HEaRT2015

2nd International Conference on

Historic Earthquake-Resistant Timber Frames in the Mediterranean Area

Lisbon • LNEC • December 2-4, 2015

Book of Abstracts

Edited by:
Helena Cruz, José Saporiti Machado, Alfredo Campos Costa,
Paulo Xavier Candeias, Nicola Ruggieri

Foreword

Historic masonry reinforced with timber framing is a constructive system common to many European Countries. This system has proved its high resilience in earthquake scenarios and thus its suitability in seismic regions all across the Mediterranean basin.

Numerous timber framed buildings have survived severe earthquakes with negligible damage.

Besides, timber systems, like roof and floor structures, may play a fundamental role in bracing masonry walls and contributing to the overall earthquake resistance of historic buildings.

Learn from the experience and integrate innovative approaches towards a better assessment, improvement and safeguard of these structures are great challenges. Sound commonly accepted criteria regarding safety requirements, performance based assessment and code provisions applicable to existing buildings, particularly historic timber frames, are also key aspects that deserve our attention.

The Conference covered a broad range of areas, namely:

- Assessment on site
- Historical and constructive aspects
- Physical modelling of joints, systems and structures
- Numerical modelling
- Performance based assessment
- Safety requirements and code provisions
- Monitoring
- Conservation and strengthening

H.Ea.R.T 2015 provided a forum for engineers and architects, researchers, practitioners and authorities involved in history of technology, seismic engineering, construction, assessment, modelling, conservation, reinforcement and monitoring.

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Final Programme

	2 December	3 December	4 December
9.00 – 10.40	**Session 2.a** **Opening and Welcoming Session** Welcome Keynote Presentations	**Session 3.a** **Reliability / Assessment and diagnosis** Keynote Presentations	**Session 4.a** **Historic / Traditional buildings** Presentations
10.40 – 11.10	Coffee Break	Coffee Break	Coffee Break
11.10 – 12.50	**Session 2.b** **Historic / Traditional buildings** Presentations	**Session 3.b** **Safety and codes + Discussion** Keynote Introductory presentations Discussion	**Session 4.b** **Repair / Reinforcement** Presentations 12.30 Closure
12.50 – 14.00	Lunch	Lunch	
14.00 – 15.40	**Session 2.c** **Historic / Traditional buildings** Keynote Presentations	**Session 3.c** **Assessment and diagnosis** Presentations	**Technical visit**
15.40 – 16.00	Coffee Break	Coffee Break	
16.00 – 17.20	**Session 2.d** **Timber structures** Presentations	**Session 3.d** **Repair / Reinforcement** Presentations	
19.30 – 22.00		**Conference Dinner**	

Endorsements

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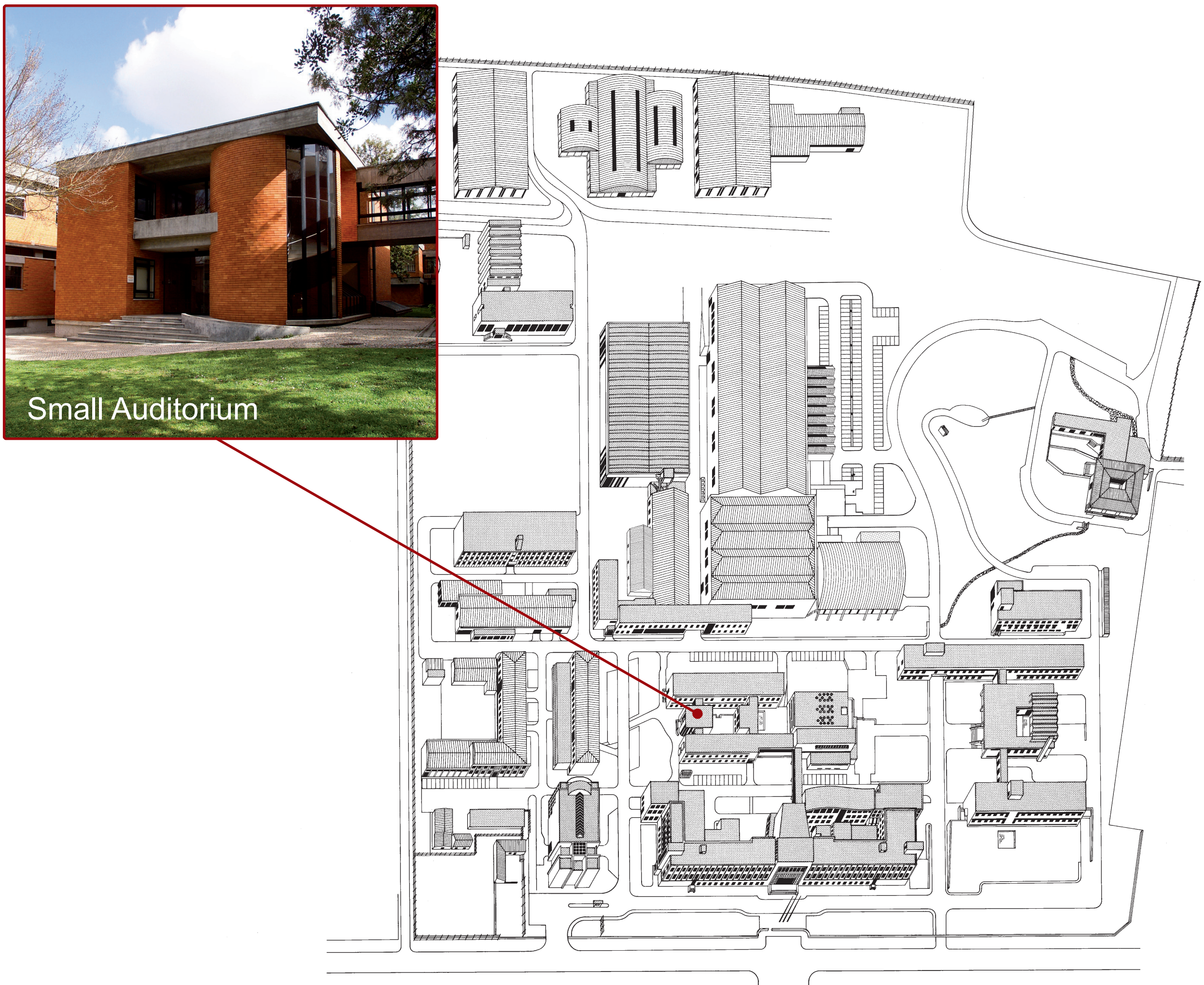

LNEC Presentation

LNEC's mission is to undertake, coordinate and promote scientific research and technological development, aiming to the continuous improvement and the good practice of Civil Engineering.

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As an independent and impartial R&D institute, LNEC's priority is to make Science, as to contribute to the creation, development and dissemination of applied research in areas related to civil engineering, such as:

- Public works: dams, harbours, airfields, roads and railways infrastructures;
- buildings;
- housing and urban planning;
- water resources, coastline and environment;
- transport;
- materials, components and other products for Industry.

