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A Peculiar Spanish Timber Floor, the “*Revoltón*”: a Diagnostic Example at the “Palacio del Marqués de Benicarló”

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Abstract. The paper deals with the application of the Italian method for assessing on-site and diagnosing timber elements to a distinctive Spanish type of horizontal structure called “*revoltón*” i.e. jack arch floor. As in Spain does not exist a specific regulation for the on-site diagnosis of timber elements, this analysis was performed according to the Italian standard UNI 11119. Due to the peculiar features of the jack arch floor some modifications were applied to the method.

During spring 2012 the authors had the opportunity to carry out a pilot project by making a diagnostic analysis on a whole three stories building. The building, Marquess of Benicarló’s Palace, located in Spain in the town of Benicarló, between Barcelona and Valencia, was erected during the second half of the XVIII century. It maintains the original internal distribution and structure, and it is characterized by precious ceramic decorations on walls and floors. All the horizontal structures studied inside the palace were jack arch floor except the roof structure that was also made of timber.

The results of the project described in the paper clarify the specific problems of the horizontal structures and the roof surveyed during the fieldwork. These results are accompanied by several plans that represent the information recovered on-site and lead to a complete assessment of the structures. The plans include the grading based on wood defects, the local moisture content of wood, the superficial and inner decay due to insects and rot and the deformation of the joists. In this way it was possible to locate the areas of the palace where more problems were concentrated, and better understand the causes and origin of the damages.

Introduction

In the town of Benicarló, Spain, the 18th century Marquess of Benicarló’s Palace is settled in a privileged location. The horizontal timber structures inside the building are characterized by jack arch floor known, in Spain, as “*revoltón*”.

The jack arch floor is largely diffused in historical buildings, especially along the Mediterranean coast of Spain and can be considered as a main feature of the historical architecture of the area. The structure is made of timber joists, with round or squared section; the space between them, with a range of 50-100 cm, is covered by shallow vaults either made of brick or poured plaster and supported by the side surfaces of conveniently shaped joists. The section of these vaults has a segmental arch shape. The system allows the construction of quite a thin and light structure using a reduced amount of wood. The first examples of this kind of structure date back to XV century and were later largely applied up to the middle of XX century. Wood is generally local pine, in case of the old structures, or imported from USA, in floors from the XIX century onwards.

In order to assess these structures, the 2009 Spanish standard UNE 41805 IN about the diagnosis of buildings has two sections UNE 41805-8 IN and UNE 41805-9 IN that deal with timber structures and roofs. Even if their essential tables contain useful information to understand and recognize the

pathologies, there is no mention about how to infer the residual mechanical properties of the on-site timber. For this reason a pilot project about the use of Italian standards on the Marqueses of Benicarló's Palace was developed. The Italian standard for the on-site diagnosis is the UNI 11119 of 2004. The method described in this standard leads the assessment through the grading of each and every timber element and the assignation of bearing properties that are essential for the consolidation project.

Marquees of Benicarló's Palace

History of the palace. [1,2,3] Before the actual palace, the same plot used to host a building property of the military Order of Montesa. The construction was completely renewed when acquired by the Miquel family. They moved in in 1776 and, as a consequence, the classicist sober façade shows Miquel, Lluís and Polo families' coat of arms, which is the only sculptural ornament of the front as in most of noble Valencian houses of that period. Apart from the enormous portal with a stone frame, the only visible elements are the windows, the balconies, the oval openings and the top cornice (Fig. 1).

The typical internal distribution is structured among four main floors through a double staircase. On the ground floor, the attention is drawn by the double height hall (Fig. 2) that lead to the private chapel on the right and to the back yard through the carriage area straight from the entrance. The mezzanine floor hosts the masterpiece of the palace that is the original 18th century kitchen. Its walls are completely covered with hand painted tiles that depict food and dishes as well as the servants that prepared them and the masters of the house. The main floor is characterized by big chambers with tall ceilings, original tiles on the floor and the direct access to the terrace that opens to the back yard. Finally, the attic was commonly used as a ventilated storeroom and, from there, starts the small spiral staircase that leads to the flat external part of the roof.

