Interventions on historical building timber floors: Retractable – visible? Invasive – not visible? ……… A case study

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**ABSTRACT:** This paper examines the main types of floor found in Italian historical buildings and analyses their deterioration and failure. The various aspects of current restoration interventions are examined, by comparing innovative as well as traditional techniques. The paper ends with a case study, which is deemed exemplary for diagnostic purposes (geometric measurements, constructive elements, visual investigations of materials, resistance measurements, thematic maps relative to the state of preservation of the material, flaws, deterioration and instability), illustrating the subsequent rehabilitation interventions, which implement alternative solutions in terms of "non visibility" and "retractability" of the intervention.

The case study refers to sixteenth century, polychrome painted or "papier-mâché" decorated timber floors, of particular historic and artistic value located in Lagnasco Castle (Province of Cuneo, Piedmont, Italy), currently awaiting restoration. The floor is also emblematic for the objective difficulty of proposing innovative interventions for the inherent specific peculiarities.

The fundamental steps in diagnostic methods and intervention techniques are illustrated in this paper.

1 INTRODUCTION

Recently, the restoration of ancient timber floors has become a topic of interest within the wide-ranging debate on historical heritage as well as for the issues relating to their actual preservation.

Today, the reasons for this debate can be considered as the sum up of four different issues: floors are structures and, as such, in a restoration project they are often relegated to a secondary role; floors are supports of "forms" and "decorations" that are considered of greater historical importance; floors are made of wood, a material neglected in the 20th century and only vocationally thought as a substitute; floors are often hidden (by false ceilings, etc) and by consequence, their use, enjoyment and visibility become limited. However, in the past years, a renewed interest, especially in Italy has arisen confirmed by an increase of studies and research in the sector (historical, technologic, structural etc.) as well as by a considerable number of technical intervention proposals introducing the use of new materials and innovative technologies. Read critically, these new techniques shape the wide theoretical range that characterises the restoration debate: from the minimalist intervention and the preservation of the original function, to that of "safeguard" intended as preservation of the object image deprived of its supporting functions, to the more extreme, calling for its complete cancellation, justifying it by an increase of the working loads, or for security reasons (true or presumed), static adjustments (necessary or presumed). With this preamble, the aim of this paper is to analyse, after a brief survey of the building typologies and of the techniques currently in use, two categories of intervention on a real case, in order to offer an alternative to the restoration
techniques currently in use, whose durability and efficiency in the sense of historical heritage are still the object of debate.

2 TIMBER FLOORS IN THE HISTORICAL ITALIAN BUILDING: TREATISES, NOTES.

In historical buildings one can distinguish three types of floors, caisson, and double and single frame floors.

To begin a study of the ancient timber structures it is necessary to consult the source in the available treatises: the knowledge of the structural complexes in these sources is based on the arrangement of the timber elements (dimensions and laying out) forming the structure with operations aimed at improving the structural performance at the actual state of preservation of the handwork. The provisions recommended by various authors will be examined in detail hereafter.

Generally, in the historic treatises, they are defined as floor of length equal to the width of the room to be covered and it is further classified as "simple floor" made of beams set according to the width of the room at a close distance between centres with a superposed deck and a "compound floor" of main beams always placed along the short side of the room and by secondary beams laid out orthogonally with respect to the first and to the deck.

In relation to the dimensioning of the simple floor beams, Scamozzi (1615) supplies indications on the basis of specific proportional ratios in function of the beams' clearance: heights equal to 1/24 or 1/30 of the span, bases 1/4 or 1/3 to the height and pitch equal to the height of the beam; furthermore, Scamozzi emphasises two recommendations: "...use the same type of timber for all the beams used for the floor and set the beams at the correct distance, because, in case the beams are too close, their weight and the resulting excessive holes will weaken the masonry, while, on the other hand, in the case of beams too spaced, their increased deflection could provoke cracks in the floor above".