LNEC activity essentially aims to the following objectives:

- The quality, the safety and the economy of works;
- the safety of persons and assets;
- the protection and rehabilitation of the natural and built heritage;
- the technological modernisation and innovation.

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Session 3.c - Assessment and diagnosis

Session 3.d - Repair / Reinforcement

Session 4.a - Historic / Traditional buildings

Session 4.b - Repair / Reinforcement

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SEISMIC VULNERABLITY ASSESSMENT OF HISTORIC BUILDINGS - THE ROLE OF TIMBER STRUCTURAL ELEMENTS

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Keywords: Seismic performance, assessment, strengthening, shaking table

The inclusion of timber structural elements in masonry buildings to increase their seismic resilience has a long tradition in Mediterranean earthquake prone regions as the result of an existing local seismic culture. Examples of this strengthening construction practice can be found in Portugal, Greece and Italy and were generally enforced by local authorities after the occurrence of destructive historical earthquakes. Two emblematic examples are the structural dual system used in the island of Lefkadas in Greece and the "Pombalino" buildings of downtown Lisbon [1, 2] (Fig. 1).

Figure 1 – A combined masonry and timber structural traditional system used Lisbon, Portugal

More cases, in Mediterranean region and around the world, showing the use of timber structural elements to reduce the seismic vulnerability of ancient buildings could also be mentioned, proving that a traditional seismic construction culture inspired the concepts and requirements underlying modern seismic construction codes, which are: lateral load bearing capacity combined with ductile capacity; redundancy assumed by a box type behaviour of the global structure providing load-path alternatives for inertia forces; architectural and urban regularity in height and plan. Many of those requirements were tackled by introducing bracing timber trusses, infilled with brick or rubble stone masonry.

Despite that, the economic pressure during the last century of urban societies towards a drastic change of the use of historic city centres promoted the degeneration of those typologies. Fig. 2 illustrates such human interventions.

Recently, being aware of the seismic risk of masonry buildings in Portugal, LNEC endorsed several experimental research programmes, not only addressing the general issue of seismic vulnerability assessment of masonry buildings, but also promoting several strengthening techniques, deemed to improve the seismic behaviour of this type of buildings [3, 4, 5].
In these studies the role of timber structural elements was taken into account. In the first two cases, improvement measures of the seismic performance of the buildings were tested. These were intended to prevent the out-of-plane collapse of the façades taking advantage of the floor timber structure diaphragm capacity as structural connecting element, thus preventing relative displacements between opposite walls. The focus of the third study was the experimental assessment of “Pombalino” cage building systems and the possibility of getting a better seismic performance by nailing flexible steel plates in the joints of the truss wooden bars.
This paper presents the aims, the approach and main achievements of a number of studies carried out at LNEC in this scope.

 a)  b)

Figure 2 – Traditional “Pombalino” buildings in Lisbon: a) removal of a masonry wall, replaced by a steel H shape steel beam; b) total rebuilding of the first floors to create a commercial open space producing the masonry wall-piers discontinuity on both façades of a “Pombalino” corner building.

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A COMPARATIVE EVALUATION OF THE RESULTS OF TWO EARTHQUAKES: ISTANBUL AND LISBON EARTHQUAKE IN 18TH CENTURY

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Keywords: Lisbon earthquake, Istanbul earthquake, timber housing.

Abstract

Earthquakes affect both urban texture and social structure of cities in history. It can be seen that in two scales such as urban scale and building scale. In this context, two earthquake examples such as the 1755 Lisbon Earthquake and the 1766 Istanbul Earthquake will be analyzed in different scales.

This paper is giving introduction to the main urban texture in 1700's consisting of timber housing structures and damages of these earthquakes. Construction system of Istanbul and Lisbon will be analyzed. In the methodology of this study a comparative evaluation of the 1755 Lisbon Earthquake and the 1766 İstanbul Earthquake will be presented.

By looking at the archive records, the development of urban structure after earthquakes has different tendencies in Lisbon and Istanbul. The first inclination is to remove the old city and re-build completely the new city as in Lisbon. By doing this renovation the new regulations are settled down. The second inclination is reproduction of the old housing construction system in Istanbul. It could be seen from both the local archive documents and European travelers' records.

The aim would be a comparative approach in order to develop and preserve the historic urban areas and historical buildings that has a potential to make an evaluation by the reflection of past to the present.

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URBAN PLANNING AND BUILDING RECONSTRUCTION OF SOUTHERN ITALY AFTER THE 1783 EARTHQUAKE THE CASE OF MILETO

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Keywords: 1783 earthquake; *Borbone* anti-seismic code; Masonry reinforced with timber frames; Seismic vulnerability.

Extended abstract

In February and March 1783, devastating earthquakes upset Southern Italy (Calabria) and caused massive damages. Almost 200 of the 391 urban centers in *Calabria Ultra* were completely destroyed or swallowed by the earth, causing over 35.000 victims. The remaining town suffered serious damages and only 3 were unscathed.

The *Borbone* government immediately began the work of reconstruction of the underdeveloped kingdom's Southern provinces. The centers that had to be reconstructed in other safer sites and those that could remain in the same place were identified.

The reconstruction plans foresaw to realize the new buildings according to the anti-seismic conception theorized by Giovanni Vivenzio, the so called "*casa baraccata*".

Mileto, an important episcopal see, was one of the first examples to be reconstructed with a predefined plan. The latter was characterised by an enlightenment inspiration and was drawn by the royalist engineers Antonio Winspeare and Francesco La Vega in April 1783, carrying out with partial changes by Vincenzo Ferraresi in the aftermath.

The new chessboard plan of Mileto (Vv) replaced the articulated medieval structure and established relations with the territory through the previous connective tissue. However, the plan did not take account of the landowners system. Accordingly, the multiple demands of the population, few inclined to change the tradition models of urban settlement and housing for a new system, influenced by the environment and the construction techniques.

Among the buildings constructed with the *baraccato* system, that required a census in order to pursue their maintenance and valorisation, the Bishop's Palace represents an interesting example for the central location (in place of the hypothetical "double-square"), the architectural features (spatial and in details) and the construction techniques (timber framed structure), despite its advanced state of degrade.
The documentation of the traditional constructive systems and a preliminary census are the main aims, in order to make aware the citizens and the Institutions responsible for Built Heritage to rediscover the architectural, civil and constructive values in view of its recovery and reuse.
This paper is part of an extensive research carried out by the Department of Architecture of the University Roma Tre, in collaboration with the ISCTE-IUL/ DINÂMIA'CET – IUL (Lisbon) and the Municipality of Mileto, with the primary aim of reviewing and documenting the Calabrian Heritage.

