

RETROFITTING STRATEGY TOOL FOR TIMBER FLOOR STRUCTURES

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ABSTRACT

In old city centers, the majority of these buildings were mainly designed as load-bearing masonry structures (stone or ceramic bricks), with timber structured floors and roofs. As consequence of aging, loading (sometimes accidental), alteration of use, moisture content, lack of maintenance and repairing actions, amongst others, these buildings have slowly decayed, particularly timber elements of floor structures and roofing systems more susceptible to the degradation of the load bearing capacity and sensible to excessive moisture problems at the connection areas with masonry walls, aggravating stress levels of the timber resisting elements, even in cases when subjected to seismic action.

This paper, intends to deepen existing studies, by proposing strategy definition for retrofitting and strengthening of timber floors, taking into account that wood is considered a noble material, with excellent structural properties, ecological and sustainable. So, taking into consideration specific limitations of old buildings and preventing the loss of authenticity of the original materials, it is suggested the use of

similar materials, assuring the safety and durability of structures, as well as the improvement of the serviceability conditions of buildings.

To consider the presented solutions in terms of execution, it is necessary to resource to strategy definition tools to complement the inspection tasks and defect identification, as well as compatibility of performance levels (thermal, acoustic and structural), or definition of eventual non destructive “in situ” testing if needed.

Key words: Timber Structures, Strategy, Retrofitting and Strengthening.

Introduction

In the latest years, it is noticeable an increasing overall development in the rehabilitation of old buildings, as well as the establishment of governmental priority in this field. Faced with this growth, it has arisen the need for more insightful studies and knowledge concerning historical evolution, origin, project design and safety evaluation, as well as the privileging of maintaining original materials in alternative to their replacement. Therefore respecting the typological and morphology characteristics that assign the local architecture in which the construction is included should be harmoniously integrated.

To configure a sustainable intervention, it was developed a table to support an intervention strategy in which the owner may base the definition of the rehabilitation program proposed, taking into account the particularities of each situation.

To test this approach, some case studies were selected. Results have lead to successful interventions made the rehabilitation of the historic center, in an attempt to maintain and preserve the original materials, or replaced by similar materials, but always ensuring the structural safety conditions, as well as the comfort of buildings and architectural authenticity.

Timber Floor Requirements, Maintenance and Rehabilitation Strategies

Structural Detailing and Construction of Timber Floors

The wood structure floors are constituted of timber beams distanced on average, among 30 to 60 cm in which is placed a wood covering in the transverse direction (see Figure 1). The distance of the timber framework is the reflex of the better or worse quality of the building. The transverse section of the beams vary in function of the

room span, but for average spaces (ranging about 3 to 4.5m) the dimensions are very dispersed, they range among 10 to 20cm for the width and from 12 to 25cm for the height.

The connection of floor beams, in the majority of the buildings, simply consists of the fitting of the wood framework into masonry openings with the dimensions of the timber beams. In other cases was seen the existence of an element of load distribution, horizontal beams and vertical wood studs embedded in the wall, avoid the stress concentration of the masonry.

Most rare are cases in which the effectiveness of the floor diaphragm and wall connection is guaranteed, with resource to metallic elements and steel tendons crossing walls. The decay of these hidden timber beams and elements have lead to bulging and fracture of the walls. The later alterations have disrespected the original structural, cutting and removing of structural members of wall timber framed elements and floor. The adaptation of old buildings, by introducing new or remodeled bathrooms and kitchens has lead to the use of a thin concrete slab over the timber framework as shown in Figure 1.

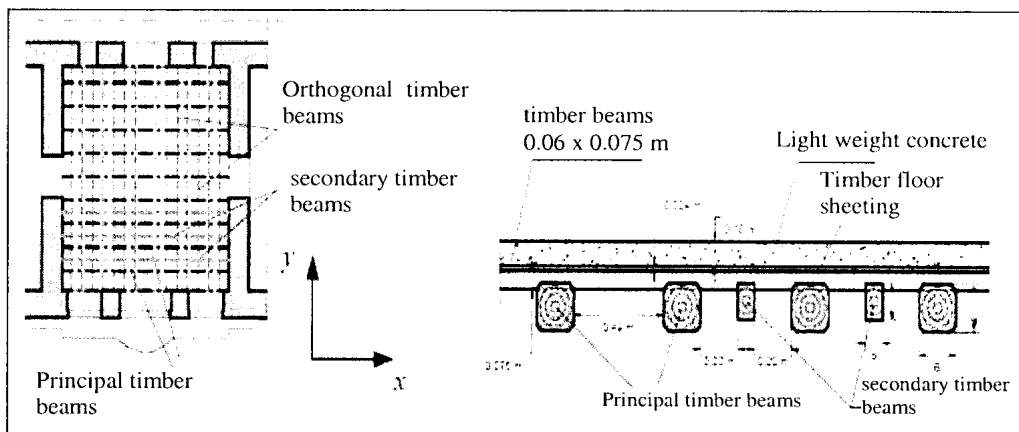


Figure 1 : Wood floor structure [1]