Toward the end of 1800, the practice of laying out simple floors in rooms with a width of less than 3 m and double floors in rooms with a width between 3 and 6 m appears to have been well established: for simple frame floors, Pareto and Sacheri (1889) and later on Donghi (1923), propose a distance between centres of 0,40 to 0,50 m, while for compound floors, the main beams distance from the centre will be between 2 and 3 m and 0,40 to 0,50 m for the secondary beams (fig 1, 2, 3, 4).

On the other hand, the following solutions were mainly adopted for the bearing of the beams on the masonry:

- bearing on stone trass connected to the masonry by means of cramps, copper clasps or iron cramps and metal fibulae; these are solutions already adopted in the past and particularly congenial to Alberti (1485) and Milizia (1785).
- fixing to a depth equal to half the thickness in case of particularly thick walls and to the same thickness in case of thin walls, Scamozzi, and Valadier later on (1831) are particularly favourable to this solution. In general, the Authors indicate a fixing depth of 0,25 - 0,30 m according the thickness of the masonry; only Emy (1856), suggests 0,32-0,33 m for masonry with a thickness of more than 0,50 m and for timber sections of considerable dimensions.
- bearing on timber stringers which, in their turn are fixed in ¾ or in the entire thickness of the masonry, or are rested on brackets on consoles; the joint between beam and timber stringers is of the mortise and tenon joint type; a solution proposed first by Emy and subsequently adopted by Breymann (1880), with section values of the stringers of 0,12 - 0,15 m

Furthermore, the historical treatises propose solutions to avoid the recurrence of decay of the headpieces of the timber beams infixed in the masonry. The main solutions are:

- to prepare an air space around the headpiece (Alberti, Emy) while Pareto and Sacheri recommend an air space of 4-5 cm around the head with a hole on the outer wall covering it with a grid to allow the airing of the headpieces;
Figure 1: Double timber frame floor called “solaro a regolo per convento”, Valadier (1831).

Figure 2: Double timber frame floor, Chevalley (1924).

Figure 3: Connection between beam and masonry with single and double steel element and punch, Pareto and Sacheri (1889).

Figure 4: Double timber frame floor, Chevalley (1924).
- to lengthen the beams headpieces up to the outer surface only in case of masonry with a feeble thickness and not exposed to the rain (Emy, Pareto, Sacheri);
- to insert hardwood or stone brackets under the headpieces of the floor beams (Emy);
- to set dry or air bricks around the headpiece to form a box (Formenti, Donghi and Chevalley);

Other indications found in the treatises are relative to the techniques and the materials that must be placed under the headpieces of the beams inserted under the masonry in order to avoid decay.

3 INTERVENTION TYPOLOGIES: NOTES

The intervention categories can be summed up as follows:
- interventions in specific sections aimed at restoring or at increasing the resistance of the single frames;
- interventions in all structure aimed at increasing the strength of the entire structural unit;

Interventions in specific sections are put into effect in case of localised deterioration or instability of the frames in order to restore the original strength, which, in case of an extensive intervention on the entire framework is aimed at restoring or increasing the strength of the entire element. In timber beams, the most common deterioration, mainly caused by Xyilophagous agents, are to be found next to the brackets, and are caused by water seepage, by the increase of dampness and by lack of airing. The techniques that have proved reliable and lasting are:

- Application of metal casings
- Integration by means of wooden or glulam protheses
- Strengthening by restoring the deteriorated timber by inserting thin metal sheets
- Use of encasing systems by means of metal or composite materials

In brief, the techniques to increase the framework resistance are:
- Application of metal tension bars at the intrados: reinforced beam (fig. 5)
- Application of solid wood outer grips, laminar wood or structural multilayer
- Insertion of steel beams in the extrados o in bond tie
- Insertion of thin metal sheet of various materials inside the beam.

Another intervention category that can be necessary for a wooden floor is to increase the strength and/or the stiffness in order to obtain a mechanical performance superior to the original one. In this case it is useful to recall the intervention techniques that realise:
- Mixed wooden-wooden structures
- Mixed wood-concrete structures.