THE ROLE OF A POST-BYZANTINE TIMBER ROOF STRUCTURE IN THE SEISMIC BEHAVIOR OF A MASONRY BUILDING - THE CASE OF A UNIQUE TYPE OF TIMBER-ROOFED BASILICAS IN CYPRUS (15TH-19TH CENTURY)

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Keywords: Timber, Roof, Masonry, Church, Anti-seismic behavior.

Extended abstract

In the island of Cyprus there is a distinctive type of wooden roofed basilicas, dated from the mid-15th to the late-19th century AD, which, according to many researchers, is unique in the European and Mediterranean area. There are more than 130 churches of this type, all of them located in the Troodos Mountain Area, which is the highest of the two mountain regions in Cyprus.

The steep inclination of the roof was associated, mainly morphologically, with the western European roofs and was attributed to the influence by the Franks, who ruled the island from the 13th to the 16th century. As it will be suggested, this association does not take into consideration the findings of a thorough constructional analysis, which strongly links this particular roof with the eastern-type construction systems.

One close look to the geological map of Cyprus reveals that most of the 130 churches are situated within the margins of the Troodos Volcanic Rock Zone. The local stone of Troodos is so hard that it cannot be carved and used in arches and domes. It is suggested that this fact, along with the plenty timber available from the local pine forests, played the most important role in the evolution of this construction type.

These churches differ strongly from the other churches in Cyprus, not only morphologically, but also due to the uniqueness of the construction system of their wooden roof. The unique constructional feature of the wooden roof churches of Troodos is the existence of two, distinctive, but cooperating parts of the roof. The Inner Roof, a rigid triangular prism, is based on the southern and northern walls. The Outer Roof, which carries the heavy tiles, is actually suspended from the Inner Roof, and it overhangs the two long walls, protecting in this way their upper part from the rainwater.

The load of the roof is totally carried, through the two composite beams, on the southern and northern walls. In relation to the maximum compressive strength of the walls, the static load from the roof is relatively small. The main question is the way, in which the entire structure behaves, when the dynamic load of an earthquake is applied.

It is well known that masonry walls cannot resist significant dynamic loads perpendicular to their plane. In terms of vulnerability, the northern and southern walls present the lower one, followed by the wall of the Sanctuary. The lower part of the eastern wall presents significant resistance to out of plane loads, due to the hemi-cylindrical construction of the niche.

The highest level of vulnerability is presented by the western wall, due to its height, the absence of ribs, the poor connection to the roof and the lack of a significant static load. To confront this weakness, the builders placed two tie-beams in contact with the western wall, one internal and one external. Despite their awareness about the problems caused by the exposure of the wooden beam in severe weather conditions, the decision was considered critical to achieve the full co-operation of the wooden roof and the stone masonry. Finally, the tie-beams at the western and eastern end of the church are forming, along with the two composite beams on the northern and southern walls, a full timber circumferential binding.

The anti-seismic behaviour of a wooden roof structure is very difficult to be completely simulated and fully analysed by computer models, although this is currently the most accurate scientific method for approaching the truth. For the wooden roof churches of Troodos there is a unique case which confirms, in practice, the important role of the wooden roof in the overall seismic behaviour of the church.

The Church of Ayia Marina is located in the village Filousa Kelokedaron and is dated back to the 17th century. It is one of the 26 three-aisled wooden-roofed churches and one of the few that are constructed with the local calcareous stone, as it was built just outside the geological boundaries of the Troodos Rock region.

At this church a rare phenomenon is recorded, that of a gradual inclination of the entire construction, most probably due to a foundation system differential settlement. The construction's inclination seems to be increasing very slowly until today.

Some walls and arches of the church present inclination close to the limits to be overturned. Despite that, the church did not overturn until now because of the "box-like" integral behaviour of the whole structure and the corresponding stiffness of the wooden roof. This case can be recorded as an experimental simulation, in full scale, which clearly demonstrates the important role that this wooden roof system plays in confronting the dynamic loads on the entire structure.

A comprehensive constructional analysis showed that most of the characteristics of this type of construction are similar to the eastern type roofs: The timber circumferential binding ("Imantosis"), the "box-like" integral behaviour of the entire structure, the uniform distribution of the loads throughout the structure, the relative flexibility of the connections and its hyper-static behaviour. Timber roofs in the seismic area of the Eastern Mediterranean are constructed in such a way, mainly to cope successfully with the frequent earthquake phenomenon.

The timber-roofed churches of Cyprus, built between the 15th and the 19th century, fully adopt the principle of a uniform distribution of loads on multiple paths, and obtain their overall stiffness through numerous partially semi-rigid joints. To achieve this goal, this particular roof structure was developed through the years into a unique and cleverly designed bearing system, retaining a high level of simplicity in all construction details. As far as the overall structure is concerned, the timber-roofed churches of Cyprus present a unique system of co-operation between the rigid roof and the stone masonry, achieving in this way the absolutely necessary stiffness for both.

A MULTIDISCIPLINARY APPROACH TO THE ANALYSIS OF THE TRADITIONAL LEFKADA HOUSES

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Extended abstract

Traditional construction techniques in seismic areas have been characterized, for several centuries, by a very large variety of structural solutions based on the combined use of masonry and wooden elements, according to local availability and to carpentry tradition. Such techniques span from the simple use of timber elements for horizontal structures and roof systems, to wooden trusses embedded into masonry walls, in the case of more sophisticated situations.
Research works, based both on direct survey and literature studies as well, demonstrate the presence, since the Minoan era, of horizontal, vertical and diagonal wooden reinforcement inside masonry within a wide geographical area extending from the Mediterranean to the Himalayan region, wherever the seismic hazard is pronounced.
In this work, a specific study case has been selected, belonging to the vernacular architecture still existing in the Lefkada historical city centre.
Lefkada belongs to the Mediterranean Ionian Islands and is separated from the Greek mainland by an isthmus. Despite its picturesque look, the Island and in particular the homonymous capital, is characterized by a couple of critical issues: frequent and strong earthquakes and poor soil conditions. Due to the permanent need to face critical environmental conditions, the building tradition has developed efficient solutions for both the urban setting and the building design, in relation to the different realities over the Island.

This research aims at reaching two main objectives: on the one side, showing the Lefkada traditional system as a borderline example in comparison with the Turkish *Himis*, the Italian *Casa Baraccata*, the Portuguese *Gaiola Pombalina* and, on the other, understanding the construction typology behavior through a qualitative description and simplified resistance considerations.

From the analysis of literature, it appears that the Lefkada construction system was subject to restrictive definitions or misinterpretations, and above all, the seismic response has been analyzed in detail only for the above ground structure.
In this work, with the purpose of presenting a state of the art, the traditional building is briefly described, summarizing its main characteristics; this review includes also the foundation system which, until recently, has been studied only to a limited extent.
Starting from this global overview, the traditional building is presented and its resilient behavior is argued through two levels of investigation: both ~~a~~ qualitative and quantitative.

