TIMBER-TO-TIMBER STRENGTHENING OF A 17TH CENTURY TRADITIONAL TIMBER FLOOR

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Abstract. The subject of this work is the restoration of the timber floors of a 17th century building located in the city center of Milan. According to the Italian Cultural and Landscape Heritage Code (Dlgs 42/04), this building is listed. Over the centuries the building has been deeply damaged and in order to be re-used, a restoration intervention was needed. The intervention involved the building as a whole: timber roof structures, masonry walls and timber floors. In this paper the attention is focused on the strengthening of the timber floors. The criteria adopted in the design are based on the Guidelines for Cultural Heritage Buildings issued in 2010 and on the Chapter 4.4 of the Technical Italian Code (NTC 2008) focused on timber structures.

On the basis of the preservation state of the timber beams and joists, two different interventions were identified. Floors in bad state of conservation or with increased loads due to new functions will be substituted adopting beams and joists of same dimensions, same span and construction technology. Existing timber floor in good state of conservation but with insufficient cross section dimensions will be strengthened using similar timber beams and joists connected with the original elements through metal fasteners in order to obtain a whole cross section. The leading concept of the whole intervention is to preserve the original structure as much as possible or to consolidate it adopting the less invasive and the more compatible construction technique.
1 INTRODUCTION

The object of this paper is the strengthening intervention on historical timber floors of a building located in Milano, Italy, close to the Duomo Cathedral (fig. 1). Since it is a public building and it is more than fifty years old, according to the Cultural Heritage and Landscape Code issued in 2004 [1] the building is listed. Moreover, since the building is close to the ancient church of S. Stefano and it is situated in a Landscape and Archeological Area, according to the Preservation of Historic and Artistic Heritage Code issued in 1939 [2] the building is listed one more time.

![Figure 1. Milano plan. G.B. Clarici 1579](image)

The building has an irregular plan and it is made of two parts: a three storeys building close to the S. Stefano church and a secondary building south facing (fig. 2). In both cases the vertical bearing structure is made of masonry. The roof structure is covered by clay tiles, the bearing floor structure is made of timber and it is almost in quite bad conditions.

Except for the ground floor, the building is actually not used and due to the bad state of conservation of roof and floor structure and of the façade, maintenance and reinforcement interventions are needed.
2 ARCHITECTURAL ELEMENTS

The vertical bearing structure is made of bricks of different thickness; the floor structure is made of timber beams and joists with timber boards, floor layer and tiles. Underground floor is covered by barrel vaults made by bricks.

Staircase is made of brick masonry and cladded by granite boards; balconies have granite boards supported by granite cantilever beams.

North-facing hip-roof structure is made of timber with flat clay tiles; south-facing building has a gable-roof structure made of wood and curved clay tiles.

As a general remark many previous interventions can be detected; these procedures led to partially transform the original building features.

These interventions were carried out mainly in the ‘50s of the 20th century, in order to repair the World War II damage (the building was one of the most damaged by 1943 bombing).

Along the years the building has been reinforced and partially rebuilt, in particular in the west area of the building. Moreover, lodgers made changes and interventions in the apartments, partially modifying the internal frame.

2.1 Floor interventions

In the ‘60s of the 20th century further structural interventions were carried out: walls position was modified due to different destination of the building and a consequent higher live load was acting on the floor. Thus, a floor reinforcement intervention was needed. A new floor made of NP200 steel beams and bricks was superimposed on the existing timber beams of the first floor (fig. 3). The depth of the floor level increased and was higher than the balcony level. Steel beams were disposed at 1 m distance over the timber floor.

Other floors were strengthened by a concrete slab layed on the timber beams.
3 STATE OF CONSERVATION

The state of conservation of the roof structure was almost bad, due both to the decay of timber elements and of the roof tiles. In the past many refurbishments and substitutions were carried out.

As regards timber floors most of them were in a very bad state of preservation (as in fig. 4) due to poor maintenance, insufficient cross section dimensions, poor construction quality, weak or missing connection between elements, fire.

In order to preserve the existing timber floor as much as possible and to reduce new timber elements to the minimum, according to the floor typology and to the conservation state, different strengthening intervention were adopted and are described in the following.
4 FLOOR TYPOLOGIES AND WOOD SPECIES EVALUATION

Floors are made of timber beams and joists although many interventions have been carried out along time. In order to define the better intervention for each type of floor, five different types has been identified:

1. Timber floor in good state of conservation and not consolidated: most of the floors are made by beams and joists and timber boards on them;
2. Timber floor previously consolidated with a concrete slab;
3. Timber floor damaged by fire;
4. Timber floor in bad conditions made by new timber elements with new joists or recently repaired;
5. Timber floor made by small dimension elements on which the ceiling is hung down.

For each floor typology a strengthening intervention was proposed and carried out.

In order to assign the strength resistance of timber and to evaluate if the element dimensions are adequate to the actual Code [3] or not, visual grading has been carried out according to [4] and [5]. Two different wood species have been detected: chestnut and spruce; both of them were classified as C24 resistant class.

5 STRUCTURAL ANALYSIS

5.1 Structural control of the main beam

The main beam of the floor is made of spruce and it is 5.2 meters long; its transversal cross section is 18 cm wide and 30 cm deep. The normal stress value was 80% over the Code limit value and the value of the instantaneous deflection was about 40% over the maximum. Thus a strengthening intervention was needed: an additional spruce beam C24 10 cm wide and 28 cm deep was overlayed on the existing one.