Strategies for Regular and Scheduled Maintenance

The rehabilitation of timber floor structures and coverings should be planned to be the least intrusive possible, without increasing weight, with little visual impact, and with minimum replacement, privileging the use original materials. A decision to intervene in an old building, is more than an action of cleaning, reactive maintenance and conservation, it must assume the existence of an accurate diagnosis, supported by scheduled inspections, studies and possible monitoring if necessary. The more detailed, the better the intervention and optimization of resources used. The

investigation of a possible defect or malfunction should come before coming to a resolution. The defect in some cases cannot be directly related to the construction element, itself, but rather with its surroundings, as is the case of water penetration through the wall and that can affect the timber beam elements.

Before going into a rehabilitation or refurbishment, it must also be taken into consideration the issues relating to the functionality (thermal performance, acoustic insulation, fire resistance and infrastructure/piping installations), to guarantee minimal comfort requirements.

After the diagnosis of defects identified, the next step is to adopt a strategy to implement treatment measures more or less intrusive or simple preventive maintenance actions to prevent atmospheric, aging and biological decay [2].

Inspection, Conservation and Protection

Cleaning (inspection), conservation and protection should be carried out regularly, even after rehabilitation actions, to early identify defects of all timber based building components (roof and floor structures, doors and windows, timber partition walls, piping intersections) in order to eliminate possible sources of damage and decay, particularly to prevent the water penetration into the building and avoiding the degradation caused by atmospheric and biological agents, including fungi, insects, algae, vegetation.

Chemicals substances are designed to enhance the durability of wood, making it more resistant to the attack caused by biological agents, weather and fire. The preservatives impregnable in the wood, have a protective role over time and not reduce the performance of wood for the conditions, according to NP 2080/85 [3] EN335-1 [4] and EN460 [5] (which can be highlighted: the waterproofing products and bituminous solution, applied at the ends of the beams in contact with possible sources of water and other products with flame retardants). These products should be applied carefully and should take into the following aspects: the residual color and odor of treated wood, the corrosive action on metals, the compatibility with finishes and toxicity to humans, animals and plants.

Strategies for Structural Rehabilitation and Functional Requirements

Structural Rehabilitation

Regarding the structural rehabilitation, it can pass through the substitution of timber elements that are in an unrecoverable state, or by consolidation using metallic, epoxy resins or composite materials with the aim of recovering the initial resistant load deformation capacity of the structure.

Concerning to the replacement, consolidation or strengthening of timber structures, there are different techniques that depend on the location, and cause of degradation of the material to be applied:

Rehabilitation in Regard to Functional Requirements

Functional rehabilitation is equally important as the structural safety, for reasons of comfort, welfare of the residents:



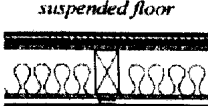

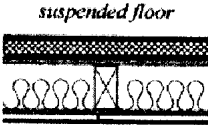
- Acoustic insulation, in respect to the National Regulation Requirements for Building Acoustics (RRAE) [6];
- Energy performance thermal behavior, in respect of the Thermal Code for Buildings (RCCTE) [7];
- Fire resistance, combining the various specificities of the building and its type of use, as well as other protection measures for Fire Risk in Old City Centers [8];
- Implementation of technical installations, such as water supply and sewage systems, electricity, telecommunications, cable and gas, thus complying with the specifics of each infrastructure.

In case of sound insulation of timber floors it is essential to prevent the occurrence of hard links, between the existing elements to avoid the transmission of noise, which means the installation of elastic hangers on false ceilings or the installation of resilient supports for floating floor coverings. In both cases there is the need to install sound absorbing material in the air-gap between the superior and inferior wood batten.