Firstly, on the basis of an interesting concept expressed by P. Touliatos in 2003, attention is focused on the relationship between the recurring frequency of the most severe earthquakes and the building

quality. Through a comparison between historical seismic data and the relative damage level a meaningful diagram is presented, which aims to offer a qualitative evaluation of the global building behavior during the strong earthquakes occurred in a specific period, ending at the beginning of the modern age.
As a first conclusion, it is possible to assume that in Lefkada, the frequent recurrence of earthquakes and the knowledge of the damage mechanisms have allowed the development of resilient buildings, allowing to keep under control the consequences that earthquakes can produce on buildings. The earthquake which took place on August 14, 2003 (M = 6.2) provided a further proof of this.
Finally, with the second step, the research intends to discuss the results coming from a simplified quantitative analytical approach. The calculations show that the value for the maximum ground acceleration is in line with the expected values for the region (in the range 0.4 - 0.5 *g*), as indicated in the 2013 European Seismic Hazard Model (ESHM13).
Although approximate, this analysis leads to a simple explanation for the system seismic effectiveness: the high value of resistance is related to the strong mass reduction in the upper levels.

The proposed analysis aims at a multidisciplinary approach, based on both a typological and structural study, with the purpose of identifying the seismic vulnerability and the potentials of this Greek construction system, which nowadays needs to be protected, further investigated and preserved.
Due to the different investigation levels, it has been possible to show that the Lefkada system is characterized by a pronounced peculiarity, at the limit of the usual classifications and, at the same time, it proves an effective behavior during earthquakes.

This study provides a multidisciplinary framework to a very complex issue: vernacular architecture in seismic areas. From both on site and archive analyses, it was possible to develop a heterogeneous and original state of the art.
In relation to these buildings, which provide the only surviving example of the building tradition in the Ionian Islands, the preservation need is accompanied by the interest to acquire a deep understanding of the conceptual design, as well as of the real resources of the building system.
This study offers a starting point from which to develop further analyses. This issue, indeed, has been so far investigated to a limited extent, although it touches several disciplines.
The continuation of this research will concentrate on the following topics: the analysis of historical seismicity through the transcription of the documents found in the archives of Lefkada, Venice and London; the analysis of the soil-structure interaction, including also the foundation system; the analysis of materials and their origin, in particular, the mortar mixed with pozzolan.

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TRADITIONAL TIMBER-FRAMED INFILL STRUCTURE EXPERIMENTATION WITH FOUR SCALES ANALYSIS (FROM CONNECTION THROUGH TO A HOUSE SCALE)

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Keywords: earth, Seismic-resistance, Earthquake, Timber, Shake-Table, DIC

Abstract

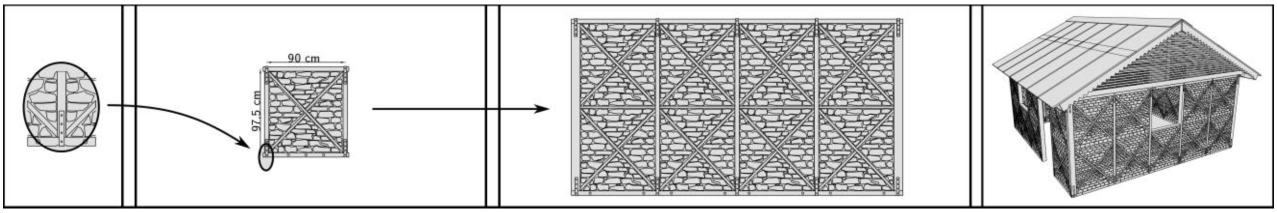
Timbered masonry structures are popular worldwide mainly for their reduced construction cost, thanks to the use of local resources and know-how, as well as for their aesthetics and/or ability to achieve greater resistance to seismic forces. But unfortunately, these kinds of structure are actually forsaken by local people and by decision-makers because the lack of knowledge of their behaviors and the lake of building code and standards to design its. The aim of this paper is to contribute toward a better understanding of the seismic behavior of timber-framed infill structure.

For this purpose, the results of four scales of experiments during which cyclic, monotonic and dynamic loadings are considered (Fig.1). The type of construction studied herein is a timbered masonry structure adapted from Haitian heritage, called “Kay peyi”. The infill material is stonework bound by an earth-based mortar. This type of structure has already been built in Haiti as part of various local reconstruction projects (i.e. Misereor, SC/CF projects in collaboration with the CRAterre Laboratory and local partners, including the Haitian NGO “GADRU”, Entrepreneurs du Monde).

At the connection scale, tests are performed in both normal and tangential directions. At the elementary cell and shear wall scales, push-over and reversed-cycle tests are performed to obtain the hysteretic behavior as a function of infill characteristics. Lastly, shake table tests are carried out on a full-scale of Haiti traditional rural houses is presented and discussed. Classical measurement are used to follow movements of the house (LVDTs and accelerometers) and hight speed camera is added to measure the full-field displacement of a shear wall of the house.

The innovation in this paper is to prove the feasibility of this measurement into a large sample which have real dimension of a house's wall (9.3 m^2) and under a seismic loading applied by a shake table (Figs.2 and 3). To validate the DIC analyses, a comparison is made from the displacement recorded by LVDT. The difference between the two measurements was less than 5%. The powerful of the DIC method give new perspective in the engineering structure analysis.

The experimental multi-scale analysis provides a direct proof of he seismic-resistant behavior of a filled timber-framed structure. Specially at the scale 4, the house displayed a good resistance when submitted to a ground motion equivalent to the January 12th Haiti earthquake. No damage was observable.



Scale 1	Scale 2	Scale 3	Scale 4
Joint	Elementary cell	Shear wall	House

Fig. 1. The four scales of this experimental study

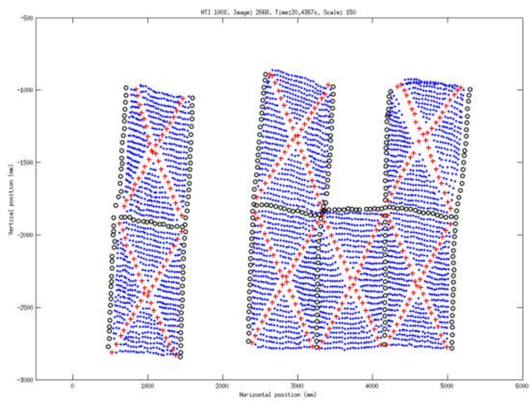


Fig. 2. Deformed configuration with DIC measurement

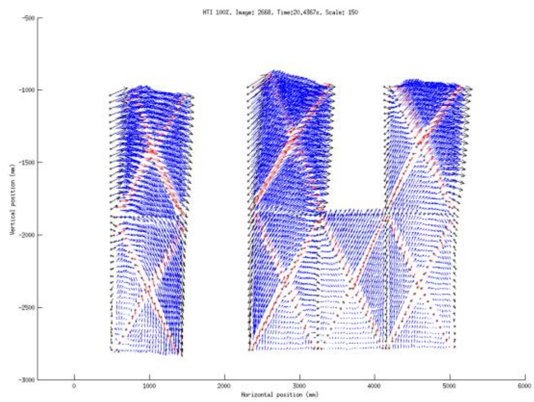


Fig. 3. Vector displacement with DIC measurement

LOCAL SEISMIC CULTURES: THE USE OF TIMBER FRAME STRUCTURES IN THE SOUTH OF PORTUGAL

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Keywords: Pombalino construction system, Vila Real de Santo António, Local Seismic Culture, Seismic vulnerability, structural alterations.