5.2 Main beam strengthening

Considering, on the safe side, that the whole beam is 10 cm wide and 58 cm deep, the normal stress value is now within the Code limit being about the 80% of the design value. The instantaneous deflection is about 40% of the maximum value. In figure 5 is represented the value of the elastic deflection ($f_{el}$) of the main beam due to a 2 kN/m live load. In figure 5 the vertical line ($f_{lim}$) indicates the maximum admitted value: before the strengthening intervention (18 x 30 line) the limit is reached with a 1.5 kN/m load. After the consolidation (10 x 58 line) the deflection value is within the limit. The new transversal cross section fulfils the National Codes requirements and stress and deflection values are finally lower than the Code [3] values.
The connection between the existing beam and the new one is provided by double thread metal fasteners (2 screws 8.2 mm x 300 mm, inclined at 45°, disposed at 90÷100 mm distance close to the supports, and 200 mm distance at midspan) as in fig. 6.

According to the data provided by the producer the metal fasteners can take up a shear force equal to:

\[ R_{V,k} = 11.30 \text{kN} \]

The highest shear force is:

\[ V = (1.5 \times 2.00 + 1.3 \times 3.00) \times 3.2 \times 5.20/2 = 57.4 \text{kN} \] (1)

Therefore the distance of the fasteners is equal to:

\[ e = [2 \times 2 \times 11.30/1.5 \times (300 + 280)]/(3 \times 57.4) = 102 \text{ mm} \] (2)
In order to enhance the heat and acoustic properties, the volume between the joists has been fulfilled with natural powdered non-hygroscopic mineral. The whole floor was then covered by two OSB boards 20 mm thick, in order to enhance floor resistance and have a better behavior in both directions (fig. 7).

The timber floors with a higher floor level that were previously consolidated by a concrete slab, were strengthened in the same way after having removed the slab.

Figure 7. Strengthening intervention: new timber beams and joists connected with the existing structure.

The beams and joists damaged by fire were substituted by new spruce C24 elements adopting the same typological and structural layout and the same dimensions of the original one; finally, the same strengthening intervention made on the floor of the first type was carried out also on the floor damaged by fire.

As regards the timber floor beneath the roof structure, since the original dimensions were extremely underestimated the beam could not bear the load acting on it, were substituted with new spruce C24 elements 16 cm wide and 24 cm deep (fig. 8).
5.3 Structural control of the joist

The structural control of a chestnut joist 3.3 m long having transversal cross section 9 cm wide and 15 cm deep disposed at 75 cm distance pointed out that the transversal cross section did not fulfill the actual building Code requirements [3]. Considering the live loads (2 kN/m) provided by the Code, the values of normal stress acting on joists are about 10% over the maximum admitted value.

As for deflection control, the value of the instantaneous deflection is about 20% over the maximum; the net final deflection is much more than 100% over the value indicated by the Code. Hence both the normal stress and the deflection values are over the limit. Thus, in order to have values below the limit, it is necessary to design a strengthening intervention.
5.4 Joist strengthening

In order to reduce normal stress and deflection values, it was suggested to add a spruce C24 joist 8 cm wide and 8 cm deep over the existing one, considering, to be on the safe side, the whole section made of spruce being 8 × 23 cm and assuming that joists are perfectly working together. The effect of the intervention is the decreasing of the normal stress (about 70% less of the previous one) and of the deflection values, now within the Code limit, as can be seen in figure 10.

The connection was provided by double thread screws 8.2 cm long, 220 mm diameter, disposed at 45° at 90÷100 mm distance in the first fourth of the span from the support in which the shear force is higher, and at 200 mm distance at midspan. In some cases additional joists can be added in order to have the same floor level as in fig. 9.

According to the data provided by the producer, the metal fasteners can take up a shear force equal to:

\[ RV_{s_k} = 7.95 \text{ kN} \]

From the internal force evaluation a shear force equal to 8.54 kN is found and therefore the distance between the fasteners is:

\[ e = \frac{2 \times 7.95/1.5 \times (150 + 80)}{3 \times 8.54} = 95 \text{ mm} \tag{3} \]

In fig. 10 is represented the value of the elastic deflection \( (f_{el}) \) of the joist. The vertical line \( (f_{lim}) \) indicates the maximum admitted value: before the strengthening intervention (9 x 15 line) the limit is reached with a 1.6 kN/m load. After the consolidation (8 x 23 line) the deflection value is within the limit.
6 CONCLUSIONS

The consolidation intervention was leaded by the idea of preserving the building as much as possible.

The strengthening intervention described were adopted on timber floors not previously consolidated and in a good state of conservation or on a floor consolidated by a concrete slab over the timber structure; in this case the concrete slab was removed before the strengthening intervention.

In particular the intervention on timber floor preserved beams and joists in good state of conservation despite their dimensions were underestimated. The element dimensions were enhanced by the addition of new beams and joists jointed to the original one by metal fasteners in order to have stress and deflection values lower than the Code limiting values. The intervention carried out was a timber-to-timber and dry timber intervention, in order not to modify the moisture content of timber and not to change wood mechanical properties. This intervention in fact was carried out according to the traditional building techniques and, as suggested by the Cultural Heritage Italian Guidelines, it is a reversible intervention: it is always possible to go back to the original situation simply removing the OSB board, the fastener and the new beam (or the joist).

7 REFERENCES


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