have an uncanny knack for getting lost", making this first step more difficult. The information collected in this first work will be very valuable for future actions and for proposing a conservation plan. A specialist or even a team of specialists should do this first step. The knowledge needed shall range from civil engineering issues such as wood structure design and foundations, architectural issues such as history and a design's common defects, historical documents research and biological issues such as biodeterioration agents' habitudes and control techniques.

Considering the wood structures, the identification should bring a detailed information about each structural element including (Freas et al. 1982):

- its dimensions and condition;
- specie of wood employed;
- kind and condition of the connections;
- service environment in terms of temperature, moisture, acidity and proximity to soil;
- information related to magnitude and distribution of loads;
- recent modifications to the structure or its loads;
- distinctive stylistic features and examples of skilled craftsmanship.

The detailed inventory of the building will rise attention to areas that might need immediate repair or upgrading to meet standards. Those important measures should not shadow the importance of establishing a effective maintenance program, including routine inspections.

3.7 Minor modifications for better conservation

Ideally any historic object should be maintained as close as possible to its original state. All modifications done should follow the heritage rules such as "reversibility" of the intervention and the "gentlest means possible" proposed by local Cultural Heritage Agencies such as IPHAN (Instituto do Patrimônio Histórico e Artístico Nacional), in Brazil, or the Secretary of the Interior, in the U.S.

Although thoroughly discussions must be carried on with conservation professionals, some minor changes may be planned for a historic building in a way that very little of the original appearance and function is changed, in exchange for better conservation. Correct modifications will aim to lower wood moisture, create inspection accesses and isolate wood from its deterioration agents.

Such modifications might be:

- use of paint, stain or other wood surface treatment that will protect from eventual humidity and create a physical or chemical difficulty to biodeteriorators, without changing much of the original appearance;
- chemically treat wood in permanent contact with water or moisture to increase its resistance;
- obstruction of wall cracks, electrical conduits and other openings that might be used by subterranean termites as a covered way to get from soil to timber, using elastic material;
- installation of physical barriers that will force subterranean termites to contour them, facilitating the attack identification;
- if in a subterranean termite or marine borer area, provide a physical or chemical barrier in the building contour whenever possible;
- providing openings in ceilings, craw spaces and basements in order to improve ventilation and lower the humidity;
- providing inspection windows and passages to otherwise inaccessible places;
- improving gutter and other rain water systems to guarantee that wood will remain dry;
- in cold climates, take the provisions necessary to avoid condensation humidity and icing humidity (Freas et al., 1982);
- change wood connections to wall where moisture might get to wood by providing humidity barrier (metal sheets or bitumen paper, for example) and/or space for better air circulation.
- covering soil in crawling spaces and basements, or repair settlement cracks, to mitigate soil moisture migration which is the largest single source of moisture in a building (Smulski, 1997);
- providing clothes dryers, bath and kitchen with exhaust directly outdoors (Smulski, 1997);
- localising and eliminating stumps and wood cut-offs after identifying possible deterioration agents.

For every change or repair made, records should be kept with date, location, work description and recommendations for monitoring, adjusting or special maintenance.

3.8 Routine inspections and conservation

Responsibility issues are most often a gap between responsibility and almost never an overlap or responsibilities. A well conducted technical report and recommendations are useless if forgotten in a drawer because no one was assigned to fulfil the tasks or no deadline was proposed to the tasks.

After a comprising inventory and assessment of a wood structure is done, a inspection and conservation program should be delineated in order to guarantee a day-to-day observation of the structure and a year long schedule of inspection and conservation tasks. Because those tasks will consume resources, a person with administrative responsibilities must be assigned and a budget provided accordingly, as suggested by Tuomi (Freas et al. 1982).

Along with defining responsibilities it is important to give adequate training to involved personal. Topics of training should comprise basic understanding of wood as a building material (Hoadley, 1980), understanding of biodeterioration agents habitudes and identification, inspections techniques and tools. Practical workshop classes, within the building itself, will be of great value to effective inspection practices. Depending on the complexity of the building and its operation it might be interesting to give a basic training to several users of the building, so they will be able to make day-to-day critical observations (making it easier to track water leaks or biodeterioration indices).

Scheduling routine inspections and maintenance might look much like a car maintenance manual schedule, with tasks associated to a event or given time, as shown in table 1. TUOMI (Freas et al. 1982) proposes three levels of inspection: daily, routine and timely.