Abstract

The well-known timber frame *Pombalino* construction system was devised after the 1755 Lisbon earthquake by the Portuguese government and its use was mandatory for the complex reconstruction process carried out in the city. It can be considered as the first technical regulation regarding seismic resistance. However, its use was not limited to Lisbon and the system was also embraced by local communities, which adopted it as a model of earthquake resistant construction. Its use thus spread around the country and eventually took root in the vernacular way of building of the country, becoming part of the Portuguese Local Seismic Culture. Nowadays, *frontal* walls can be identified in many vernacular constructions scattered across the country. This paper studies the use of *frontal* walls in vernacular buildings in the South of Portugal, which is the area with highest seismic activity within the country.

The paper particularly focuses on the city of Vila Real de Santo António, which was chosen as the main case study. This singular city is located in the Algarve region by the Spanish border. It was planned and erected *ex novo* at the end of the 18th Century, following a carefully planned *Pombaline* development that showed a clear seismic concern. Specifically, construction works included the provision of timber frame partition walls for some of the buildings, following the example of Lisbon. An overview of the extended use of *frontal* walls in many buildings in the historical city center is provided.

Nonetheless, the original *Pombaline* city center is nowadays deeply altered and another main research question arises whether or not and to what extent have these changes on the original plan affected the seismic vulnerability of the city. One of the most common alterations observed was the elimination and substitution of the *frontal* walls. The paper finally discusses the possible negative effects of the abandonment of this distinctive technique resulting from the Portuguese Seismic Culture on the overall vulnerability of vernacular constructions. The efficiency of traditional strengthening techniques resulting from Local Seismic Cultures has been successfully tested by time and they can be recovered to preserve and retrofit surviving vernacular architecture examples.

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THE USE OF WOOD WITH AN ANTISEISMIC FUNCTION IN THE ARCHITECTURE OF PALERMO DURING THE 18th CENTURY

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Keywords: Sicily, 18th century, earthquake-resistant frames, wooden structures

Extended abstract

Sicily, as it's known, is a seismic region, as witnessed by the many earthquakes that have affected the island over the past centuries.

The earthquakes that struck Palermo in 1726 and 1751 forced technicians to reflect upon the seismic validity of traditional constructive solutions, representing an useful occasion for considerations about the "well-built way".

The damages imposed the reassessment of materials and constructive techniques: the secular inertness of local buildings was interrupted by original practises, result of the union between the simplicity and economy of the building yard and the initiative of a class of engineers and architects that - from the affiliation to Religious Orders - derived an over-regional technical culture, able to better investigate the relationship between earthquake and the effects on architecture.

The study analyzes the post-earthquake interventions in the historical buildings after these two dramatic events, with a particular attention to the demolitions and reinforcements, and also with a specific regard to the way to make risk-free the historical buildings.

From the direct and documental analysis we could gather how, in the urgency, it was often simple to turn to unusual techniques, that will be amply utilized also beyond the earthquake damages, so to constitute a growth of technical culture.

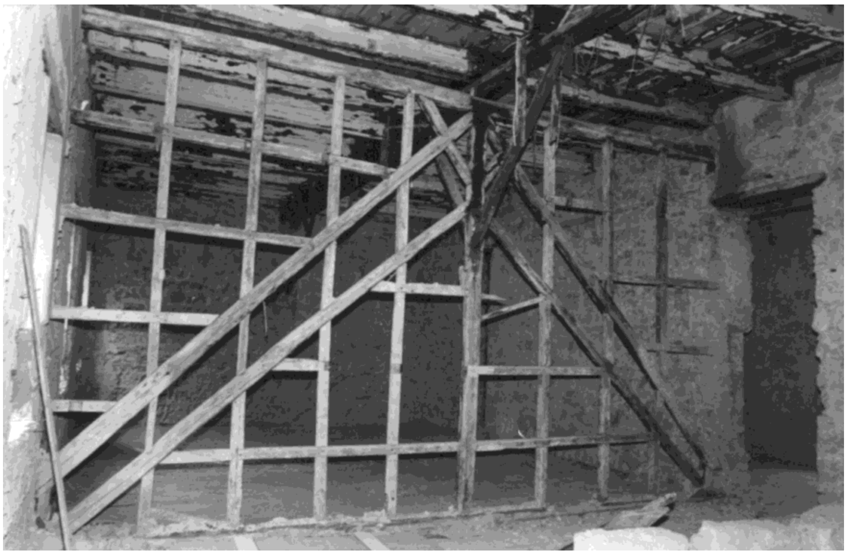
The research, based primarily on archival documents, focuses on a series of interventions in the architectural heritage, in which the use of wood for structural elements, was able to guarantee for an "antiseismic" reconstruction.

Although wood was not commonly used as other materials (iron, for instance) in the post-earthquake reconstruction process in the city of Palermo it was certified its use as an anti-seismic system in the reinforcements of the damaged buildings. Its lightness and elasticity, indeed, made it a versatile material, suitable for different applications.

It is documented, for instance, the insertion of wooden beams, used similarly to iron chains, both in monumental buildings, and also in the less valuable ones, useful to provide a better cohesion for the masonries, or the introduction of wooden and lightweight partition walls; or, even, the substitution of stone vaults with vaulted wooden structures or ceilings and the realization of staircases using wood for the entire main structure.

This study would also investigate the role of architects and workers involved in the reconstruction of the damaged buildings and it would give a particular attention to the experimentation of new

constructive systems, precisely using wooden frameworks, focusing on some particular constructive examples applied on churches, palaces and also on the diffuse built-up historical area.
This study demonstrate how in the eighteenth century Palermo and Sicily were fully incorporated in the great plan of post-earthquake reconstruction, and how the technical culture was able to adapt the established knowledge of the "rule of the art" to the trials and the technological evolutions that the reconstruction was able to activate.
There is, therefore, an extended repertory of study-cases and applications, that testify a constructive heritage to know and preserve; this baggage of knowledge, indeed, could actually address the designer and technician occupied in the maintenance and recovery and restoration of the historical buildings of Palermo to better recognize and identify these reinforcement systems.



Wooden systems for ceiling support and lintel of openings and lighten partition wall.

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COOPERATING TIMBER AND STONE ANTISEISMIC FRAMES IN HISTORIC STRUCTURES OF GREECE.

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Extended abstract

On the western part of the Kefalonia Island, at the eastern part of Lixouri Peninsula, a Historical Building, called "Samoli Mansion", dated back approximately to 1670, is located.