The palace changed its name during the history: the primitive gothic building, headquarters of the commander of the Order of Montesa, received the name of "*Palacio de la Encomienda*" (Palace of the Entrusting). Later, when Joaquín Miquel Lluís acquired the construction and build his palace on top, it received the name of "*Casa dels Miquel*" (House of the Miquels). Finally, when Juan Pérez San Millán y Miquel received the title of Marquees in 1905 the edifice received the name of "*Palacio del Marqués*" (Palace of the Marquees), name that is still used nowadays.



Fig. 1. Exterior of the palace
(by Tato Baeza)



Fig. 2. Main hall of the Palace
(by Tato Baeza)



Fig. 3. Roof structure

Jack arch Floor. [4] In the construction of all horizontal structures of the palace, jack arch floors were used. This structure is characterized by a sequence of timber joists with small timber vaults that cover the spacing between them. The word "*revoltón*", a Spanish term used to indicate this kind of floors, refers to these timber vaults that link one beam to the other. The simplicity in the construction is the main advantage of this system as well as the little use of wood.

In general, joists can be made of one piece of solid squared or round wood or made up by two strips nailed to a central core. In the first case, which is the case of the Palace, timber joists are cut out so that the vaults can properly rest on them. These segmental vaults can be made of a single layer of bricks which are positioned with lime or plaster mortar without any centring or external support. The filling

between the bricks and the extrados is a conglomerate made with scrap material and lime or plaster.

In other cases, especially in rural areas and towns, the vaults between two contiguous joists are built entirely with a conglomerate poured from above after placing a timber formwork or mould beneath. These formworks are placed, taken away and moved so that all vaults can be built with only few of them.

Type of Floors in the Palace. Despite the numerous possible variations of the jack arch floor structures, in the Marqueses Palace it was possible to recognize seven traditional types and two new ones used as substitution (Fig. 4).

On ground floor most of the horizontal structures are Type 2 floor. The joists are round with a diameter between 17 and 21 cm and a maximum length of 520 cm. Type 2 floor has the typical timbrel vault made of bricks with a span of approximately 47-55 cm.

Type 1 and Type 3 floors have a double layer of boards lying on top of the cantilever beams, beneath them there are thin vaults made of conglomerate. The main difference between the two types is the beam section. In the first case the timber elements have a section of approximately 9 x 15 cm with a maximum length of 105 cm. In the second case the base of the joists vary between 20 and 21 cm with a length of 140 cm. Both these joists have two bow-tell mouldings along the whole length and a span of 56-60 cm.

On the first floor there are three types of structures with three different types of joists sections. Type 6 joists have a rectangular section which base varies between 19 and 22 cm with two bow-tell mouldings. They have a maximum length of 705 cm on top of the main hall and a span of 47-50 cm. Type 7 joists have a diameter of 16 - 20.5 cm with a maximum length of 570 cm and a span of 47-48 cm. The section has also two longitudinal cuts as decoration. The third type, Type 8, in the southern part of the floor, are simply round with the diameter between 13.5 and 16.5 cm, a maximum length of 430 cm and a span of 37-39 cm. This latter structure is different from the others because, while the vaults are made of conglomerate, there are one or two horizontal layers of bricks on top.

On the second floor, only two structures were visible because the rest were hidden behind a false ceiling. These two ceilings correspond to Type 9 and have a section of 22 cm, a maximum length of 700 cm and a span of 43 and 49 cm.