![Figure 5: Reinforced beam with metal tension bar at the intrados, Pareto and Sacheri (1889).](image-url)
Furthermore, in a context of particular historical-monumental interest, in addition to the requirements relative to the static performance, the respect of other criteria is required, i.e. the “compatibility” and the “retractability” of the intervention. Considering these presuppositions, the strengthening intervention calls for higher degree of attention: the durability, that is, the duration in time of the accomplished intervention, the “retractability” estimated on the basis of the possibility of proposing other intervention in the future. To sum up, this criterion could guarantee the possibility of treat again the intervention carried out also in view of technological innovations, new materials that in the future could guarantee more efficient and lasting interventions.

Among the recurring intervention techniques taken into consideration, the ones using wood and its by-products should be favoured because they respect the criterion of compatibility between the existing and the inserted material: in case of timber portion completely decay and no longer able to perform the original static functions, the reintegration of the structural unit by means of wood, newly inserted or already existing, should be favoured, paying also particular attention to the type of joint that must be achieved to guarantee an efficient solidarity. Furthermore, the restoration intervention with wood or with its by-products, such as glulam or micro laminar wood, can certainly guarantee a good compatibility and a high level of durability, allowing the keep the original static scheme unaltered. Remaining in the context of recurrent techniques, those employing different binding systems to restore a certain compactness to the timber element should not be neglected; in fact, in case of localized cracks it is possible to use clamps, preferably adjustable ones, i.e. of the type that can exert a precise compression on the wooden element checking thus the crack and stopping its worsening. At he current state of knowledge, instead of the iron clamp, widely recurrent in the traditional manuals starting from the end of 1700, new devices made of various materials such as steel and composite fibrous materials (i.e. carbon fibres and Kevlar®) have been adopted. It is also possible to use metal devices placed next to the timber paying, however, particular attention to the contact surface between the two different materials in order to avoid condensation problems without forgetting the problem of the solidarity between them.

Among the intervention techniques on a whole floor, the realization of composite structures with a wooden slab (continuous or discontinuous) presents a better result as far as the compatibility, durability and retractability are concerned. Furthermore, this technique allows achieving an excellent level of static performances, which imply a considerable increase of the stiffness and of the strength of the entire structural unit. Furthermore, it should be remembered that performance being equal, the mixed wood-concrete systems are completely irreversible, they cannot be retracted and their durability in time must still be proved satisfactorily.

4 CASE STUDY: THE TIMBER FLOORS OF THE LAGNASCO CASTLES

The complex of the Lagnasco Castles constitutes an historical heritage of considerable historical as well as artistic interest; it belonged to the various branches of one of the most powerful Piedmontese families, the Tapparelli d’Azeglio. Even if its primordial nucleus dates from the XII century, the main building phases transforming the complex from a defensive one to a Loisir and State Villa, took place in the XV and XVI century. In this case study, the analysis of the timber structures is particularly significant both for the great number of timber floors realized – in fact, about 2/3 of the floors existing in the whole complex are timber floors - as well as for the excellent preservation state of their majority.

The floors to be found in the castle belong to two types, the single floor and the double floors: as far as the single floors are concerned, the average net clearance varies from 6 to 6,50 m and the average distance between centres is 0,65 to 0,70 m; in the double floors, the net clearance can vary between 4,50 and 7,50, the distance between centres of the main beams is between 1,50 and 3 m and it can vary between 0,40 and 0,60 for the rafters. These floors can be further subdivided in “rich” floors, characterized by finely decorated chamfered beams resting on elegant timber brackets and by division lists of the planking- formed by boards with regular dimension – and in “poor” ones, with plain beams without any lists and with a deck formed by irregular decks.
In the castles, the “rich” floors of the State Halls – the Shields’ Hall in the Eastern Castle, the Justice Hall and the Heads’ Hall of the Western Castle - are richly frescoed with geometric and/or floral motives partly painted and partly in relief – modillions and Papier-mâché panels – nailed to a wooden support.