The structure of great historical and constructional interest, withstood successfully three catastrophic earthquakes of 1768, 1867 and 1953 until the earthquakes of 26th of January and 2nd of February 2014, during which it partially collapsed. During following months a systematic analysis of the monuments failure mode was carried out proving, finally, that the main reason of the destruction was the wrong repair intervention, after the disastrous 1953 earthquake, which neutralised most of the protective antiseismic techniques realised over 300 years ago. It seems, also that the Venetians had observed and understood the benefits of the local constructional system during severe earthquakes, constructing one of the best examples surviving today.

Apart from the building's indisputable historic value, it actually constitutes a rare example, for Kefalonia, of double load bearing structure that functions simultaneously and that, in the event that one of them fails, the other bears the full load until the first one is repaired. This system can be widely found on the island of Lefkas (with some variations as it was recently highlighted), on the island of Mytilene, and features of this system can also be seen in the architecture of Mount Athos etc.

The main concept behind this double anti seismic system of the load bearing structures is the following: Masonry walls made of, usually, rather good quality stonework, transfer the loads of the wooden structure of the floor and the roof, which were also simultaneously supported by a row of wooden posts placed in parallel position and close to the masonry by means of a corresponding wooden beam which was based on them.

When, during the severe and frequent earthquakes in the region of the Ionian Islands, parts of the masonry fail to function properly, then it is this second parallel system of wooden skeleton frame which takes over the load transfer, until the masonry is repaired. Moreover, this system has demonstrated very advanced and detailed connections of the wooden load bearing structures, which have pre-scheduled absorption capacity of considerable amount of the dynamic energy released by the earthquake. Therefore, this enables the structure to absorb the incoming seismic energy during the rather severe and frequent earthquakes in the region of the Ionian Islands avoiding, however, the building's failure or collapse. This system, one of the main European Antiseismic Constructional Historical Methods, as it is nominated by the Council of Europe, PACT 19, uses mainly timber frame in close cooperation with masonry.

The soil on which the city of Lefkada is built is very unstable. For this reason, good foundations were crucial. Unfortunately, it is not easy to locate some examples that would give us a more precise image of the construction. However, from the descriptions of the inhabitants, we know that it is a system of grillage, consisting of tree logs, placed on successive layers at a depth of 0.70m to

1.0m or even deeper under the soil surface. The gaps between the logs were filled with sand, non-hammered stones and "portsolana". In the case of the “Samoli Mansion”, which is actually built in the shallow water on the eastern shore of the Argostoli Bay, for defensive reasons, the foundation consists out of large stones carefully located in layers on the sand of the sea bottom.

The load-bearing walls of the ground floor in Lefcas are made of stone. Sometimes the external walls of the second floor are, also, built in stone. That is the case of the “Samoli Mansion” in Kefalonia where, additionally, the ground walls present, externally, a gentle inclination towards inward, relevant to the Venetian manner of walls building.

These masonries do not have timber horizontal reinforcements on their body — typical almost all over Greece-, apart from the heading circumferential binding that supports the wooden frame of the upper levels. The wooden skeleton of the upper levels is supported on these stone masonries. It is supported with diligence and thoroughness through wooden roof or floor sleepers built inside the wall and running along the outline of the masonries. Iron anchoring of several types links the masonry with the wooden frame, of the roof or the floor, or with the wood-fitted walls of the upper level stories.

A secondary, auxiliary load-bearing system consisting of sparsely arranged wooden columns, just behind and parallel to the exterior stone masonry, supports the floor and roof levels. During the destructive earthquakes, when parts of the masonry collapse, the building continues being supported on the secondary auxiliary wooden load-bearing system until the damage is repaired. This auxiliary wooden frame contains a system that increases its rigidity (via proper connections). It is known that the extended failures of the masonries mainly appear in those that are perpendicularly placed to the main direction of the earthquake and the rest, even broken, contribute to the rigidity of the whole construction.

All construction details prove the attempts of the traditional builders to ensure the minimum rigidity required on the auxiliary wooden load-bearing system of the ground floor, when part of the masonry fails.

The location of the upper floor's external walls was mentioned earlier. These are built on the floor beams and towards the external side of the masonries. First a sleeper is mounted along the perimeter. On the small sides, this sleeper is the same, as mentioned, as the extreme "patomatero". On the longer sides, it is placed perpendicular to the "patomatera" and level with the sleeper that lies underneath them. The whole construction ensures the transfer of the loads of the overlying structure to the masonry and the interior columns.

Both, on the upper and lower parts of the corner columns, the "corners' are nailed. These are fixed using nails and grooves and face alternately inwards and outwards from the building. The upper sleepers of the walls are fixed on them. In the case of a second wooden level, these sleepers support its floor, otherwise they constitute the base for the roof. The "corners" on the connections of the wall are followed by the "meintania". These are diagonal wooden elements that also contribute to the wall's rigidity. Their proper function is based on their correct placement: the "meintani" usually starts from the base of the upper

"corner" of a corner column and ends at the lower part of a middle column, at the middle of the "corner". In this way, the corner formed is approximately 45 degrees and the sliding of the diagonal element is eliminated.

Roofs harmonize with the rest of the earthquake-resistant structure. Efforts are made to strengthen and increase the rigidity of the joints of the various roof elements by means of “corner” use. Moreover, through the construction of the roof, a connection between the exterior walls is attempted. The hyperstatic “Post and Beam” construction method is used.

This study, once more, proved that the recently well studied traditional Antiseismic Constructional System of Lefcas Island was known and followed, at least 300 years ago during Venetian occupation, not only on that island, but also on the central and the largest of the Ionian Islands, Kefalonia. This constructional method emphasises the significant role of timber in achievement of high structures performance under severe dynamic loading.

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SEISMIC VULNERABILITY OF BORBONE MASONRY REINFORCED WITH TIMBER FRAMES

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Keywords: Borbone system, masonry reinforced with timber frames, anti-seismic engineering, quasi-static cyclic tests, non-linear dynamic modelling

Extended abstract

After the 1783 earthquake, under the Borbone reign, new building regulations were introduced in the Calabria region (Italy) with the main scope of reducing the seismic vulnerability of the building asset in these highly seismic areas. The Borbone system, masonry walls reinforced with timber frames, pursued, among various constructive principles, building height limitation, symmetry in plan and elevation and above all proper connections between the load bearing elements. Such criteria represented innovative and modern rules for the best practice of the time for buildings in a zone with high seismicity. These Borbone measures concerning improved earthquake behaviour of buildings are recommended in the *Istruzioni per la ricostruzione dè paesi diruti della Calabria*, the Borbone Construction Practice Code [1].

In order to maintain, repair or retrofit these buildings, it is indispensable not only to understand their qualitative performance under an earthquake loading, but also to gain quantitative information on stiffness, load bearing capacities, energy dissipation capacity and failure modes. For this purpose, quasi-static cyclic tests on typical Borbone shear walls mirroring as exactly as possible a wall of the Palazzo Vescovile in Mileto (Italy) were carried out. However, cyclic tests on shear walls cannot provide information on the sustainable level of seismic action of the investigated buildings.