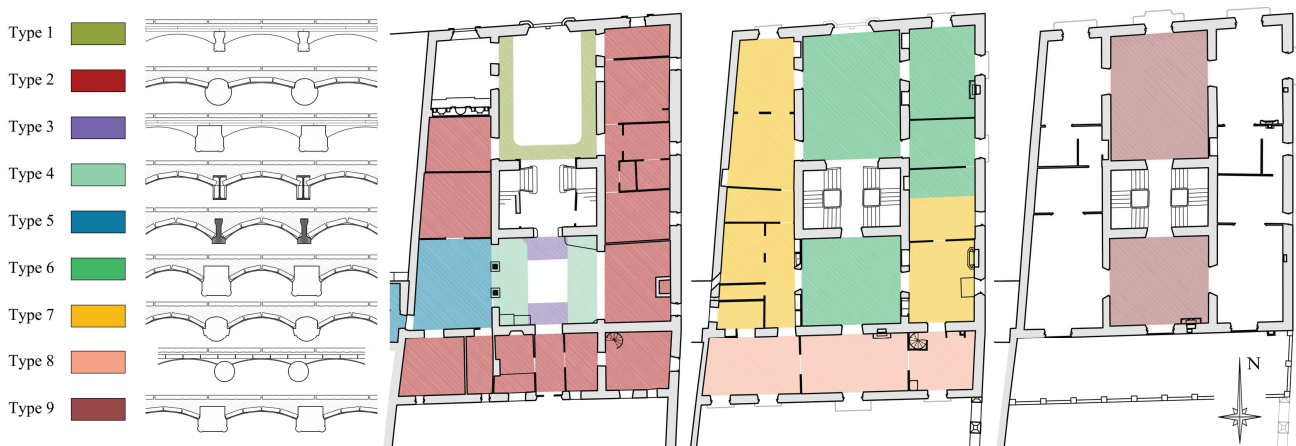


Fig. 4. Types of horizontal structures in the Palace: ground, first and second floor

Roof Structure. Jack arch floor can be found also in the roof level, for example in the structure that supports the small passage that runs around the staircase on the top floor. These cantilever joists are round with a diameter of 15-19 cm and their length does not exceed 120 cm. Likewise the rooms east of the staircase have a horizontal jack arch floor structure with 16-19 cm diameter joists and a maximum length of 535 cm. On top of this structure lays the flat part of the roof that is connected to the mentioned passage.

With reference to the proper roof structure, its features are obviously less varied than floors: the inclination is approximately 12-15° (21-27%) and the main joists have rectangular sections with their base slightly greater than height, around 35 x 30 cm, and a maximum length of 870 cm. The rafters

that lay on top of the main joists have a diameter that varies between 15 and 21 cm, and the longest is 560 cm long. The structure is completed by a sequence of battens on top of the rafters that bear directly the weight of the roof tiles with no layer interposed. (Fig. 3)

Method

Spanish Standard vs. Italian Standard. The 2009 Spanish standard UNE 41805 IN establishes the basic definitions applicable to the structural assessment and clarifies that this assessment has to be a prelude to the development of any intervention. In its introductory section, the text underlines the historical analysis and the study of the pathological process with its causes. Therefore the following points need to be studied: previous intervention on the construction, materials and their compatibility, used products, external agents that cause visible pathologies and localization of cracks.

The standard quotes: “In order to evaluate the damage, a proper diagnosis needs instrumental methods to scan and monitor. Moreover, in case of buildings with great historical, cultural, documentary and landscape significance, the study has to be completed with historical and constructive information, and the pathological processes identified, so that it can lead to a diagnosis that allows the selection of a reliable intervention. In the end, the result of the assessment will be the basis and justification of the intervention nature.”

The sections of the Spanish standard that concern timber and roof (UNE 41805-8 IN and UNE 41805-9 IN) end with a long descriptive table defining the pathologies, their symptoms, the possible localization, the cause and how to collect the data. Even if the descriptions are good and reliable, the illustrated process of data gathering only concerns qualitative kind of data, like visual localization, extension and intensity of damage.

In particular, in the “timber” section, the main non-destructive methods are listed: first the “conventional ones” like visual evaluation, hygrometer and hammer; and then the instrumental methods: ultrasounds or vibrations devices, resistographic drillings, surface impact hardness tester and acoustic detection. The list includes a brief description, but no procedure is specified so it is not possible to put the normative into practice.