Daily inspections are not formal. Once the users of the building are trained and become aware to what to look for they will report abnormal conditions to the person responsible for the building maintenance.

Maintenance unscheduled actions will be triggered by emergency situations such as such as roof leakage, gutter or plumbing malfunction. Every unplanned source of water is a important risk to wood and other construction materials, and must be repaired as soon as possible. Actions might also be taken under biodeterioration infection risks, such as termite reproduction fly control or under a termite baiting control plan.

Considering routine inspection and maintenance, different parts of the building will have different times in a yearly schedule. Roofs and gutters should be inspected, cleaned and repaired before and after the rainy season (usually spring and fall). It is encouraged to schedule roofing work contractors in advance, as in some region many buildings will be making the roof maintenance in the same months.

Basement, crawl spaces, roof, attic areas shall be inspected when heat, moisture or condensation are greatest (usually summer and winter). Those areas shall be checked for leaks, insulation, water barriers and vacuum-cleaned (Singh, 2001). Inspection must always be carried on before cleaning!

Most wood finishes are recommended to be applied in warm and dry weather and must be scheduled to a suitable time of the year, according to supplier instructions.

Junction inspection and bolt tightening shall occur during the lower relative humidity season. Tightening is especially important to unseasoned structures, which is seldom the case of historic structures. Yet junction inspection is an important activity and loose and idle bolts in seasoned timber might be indicatives of deterioration.

Timely inspections are dictated by torrential rain, severe winds, accidental damages, snow or other unusual events. Problems such as roof deflection, drainage, leaks, overload, changes in roof slope should be scheduled and checked.

Table 1 – Simplified example of wood structure inspection schedule. Specific days will be scheduled to ensure the agenda fulfilment.

Activity	Intermediate Season	Rainy or Hot season	Intermediate Season	Dry or Cold season
Daily inspections	X	X	X	X
Roof and Gutters inspection, repair and cleaning	X		X	
Basement and crawl spaces inspection and cleaning		X		X
Attic Areas inspection and cleaning		X		X
Matting fly of Drywood termites		X		
Paint and finish applying			X	
Junction Inspection and tightening				X
Annual inspection and conservation plan review	X			
Roof and gutters	After heavy rain			
Check roof slope	Upon extreme snow load			

It is considered by Tuomi that the minimum information to be reported after an inspection is: who conducted the inspection, what was inspected, when the inspection was done, what was observed and recommended actions.

In order to encourage complete inspections, a inspection methodology shall be developed to the building. This methodology may be expressed as training and a set of report forms to be filled by the inspector. It should guarantee that the right places are visited ate the right time; that special inspections instructions are followed with the care needed; that the indicatives of deterioration are looked for and reported accordingly; that the recommended actions are followed up and that the information collected will be useful to a specialist future work.

Every inspection report must be reviewed by the person in charge of the inspection and maintenance program, who will ensure that the program is being followed as committed, by the right person and ensure that the conservation actions needed are taken.

3.9 Non-destructive Essays and Monitoring

Depending on the building value, complexity, treats and resources, several techniques of inspection and monitoring are available. LELIS proposes that cultural heritage will be greatly benefited by new techniques advantages if partnerships with research laboratories are made to insure a close follow up of the practice.

Some of the techniques presented here are not new but may still be better used in the cultural heritage field. Effectiveness of some newer techniques may still have to be confirmed.

Traditional visual, point prospecting, hammer percussion inspection and coring are encouraged, especially with an experienced inspector. Newer techniques may be used to complement those traditional methods.

3.9.1 X-rays

X-rays are high-energy rays of photons that will transpose a material depending on its density. The higher the density of a material, the greater obstacle it will offer to x-rays. It is possible to register x-ray density by special sensors or special photographic films.

If a piece of wood is exposed to a x-ray font and a photographic film is placed on the other side, sound denser wood will correspond to areas of low photographic sensibilization (negative white). The portions attacked by insects or fungi will have lower densities and will show as high sensibilization areas on the film. A sensor based method was used to study the kinetics of wood degradation by Bucur et al. (1997).

Small wooden objects may be examined at hospital or airport facilities. Mobile equipment will have to be placed for structure analysis, which might be problematic.

X-ray tomography may be used to create three-dimensional images of wood objects (Bhandarkar, Faust and Tang, 1999).