This paper presents first investigations on the seismic vulnerability on simple Borbone structures where modelling assumptions such regularity in plan and elevation hold and only one shear wall system was used. The quasi-static cyclic test results were used to develop a non-linear dynamic lumped mass model of a Borbone case study building which was developed following Borbone building regulations and which was subjected to various earthquake accelerograms. By increasing the single earthquake's peak ground acceleration (PGA) value, the seismic performance of the investigated historic structure could be evaluated.

Based on the cyclic test results, a shear wall model was developed using stiff beam elements, lumped masses and non-linear springs. After calibration, the shear wall model has been upscaled to be re-used in a full-scale model of the Borbone case study building. All deformation of the shear wall model has been assigned to horizontal behaviour. The uplift, which was smaller, has been neglected. The springs were calibrated on the cyclic test results; only these springs represented the behaviour under horizontal cyclic loading. The timber frame was modelled as being

rigid in order to be sure that only the springs are working. The masses were added as lumped masses on the upper nodes of the walls. All energy-dissipating hysteretic behaviour including also additional contributions from friction was represented by the rotational springs.
The Florence pinching hysteresis model [2] as shown in Figure 1 on the left was used which has been implemented in the finite element software DRAIN 2DX. All necessary stiffness, displacement and force parameters, in total 9 parameters, were derived from the experimental hysteretic curve and iteratively calibrated, until the global load-slip graphs of test and model showed a good agreement, Figure 1 on the right.

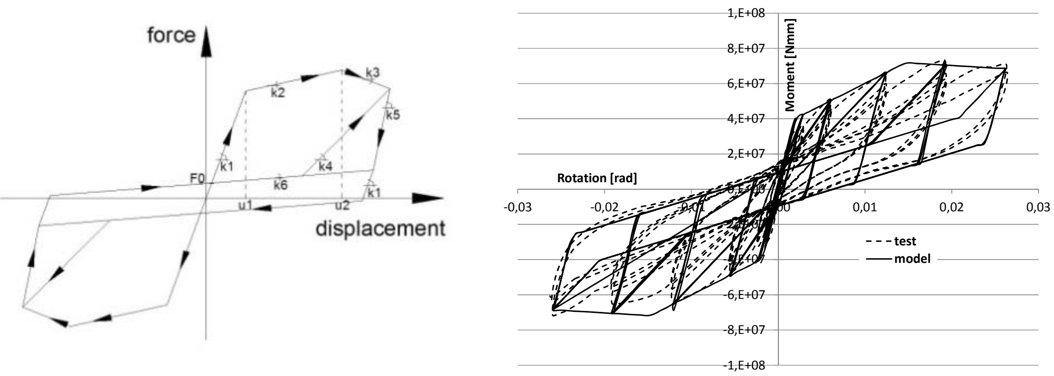

Figure 1: On the left: Florence pinching hysteresis model with six inclinations K1 to K6. On the right: Overlap of cyclic tests on Borbone wall and numerical model.

The finalised 2D building model shown in Figure 2 on the left has been subjected to different accelerograms whose PGA has been increased until the near-collapse criterion of the building has been reached. This near-collapse criterion has been derived from the cyclic tests and was a maximum horizontal interstorey displacement value of 80 mm corresponding to 2.71% drift.
Hence, as soon as a maximum interstorey drift of 80 mm has been reached, the calculations were interrupted and the actual PGA was considered as being the PGA at near collapse. Figure 2 on the right shows the modelling results for various earthquakes.
The Borbone case study tackled in the present paper has reached high values of the PGA at near-collapse state for many of the considered earthquakes confirming the good performance shown in the quasi-static cyclic tests. In fact, if the Northridge earthquake is excluded, for every investigated earthquake, the maximum sustainable PGA satisfies the minimum values required by the Italian *seismic hazard zonation map* for the Calabria region, in which the maximum PGA, whose probability of 10% exceedance in 50 years at 84th percentile referred to rock or stiff soils, is 0.3g.

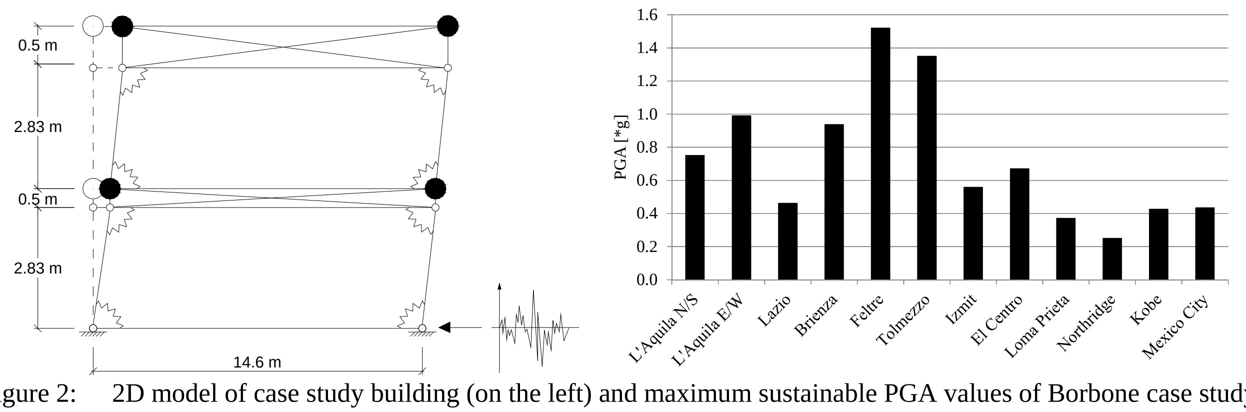

Figure 2: 2D model of case study building (on the left) and maximum sustainable PGA values of Borbone case study (on the right).