4.1 Diagnosis

The necessity of restoring and to make the entire complex functional required a deep cognitive analysis of the structures. Particularly, in order to evaluate the state of preservation of the timber floors, it was necessary to carry out a diagnostic investigation following a strictly specific scientific methodology, based on the analysis of the natural congenial flaws of the material as well as all actual degradation levels in order to determine the mechanical characteristics of the timber elements, acquiring in this manner a timely support for the restoration and preservation project of the structures.

The above mentioned diagnostic survey methodology is based on two distinct investigation levels:

- a first level investigation or preliminary visual inspection of the timber structures in order to evaluate the conditions of each framework and the alterations intervened during the life of the structure;
- a second level investigation, i.e. an instrumental survey, integrating the preceding investigation as it allows to analyse faults and anomalies not visible to the naked eye, and therefore only perceptible by means of instrumental devices.

For the complex of the Lagnasco Castles, the survey was carried out in coordination with the Institute for the Research on Timber of Florence (I.R.L. – C.N.R. 1998) and concerned the main beams of the timber floors of the entire complex. For each single framework, the timber species was identified, the sections were measured at the bearings, in the centre line and in the net clearance, in order to detect the height, to record the dampness values of the timber next to the beams and at a distance of a metre from the same; furthermore, the main flaws have been recorded – the fibre inclination, the nodosity, and fibre withdrawal fissuring, in order to carry out a mechanical classification based on the classification of the strength characteristics prepared by Giordano (1999); the biotic deterioration caused by fungi and Xylophagous insects has also been localized and quantified, through the investigations with Resistograph® in the area not directly accessible such as the heads inserted in the masonry. As a last thing, some disruptions have been detected.

The diagnostic investigation resulted in a different of evaluation for the preservation state of the Western and the Eastern Castle. It was ascertained that the surveyed beams are in deciduous timber (bay oak or sessile oak). In general, the structural beams of the Western Castle present greater problems due to the infiltration of meteoric water mostly next to the masonry facing west; this masonry, in its turn, passed the accumulated dampness to the beams’ headpieces enhancing the decay problems. The structure beams of the Eastern Castle do not reveal particularly serious conditions, almost surely thanks to the better airing conditions, excluding the service section located at the bottom floor of the eastern wing and excluding the Coat of Arms Hall located on the first floor of the eastern wing.

4.2 The Thematic Charts.

The results and observations of the surveys of all the timber floors inspected have been transferred on special Thematic Charts; three separate thematic charts have been drawn up for each floor, reporting the biotic and anthropic deterioration, the flaws and failures and the rheological phenomena of each inspected framework (fig. 6).

Following the recommendations of Eurocode 5, in parallel with the diagnostic investigation, a static analysis, by controlling the limit and working state, was carried out. In particular, the calculation of the maximum variable load for the flexure and in function of the inflexion camber showed valued of not less than 350 daN/m² for the Eastern Castle and 400 daN/m² for the Western Castle.
**Figure 6**: Thematic chart of the failures and rheological effect of the timber floor in the “Hall of Heads”, Lagnasco Castles.
4.3 Intervention Techniques

As far as the floor of the "Hall of Heads" (fig. 7) is concerned, even if the mechanical strength of two of the beams constituting the floor is high, it is however prejudiced by the presence of two extensive cracks in the centre section of the beam and near the masonry. These cracks are helicoidal and stretch on the lateral and lower faces for a total of 1.90 m (fig. 8).

The restoration intervention on the timber beams appears to be particularly difficult for the two following main reasons: Papier-mâché decorations applied on the lateral faces of the wooden beams are to be found at the intrados, while at the extrados, a floor of great value is present. The aim of planned restoration intervention is to maintain the original bearing function of the timber floor.

By consequence, two different intervention techniques basically different as far as the objectives to be achieved are concerned, are presented hereafter:

the first one proposes a completely retractable and visible technique; the second one proposes the non-visibility of the intervention foregoing the retractability criteria.