3.9.2 Controlled drilling

Any material machining needs energy. Sound wood will require more energy to be machined then decayed wood. An internal void will require no energy at all.

Especial drilling equipment were developed (Rinn, 1994, Demaus, 1993) to record the energy needed drill wood or the resistance opposed to drilling. The controlled drilling equipment will have a constant drilling speed and will record the drilling deepness along with the resistance or energy. The result will be a map of the drill line, with a diameter as small as 1mm, thus considered a quasi non-destructive essay.

Controlled drilling may be very accurate and very useful. Yet it will assess a small volume and a well trained interpretation is recommended.

3.9.3 Sound waves or stress waves timing

The travel speed of sound waves and stress waves will be higher on harder materials, i.e., materials with higher modulus of elasticity. Sound and stress waves are unable to travel between radically different materials, thus they will contour voids within a solid material by a longer way.

Sound wood has higher modulus of elasticity than decayed wood. Thus sound or stress wave will take less time to travel through sound wood than in decayed wood. When wood has voids caused by decay pockets or insects, sound or stress wave will take a longer way to contour the void, taking more time to travel the same distance in sound wood.

Sound or stress waves timing will correspond to a volume probed, related to the wavelength. The data interpretation may be tricky and should be done by well-trained personal. A good general description of this method is given by Ross et al. (1999).

3.9.2 Acoustic emission

This method is still under development and uses a sound sensor system specially conceived to capture the frequency emitted by the termites, in an attempt to eliminate the other ambient sounds. The equipment registers each sound event and a higher number of events will correspond to termite activity.

The equipment is described by Lemaster, Beal and Lewis (1997) as being able to detect Dampwood termites within a 2.2m distance. Subterranean termite proved to emit six times less sound events than Dampwood termites, thus being more difficult to detect.

Presently the method must have direct contact to wood, being finishes such as plaster or wall boards a barrier.

3.10 Termography

Temperature of the surface of a wood piece will vary in time depending on the difference of temperature between wood and air, physical properties (diffusivity, heat conductivity) and density. The density of wood will decrease if it suffers biodeterioration by fungi. Voids will be made in wood (thus density zero) when deterioration by insects take place.

Tanaka (2000), was able to locate decay and knot in wood specimens by imaging the small temperature differences caused by normal temperature changes during the day. The termography equipment used has a 0.01ºC sensitivity. The detection of artificial cavities made inside specimen was possible (3, 7.5 and 15mm from the surface) but a powerful heater (1500W) was needed to cause the temperature changes.

3.10.1 Dog assisted termite search

Although there has been little research about dog assisted termite detection, this service has been offered since the 1970's (Lewis, Fouche and Lemaster (1997). Trained beagles were laboratory tested by LEWIS, FOUCHE and LEMASTER to detect termites and could correctly identify 81% of the test blocks containing termites. However their rate of misidentified blocks (false positives) was 28%. It was found that they could almost perfectly identify blocks with a high density of termites (50 individuals or more in a 115 x 87 x 37mm block).

More research must be done before drawing conclusions.

3.10.2 Moisture monitoring systems

As low moisture is crucial for good timber conservation, it is proposed by SINGH the use of remote monitoring systems to track moisture content of inaccessible timbers, roof spaces, masonry, lintels, gutter areas and behind decorative finishes. Sensors reading may be done manually or be operated by computer, which may alarm if a sensor exceeds a programmed limit.

3.10.3 Termite baits monitoring

Although much research is still being done, baiting has been successfully used and some systems are commercially available (Potter, 2001, Lewis, 1997). Although baiting systems are designed for termite control, some systems use plastic monitoring stations containing untreated wood placed around the building to detect termite presence. If foraging termites find a station, they will be detected by periodical inspections. The same stations will be used to install the termite control baits.

Research on baiting technologies must be carried on with termite species different from the originally studied, as frequently is the case in Brazil.

4 CONCLUSIONS

As the methods described are applied to wood structures it is expected to extend its service life and ensure that the cultural heritage will be kept safe. Although a complete building conservation plan is desired, planning does not mean high costs. Many conservation actions may be planned within budget to ensure on a daily basis that the wood will be in good shape in the future, avoiding high restoration costs and loss of historic fabric.

To ensure the success of a conservation plan it is very important that the responsibilities are given to committed people with enough administrative power.

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