On the other hand, the Italian standard UNI 11119 of 2004 is more detailed about the method that should be used in the assessment. Even if the specific descriptions of each possible problem are not included, the complete account of every operative step defines a practical method that can be put into practice on every kind of structure. [5,6]

The purpose and scope of the standard quotes: “this standard establishes objectives, procedures and criteria for the evaluation of the conservation and the estimation of the structural characteristics of wood elements in buildings considered cultural heritage, through the execution of on-site inspections and the use of non-destructive testing methodologies and techniques.”

In the same way, regarding the objectives of the inspection, the standard specifies the required analysis: identification of the type of wood species, moisture content in wood, class of biological risk (in accordance with the standards EN 335-1 and EN 335-2), geometry and morphology of the timber element indicating the location and extension of main defects, damage and degradation, the position, shape and dimensions of critical areas and critical sections, the grading of these areas according to their estimated strength. All this information leads to the interpretation of the table “Stresses and modules of elasticity for the on-site grades”, by which a specific mechanical value can be assigned to each timber element.

Assessment. A pilot project was developed in order to apply the Italian standard in the specific case of Marquees of Benicarló’s Palace, and hence carry out the work in accordance with the method described in it. The diagnosis, that took place between 16th and 20th April 2012, provided the necessary information on the state of preservation of the timber structures.

The structures included in this study are the ground and first floor as well as the roof of the Marquees of Benicarló’s Palace. The second floor was ignored because the structures were almost entirely hidden behind decorated ceilings which removal would have been prejudicial to the ornamentation of the palace.

For the purposes of a detailed description and analysis, a code was assigned to each analysed item.

Following the specified standard, the analysis started with visual evaluation and followed with instrumental analysis. The used tools included hammers, chisels and screwdrivers as well as electrical devices: electric hygrometers (type: GANN Hydromette[®]) to estimate the moisture content of the wood and resistographic drills (models: Resi[®] IML-B400, IML-PD400 and IML-F400) capable of highlight the conservation condition of wood sections that are not directly observable through visual inspection. [7]

With these instruments, the on-site analysis was performed according to these four main stages: the structural grading based on wood defects, the electrical estimation of the moisture content, the evaluation of timber condition in the beam heads with resistographic drills and the identification of surface degradation due to wood boring insects and rot. [8]

These four phases were conducted in each of the 376 items analysed; the results and the collected data were recorded on index sheets, filled for each item.

The grading was carried out through the assessment of the most important defects of the timber joists: size of the knots, grain deviation, waness, localized damages, presence of deep cracks and ring shakes. Considering these flaws, a category, from 1 to 3, could be assigned to each element of the structure. If the timber piece could not be included in any of them, it meant that was not good for structural use.

The measurement of wood moisture content was done near each one of the bearing walls because they are the most important source of moisture absorbed directly by wood. 20% is usually considered as the threshold because only up to this condition rot can develop and cause the reduction of joists sections. In addition, only in the presence of moisture, termites find favourable conditions to spread along a piece of wood.

Resistographic drills, with their thin bit, are able to penetrate wood in the beam heads where their condition cannot be inferred from the visual inspection. Considering that the areas inside of the walls are the point of the structure mostly exposed to high moisture contents, their condition was checked through two or more tests performed with the drill in order to reveal the real section of healthy wood left.

In addition, 24 samples were collected to identify the timber used in the structure. Each sample had its cross, radial, and tangential section analysed through an optical microscope. It was found that all samples were *Pinus nigra* Arnold (Fig. 5.).