Both cases belong to the typology of the precise intervention carried out next to the area affected by the cracks in order to restore the strength. The two proposed solutions are:

- realisation of a trestlework tied to the beams' faces next to the lesion in order to generate a transversal compression aimed at controlling the big crack.
- Insertion of two carbon lamina into the part in tension of the beam, with epoxy glue in the area of the crack.

Figure 7 : “Papier-mâché” decoration double frame floor in the "Hall of Heads", Lagnasco Castles.

Figure 8 : Detail of the timber beam helicoidal crack in the "Hall of Heads", Lagnasco Castles.
4.4 Visible and retractable intervention

In the first instance, the intervention consists in placing a metal device on the timber beam next to the area of the helicoidal crack; the timber beam together with the bracket and the angle iron has been assimilated to a trestle system where these elements become respectively inclined rods, vertical rods and upper and lower bridle. The solidarity between the wooden beam and the metal elements is guaranteed by the alternate pull of the metal brackets. In particular, given the conformation of the reinforcing metal elements, the portion of the timber beam between the two brackets, will work like a compressed inclined rod, this implies a pressure against both edges of the crack, which will thus be contained, blocking its progress. To sum up, between the two adjoining metal brackets is the timber itself that acts as rod with the oblique wall, i.e. it acts as a hip rafter. The use of this technique is possible only if the timber beam in the areas where the metal trestle is applied can stand the stress caused by the trestlework.

4.5 Irreversible and visible intervention

In the second case, the intervention consists in inserting in previously prepared grooves in the lower part of the beam carbon fibres made integral with the beam by means of an epoxy preparation. More precisely, for each single beam, two carbon lamina in an oblique direction will be inserted next to the chamfering near the area affected by the break; among the several possible configurations, this disposition has been chosen in order to respect the decorative element. In this type of intervention, the function of the carbon lamina inserted in the beam is to resist to the traction present in the lower fibres of the beam caused by the stress of the deflection moment; in order to allow the carbon lamina to carry out this function it is fundamental to guarantee a complete solidarity, to avoid the longitudinal sliding, between the carbon lamina and the longitudinal timber fibres, by using an epoxy resin-bonding agent.

5 CONCLUSIONS

The current repertoire of new technologies related to refunctionalising or upgrading timber floors in historical or monumental buildings frequently leads to constructive procedural improvisation, which is often not coherent with the building, and to radical changes in the structural organism of ceilings and coffers. This is the case of reinforced concrete hoods, trellises and metal structures, which deprive the structural function of the timber complex. These "recovery" techniques are often not justified and present very invasive characteristics, which remove the original load-bearing function of the timber structure, relegating it to a merely aesthetic role. This is frequently the consequence of inaccurate investigations, rushed evaluations on the state of preservation of materials that are not based on a punctual scientific analysis, as well as incorrect economical evaluations. On the other hand, the increasingly frequent demand for retractable recovery interventions, in combination with the need to maintain the original structure of the work and the possibility of curing the intervention, calls for new diagnostic techniques and intervention methods from the sector experts (engineers, architects, historical heritage offices, builders).

The aim of this contribution is to analyse the timber floor that were often laid out in traditional historical buildings, it illustrates the building typologies gathered from historical treatises, records the main intervention techniques and, as a last thing, it makes reference to a particularly significant study: the Sixteenth-century timber floors in the Lagnasco Castles, richly decorated and frescoed. For this purpose, an accurate diagnostic diagnosis oriented to acquire a thorough knowledge of the timber structures, with the conviction that the knowledge of the artefact is an indispensable support for the planning of a correct intervention. The two expounded interventions, i.e. the application of a metal trestlework next to the break, and the insertion of carbon lamina in the area under tension of the beam, lead to important questions: retractable, but visible intervention are to be preferred to visible but irreversible ones? And also, as far as timber structures are concerned, is it legitimate not to openly declare an intervention carried out in case of invisible interventions? As things stand today, as far as the first solution is
concerned (retractable/visible), it appears as the more plausible one because it allows future interventions using new materials and new technologies.

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