Values in Table 1 provide sound insulation levels for impact sound ($L'_{nT,w}$) for various solutions, as well as the performance levels for air born and stepping sounds, and fire resistance, in a scale of 0 to 5 (bad to excellent). When confronted with these results the code values for impact and airborne sound, it is clear that to comply with RRAE [6], with respect to multifamily dwellings or mixed use buildings requirements, retrofitting actions are necessary, consisting of a heavy UF with floating floors (Heavy UF), so that it meets all the minimum regulations. This solution is technically complex to perform and therefore expensive.

Wood is a material that has a very low thermal conductivity. When the floor is in direct contact with terrain or near the roof, without any type of insulation, more detailed care should be assumed. Basically the air-gap of timber floors is excellent areas to apply thermal insulation. In other cases of simple intermediate floors the use of a optimized insulation with good thermal and acoustic insulation characteristics is desirable (such as mineral or glass wool). However, the thermal code [7] (RCCTE) does not impose any thermal requirements for floors and interior walls if not confining with external or high ventilated areas or compartments.

Table 1 : Possible solutions of acoustic insulation and fire protection of timber floors

Combinations of acoustic structures	Performance re. stepping sound	field of application	Impacts on floor characteristics		
			acoustic rating		fire rating ¹
			air born sound	stepping sound	
no structure UF 	80 dB	single family home	2	0	0 to 2
light structure UF 	73 dB	single family home	3	2	0 to 2
light structure UF & suspended floor 	a) timber battens b) resilient channel 66 dB	single family home multi storey buildings ²	4	a) 3 b) 4	2 to 3
heavy structure UF 	51 dB	single family home multi storey buildings ²	5	3	0 to 2
heavy structure UF ² & suspended floor 	a) timber battens b) resilient channel 41 dB	single family home multi storey buildings ²	5	a) 4 b) 5	2 to 4

rating: 0: nil, 1: low, 3: average; 5 excellent

¹ variations according to properties of fire resistance of lower sheet

² recommended requirements for service and aspect: 1/600

Although wood it is a flammable material, it resists particularly well to prolonged exposure to fire, the combustion of wood is slow and regular (when burnt chars the surface layer, protecting the inner section).

Older buildings in city centre's, still in use, need to have technical infrastructure of water supply and sewage systems, electricity network, telecommunications, cable and gas properly installed, in compliance with the specific installation and construction codes. Although they can be technically adapted and fitted, many require maintenance and replacement, and can often cause damage to the timber floors and walls, by intersecting them, increasing the risk of water leakage problems, short circuit or even gas leaks. For all these reasons the rehabilitation and refurbishment should be particularly detailed.

Case Studies of the Historical Center of the City of Coimbra

Case Study: Integration and Characterization of the Historic Building

Innumerable case studies of timber floors were assessed taking into account some special features, in particular, because they are located in the historic city of Coimbra. The buildings are situated in different sites of the historical center and presents different characteristics, in terms of its conservation state, functionality, as well as the intervention required. Only one case study is presented here, however the complete research can be consulted [9, 10].


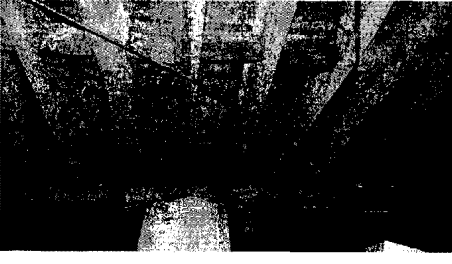

<p>a)</p> 	<p>The floor is located in an earthen platform, and presents an air gap of about 0.9 m.</p> <p>The timbering is constituted of beams arranged parallel to each other, recessed in walls which are supported by structural beams, intermediate, and perpendicular.</p>
<p>b)</p> 	<p>The floor structure consists in beams, approximately of rectangular section (0.16 m x 0.08 m). The spacing between beam axis varies between 0.30 m to 0.4 m. The beams are intersected by orthogonal beams.</p>
<p>c)</p> 	<p>Detail of the intermediate support beam recessed and based on a stone wall, perpendicular to the joists of the wood deck and supported at the mid-range by small stone pillars.</p>

Figure 2 : Structure and details of the elevated timber floor

This case study corresponds to the structure of a dining room floor, in which the timbering is accessible through an access at ground floor level. Between the inferior face and the earth surface exists an air gap. A technical inspection was carried out and the structure of the framework under consideration does not manifest any signs of biological attack, nor does the present any deformations. It was not also affected by the rainwater, and in particular, rising damp. The ventilation of the air gap has contributed to maintain the good condition. There were no signs of biological agents, eventually because the environmental conditions are not favorable to their presence (humidity and temperature).