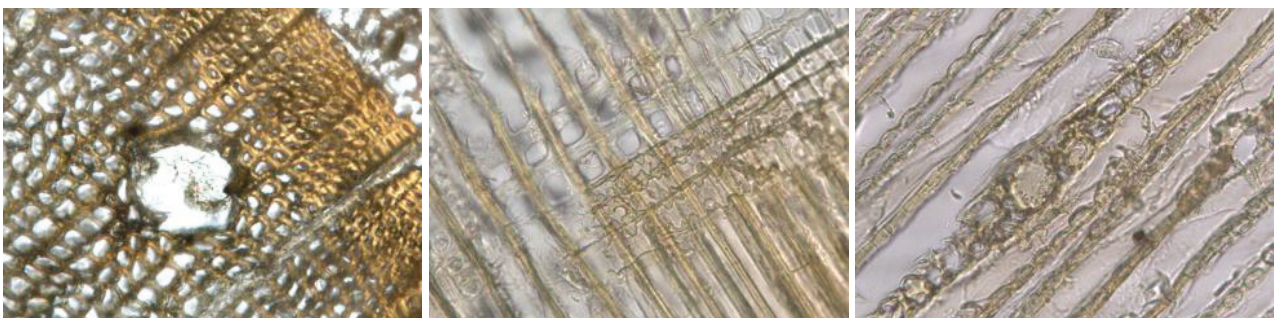


Fig. 5. Cross, radial and tangent section of a wood sample

Results

Grading. (Fig. 6) The majority of the ground floor joists had a good quality and belong to classes 1 and 2. The only problematic area was the balcony above the hall where some of them, especially on the south side, were not suitable for structural use. This was due to the fact that the section of these joists was very small. This will require a comprehensive intervention on the whole balcony structure.

On the first floor most of the joists in eastern and western rooms were classified as class 1, whereas in the south and middle area the quality was lower. On this floor, the south-east corner joists were not classified because of the bad condition in which they were found, condition that will possibly drive to the replacement of the entire structure.

The grading of the roof revealed a general worse quality of the joists compared to other levels, even if there was only one element not suitable for structural use. While the joists had bigger sections,

especially the main ones, their knots were very big, up to 11 and 8 cm. Finally all the joists holding the upper passage were non-accessible and therefore not classified, but they were clearly heavily damaged by biotic decay.

Through the table: “Stresses and modules of elasticity for the on-site grades” of the Italian standard UNI 11119 cited in the previous chapter, it is possible to link the grading with the strength of the timber elements.

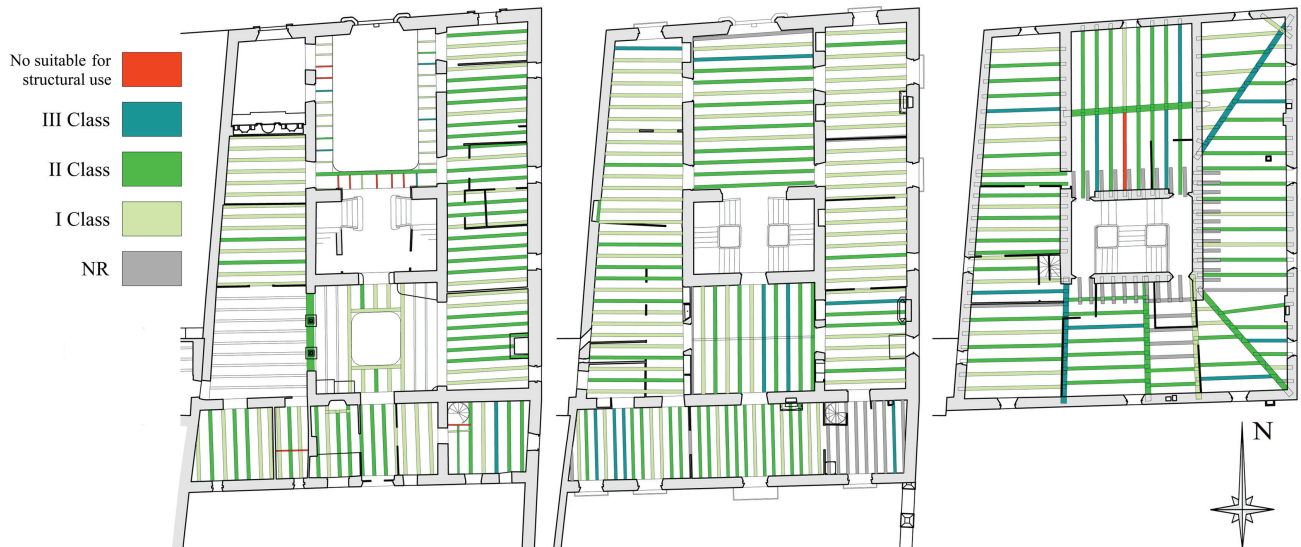


Fig. 6. Grading of single timber elements: ground floor, first floor and roof

Moisture Content. (Fig. 7) The overall distribution of moisture showed a decreasing percentage in the higher levels of the building. The number of joists showing around 20% m.c. was quite significant on the ground floor while on the roof most of the elements had less than 10% or 15% m.c..

Moisture was the biggest problem on the ground floor because, due to capillary action, walls were transformed in collectors of water. The west area of the floor had a high content of moisture, even though not higher than 20%, due to the absence of any window that caused a lack of aeration. The most humid areas were the portions of timber in the south-east room on top of the well and near the south wall toward the garden, especially corresponding to the presence of the balconies on the first floor.

On the first floor virtually all of the joists had less than 20% humidity. Nevertheless the wettest areas were still the ones in contact with the south and east perimeter wall. The causes might be the infiltration of rainwater from the balconies above and from the large terrace on the second floor. A review of the layer of superficial waterproofing of the terrace and checking its inclination is needed before any future intervention.

In the roof structure a high level of moisture was measured exclusively in some joists that were holding the upper passage because of some rainwater infiltration. All the other elements were dry because the area was extremely aerated due to the openings without closure.

Degradation of the Joists Ends. (Fig. 7) On the ground floor, the decay in the heads of the beams was quite localized and punctual. One of the main concentrations of damaged spots was visible in the eastern wall and could be caused by currently evaporated moisture: so now degradation is no longer active. On the other hand, the relation between the presence of moisture and rotting of the wood was evident in the joists that rest on top of the south east well. The most important damaged area was the southern walls where, as in the previous case, the damaged points corresponded to areas of higher humidity due to the presence of balconies in the upper floor.

On the first floor the problem was concentrated in the southeast corner along with the whole southern part of the palace. The combined action of rot and termites was detected and galleries built by those insects along walls were seen. Despite the danger meant by these insects, no animal was found alive.

On the roof the degradation was concentrated in the joists holding the upper passage; virtually all east and north joists were affected by such degradation. These problems were very deep and sharp and will require redesigning and rebuilding the entire structure of the passage.