In regard to functional issues, all timber floors of this building don't have any type of thermal or acoustic insulation. The structure does not have any fire protection. In terms of electrical infrastructure, it requires a deep intervention.

Strategies for Maintenance and Rehabilitation

The City Council of Coimbra as owner of this building has decided to rehabilitate. Taking into account the historical and cultural value and its future the following strategy of intervention was defined:

- The floor structure and the floor boarding need a general cleaning and an application of a preservative treatment against biological agent attack [3, 4, 5]. The application of a waterproofing solution (bituminous) to prevent decay should be applied, particularly at the end of the beams in contact with masonry walls. Future periodic maintenance is foreseen in order to avoid possible anomalies.
- In regard to functional issues, the timber floor is not compliant with the thermal insulation requirements. The heat transfer coefficient, U , should be inferior to $1.65 \text{ W/m}^2\text{°C}$ for this case. Therefore it is advisable to apply mineral wool as insulation material to achieve more comfort. In relation to the acoustic insulation, there is no requirement; nevertheless the application of mineral wool is beneficial.
- For fire protection of the timber floor structure, it was also suggested the application of fire retardant products [11], to ensure some resistance to fire and reduce the propagation of flames. Additionally the protection of metal components (connections between timber elements) was also specified to avoid a "weak point collapse".
- Infrastructures passage, such as the electrical and telecommunications cable. The existing ones need to be reviewed and adapted to the new use, the others will be installed. It is suggested that the air gap is used to hide and the intersections and passage of the cable.

In summary, Table 2 resumes a retrofitting strategy tool for the intervention strategy actions for this case.

Table 2 : Anomalies and functional limitations, possible strategies for rehabilitation

Case study					Maintenance and rehabilitation strategies													
					Maintenance		Total or partial replacement of beams	Structural consolidation		Structural consolidation			Compliance with the functional					
Anomalies and functional constraints	Symptoms checked	Images	Origin	Consequences	Clean, maintain and regular protect	Preservative treatment or fire retardant			Concrete application	Mixed application concrete/wood	Mortar and epoxy application	Additional reinforcement of beams	Metal reinforcement	Reinforcement with composite materials	Strengthening support elements	Acoustic	Thermal	Fire Safety
Anomalies in use, maintenance, dimensional calculation and	none	—	—	—	***	—	—	—	—	—	—	—	—	—	—	—	—	—
Biological attack	none	—	—	—	***	***	—	—	—	—	—	—	—	—	—	—	—	—
Degradation by weather and exposure	none	—	—	—	***	***	—	—	—	—	—	—	—	—	—	—	—	—
Functional constraints	Poor acoustic performance	—	Poor or none acoustic insulation	Bad or none acoustic insulation	—	—	—	—	—	—	—	—	—	—	***	—	—	—
	Poor thermal performance	—	Poor or none thermal insulation	Discomfort in a thermal level	—	—	—	—	—	—	—	—	—	—	—	***	—	—
	Inadequate fire safety behavior	—	Inadequacy of existing structures to the regulation of fire safety	Potential fire hazard and sequent destruction of the building	***	***	—	—	—	—	—	—	—	—	—	—	***	—
	Malfunction of infrastructure (water, sewer, electricity)	—	Lack of maintenance of existing infrastructure and	Functional ineffective - any leaks that may cause damage to	***	—	—	—	—	—	—	—	—	—	—	—	—	***
Intervention level					***	***									***	***	***	***

Legend: More appropriate *** Adequate **○ Less appropriate ●○○ Not applicable —

Conclusion

It is urgent a change of perspective from the technical community and the society in regard to rehabilitation and repair of old buildings, in particular to timber flooring. The Government has promoted incentives to promote rehabilitation through specific programs or by the creation of partnerships with local government.

The rehabilitation should always be preceded by a thorough analysis, as shown above: identification and diagnosis of defects, detailed study of the possible interventions and use of resources, classify the most critical needs. In regard to consolidation and structural reinforcement of timber floors, and their rehabilitation in functional terms, here too it is very useful the tool created, so that it becomes economically viable and so it is possible to continue to use wood as a structural material.

Wood is recognized as a suitable material for construction, its nature, nobility and beauty are undeniable, when compared with other current materials (concrete), however its technology and construction knowledge has been "forgotten". To continue to promote the preservation and continued use of timber floors, all constraints and requirements should be identified, so an economically viable solution is strategized.

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