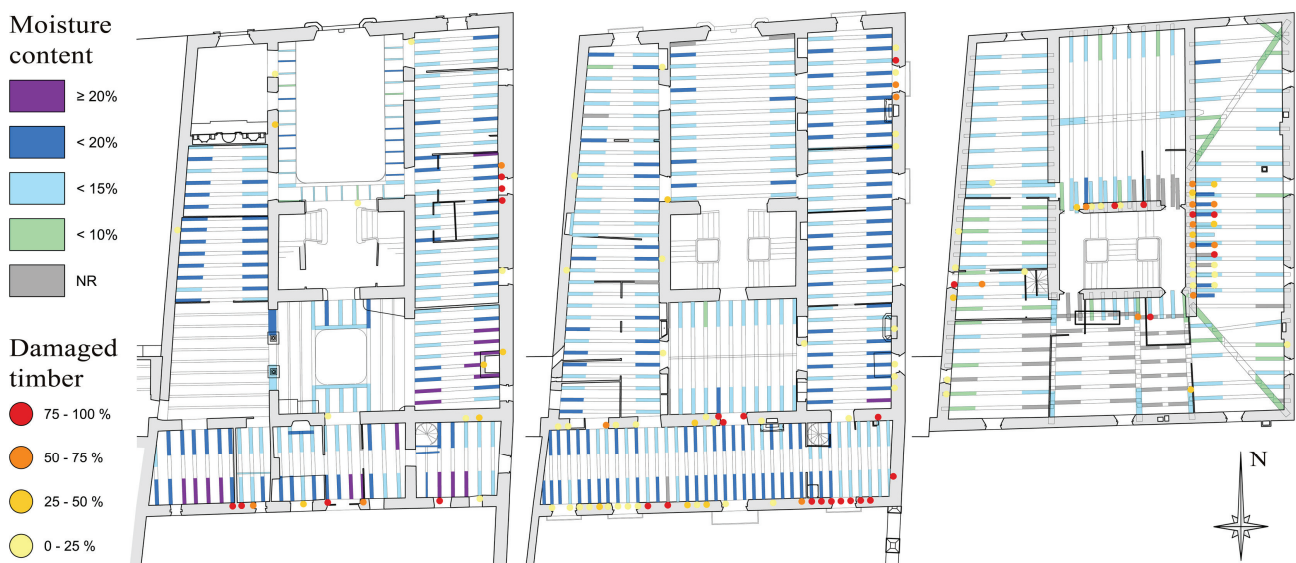


Fig. 7. Moisture content and damage in joists ends: ground floor, first floor and roof

Surface Degradation. Most of the joists of the palace showed surface degradation due to the presence of wood boring insects. The reduced dimension of the visible holes in the surface was probably caused by larvae belonging to the family of the Anobiidae from the Coleoptera order.

In some cases this attack came together with a deeper one caused by insects of the families of the Cerambycidae and Curculionidae. All these insects usually attack only sapwood. However, as sapwood in pine is a considerable percentage of the section, this surface attack has to be regarded with the greatest attention in structural analysis, because it caused a section reduction higher than 1 cm. This second kind of insects was detected and recognized because a lot of frass could be found beneath a thin layer of wood; its dark colour indicated that the attack was no longer active.

Superficial damage was deeper on the roof, as a result of open windows, and the ground floor, while was reduced on the first floor. In some cases many elements had serious problems of rot especially when the area affected was between the joist and the vault, hidden from view.

Bending Deformations. The grade of deformation was the normal expected in a historical timber structure. The deflection was measured in a sample of elements and was occasionally so pronounced that it was visible to the eye. In all the studied elements the deflection was only approximately 2% of the length and only in a couple of joists was more than 10 cm.

On the ground floor the small cantilever beams of the balcony over the main hall had the tendency to bend downward.

On the first floor, the joists characterised by the biggest deflections were those covering the main hall: this was because their length exceeded 7 m, significantly larger than any other beam. Moreover, the grading showed that many joists did not belong to the first class so it is possible that the presence of knots intensified the deformation. Many deformations could also be caused by the fact that the elements were put on site and loaded when they were still green, thus the deformation due to creep is more intense.

In the roof, the most worrying deformation was the one of the main joists that supported a lot of the weight of the structure. Despite the considerable section of these elements, their defects and the square section are the cause of the camber. The deformation is clearly visible, although it was less than 1.5% of the length and did not exceed 11 cm. These areas will need a structural intervention, not due to lack of strength, since the joists' quality was enough, but for their excessive deformation.

Conclusions

The use of the Italian standard was successfully applied and it was possible to follow it through the various steps of the assessment. The results underlined the weak points of the construction that should be taken into account for the restoration project. Due to the specific features of jack arch floors it would not be useful just to substitute a joist to ensure the proper strength of the whole structure, but it will be necessary to reinforce the entire horizontal floor, at least in the cases highlighted by the diagnostic study.

In fact, while the structure as a whole showed a general good state of preservation, it presents some important weaknesses that need a punctual solution in the restoration project.

More specifically, an intervention directed to the reduction of moisture due to capillary action in the walls of the ground floor will be necessary and the waterproofness of balconies and southern terrace needs to be checked and re-established. In any case, the southern area of ground and first floor will need a radical renovation.

The other critical points are the internal balcony over the main hall, which is not suitable for public use due to its small cantilever beams, and the passage that runs around the staircase at the level of the flat roof. In this case the degradation is so spread that there is a real risk of collapse, especially on the east side and a full reconstruction of this structure will be necessary to avoid rainwater infiltration as well. At the same level the structure of the flat roof is too slim and already presented temporary support elements so a general reinforcement seems unavoidable.

From a general point of view the whole structure and joists have to be verified considering their strength class and characteristic values to finally outline a good and informed restoration project.

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