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SOME EXAMPLES OF TURKISH HOUSES WITH WOODEN FRAME IN THE SEISMIC ZONE ANATOLIA

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Keywords: Turkish houses, wooden frame construction, Anatolia, earthquake zone

Abstract
When the Turks first entered Anatolia in the 11th century, they used the kinds of houses found there, but it is seen that when, in the 16th century, they began to expand even further and entered the Balkans, – they began to construct courtyard homes with exterior/open air *hayat*s and *sofa*s /halls. Influenced by a combination of their nomadic life style, their adopted religion of Islam, and the local cultures of Anatolia, this unique Turkish style of courtyard house remained popular up to the mid-nineteenth century. This housing space includes a *hayat*, a semi-open space extending in front of the rooms of the house, providing both shelter and a natural environment. The upper level rooms are also accessed through this *hayat*. These semi-open hall or *hayat* houses were traditionally varied according to choices of *eyvan* / iwan and kiosks, but beginning from the 18th century, the spaces between these rooms began to be enclosed, thus protecting them from the exterior elements, resulting in plans that included “inner” and “middle” sofa spaces. While there are variations according to plan types, Turkish houses always were constructed with a wooden framework. Multi-floored Turkish houses of Anatolia with sloped roofs and wide eaves were mostly constructed in forested areas on the seashore, in inner regions near the shore and in regions where the central government was in control.
There is available only very little information and statistics relative to the Anatolian Turkish houses that existed between the 13th and 17th centuries. In other words, extant historical records tell us that the Turkish House with *hayat* developed during the 13th and 16th centuries, but we have no firm clues as to the stages of this development. The earliest examples of Turkish Houses with *hayat* that survived to this day belong to the 17th century.
However, based on the documented examples of 17th century Turkish homes that remained standing until the mid-20th century, we understand that the outer walls of the 16th and 17th century houses were built of stone or mud-brick, that the interior walls of the upper level rooms of these two story structures were wood framed, with open-air halls/ *hayat*s, and primarily consisted of two or three rooms and sometimes *eyvan*. These houses had a single facade that overlooked the courtyard. We can describe these houses as being isolated from the street. As the techniques involved in wood-frame construction advanced, the exterior facades of the upper storey began to be built with wooden frames filled-in with mud-brick.
By the middle of the 18th century we see both a continuation of the *hayat*-plan house and the introduction of houses in which rooms have been built at both sides of the *hayat*. This development both isolates the rooms from the outside and introduces an inner-hall/*sofa* plan.
The changes that began in the 19th century in urban centers also affected changes in the form of the *hayat* house. Homes accessed directly from the street began to be built on smaller land parcels, *hayat* was became a central location surrounded by the rooms. The *eyvans* were either

enclosed, making them into rooms, or were discarded altogether. To provide illumination in the *sofa*, *eyvan*s were positioned at the corners of the rooms, or between the rooms. Those homes with four eyvans became the most developed type of the central-*sofa* type house, becoming a cross-patterned *sofa* plan.

Wood always represented the primary building material of the Turkish house, with a preference for wood framing. This system was preferred for reasons such as its being light, providing the opportunity of multi-stories being built, creating variety in architectural solutions, providing climate control, necessitating fewer wooden materials in comparison with the massive wooden system, rapid construction and suitable for Anatolia which is in an earthquake zone. Alongside wooden material, mud-brick and stone were used in the construction of the houses. In Anatolia, generally the space in the wooden frame system was filled with mud-brick, stones or bricks and these buildings were called *hımış*. Sometimes the houses were built in which wood and trees branches were used for fill and sometimes the inside of the wooden frame was left empty. In wood frame wall that was not filled, on the inner and outer facades over the frame, the construction was nailed down thin half-batten / *bağdadi* horizontally and at intervals and plastered or the interior facade was made covered with *bağdadi* and plaster and the outer facade was covered with wooden boards.The houses were completed generally with wide eaves and hipped roofs. In the past the roof covering was created out thin pieces of wood known as *pedavra* and set with stones, saying, ‘Don’t let it fly away in the wind’; because of fires later Turkish style tiles were used .

Anatolia is in the second degree earthquake zone. It is understood that there were the wooden frame buildings on account of the examples that have been able to survive until today of the type of building most suitable to the region that has experienced innumerable earthquakes throughout history. What a pity it is that the 16th century examples of partition frame Turkish houses with *hayat* have not survived until today because their importance still was understood in our country at the beginning of the 20th century.

In the wooden frame construction system, the diagonal braces that supported the post and base crosswise was especially set in the corners, the frame elements like the base, post, beam diagonal brace and bracket were attached to one another with iron nails both dove-tailed and pounded, with the help of the bases the connection established between the wooden frame system and the stone walls increased the sturdiness of this system against earthquake. In addition wood as a light and elastic material reduced the loss of life during an earthquake from the damage created because of material being old, rotten and neglect. In conclusion wooden frame buildings made of wood that is a natural material that can be renewed and turned for centuries both resisted against earthquake and provided for the continuation of traditional building techniques.

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THE MASONRY TIMBER FRAMED LOAD BEARING STRUCTURE OF "BARACCATO" SYSTEM: A NUMERICAL MODEL

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Keywords: 1783 earthquake; Masonry reinforced with timber frames; stiffness, strength, ductility; mathematical models;

Extended abstract

The constructive system of "baraccate" houses, invented after the earthquake of 1783 in *Ultra Calabria*, was used in the reconstruction of several towns and villages, partially or completely destroyed by the earthquake, immediately after the earthquake and in the aftermath until the advent of reinforced concrete constructions. So it is widespread within that territory, even though a census of the whole "baraccato" architectural heritage is still lacking. Given the large regional seismicity, seismic vulnerability of this architectural heritage needs to be evaluated.

The building system is composed of load-bearing walls, resulting from the interaction of a wooden frame with a load-bearing masonry made of irregular stone blocks or bricks, linked by no-cement mortar and arranged according to a pseudo-squared texture. Within the literature [1] there exist some experimental texts aimed to investigate the mechanic behaviour of this wall under cyclic loading, and evaluating its stiffness, strength and ductility. It is hardly worth noting that, given the variability of both masonry and the wooden frame, the presence of openings, the geometric dimensions etc, the test carried out on a single wall has practically the only function of calibrating some general mathematical models, in order to be able to predict the mechanical behaviour of a generic "baraccata" construction. Mathematical models for masonry materials are massively present in the scientific literature for walls characterized by periodic arrangement: these are primarily continuous models with constitutive functions obtained through homogenization methods, in order to incorporate information on the

constituent materials, the size and the geometric arrangement of the units [2]. Continuous models for irregular walls are practically still lacking.
Conversely, when the wall has an irregular texture, the use of discrete systems prevails, where the wall is modelled as a collection of rigid or affine-deformable bodies, interacting through interfaces – the mortar joints -where the whole non-linear mechanical behaviour is concentrated, and characterized by poor tensile strength, not irrelevant compression strength and shear strength governed by Coulomb's friction law [3]. Joints with different constitutive behaviour characterize the interaction between the masonry and wooden frame. Particular attention has been paid for modelling the behaviour of the half wood joints.

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ASSESSMENT OF THE MECHANICAL BEHAVIOUR OF TABIQUE WALLS THROUGH EXPERIMENTAL TESTS

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Keywords: Timber walls, experimental testing, compression strength

Abstract
The present research aims assessing, experimentally, the compression mechanical behaviour of a particular type of timber walls that is frequently present in old masonry constructions in Portugal and referred to *tabique* walls. The main motivation for this study is the lack of data on the behaviour of this type of walls that causes, quite often, interventions that consider their full substitution by new elements. The work consists on constructing 4 full scale specimens that were after tested at the Laboratory of Earthquake and Structural Engineering of the Faculty of Engineering of Porto University to measure the compression strength and buckling behaviour under no initial damage conditions. The results were also compared to numerical simulations using SAP2000 software.

Objective
The rehabilitation of old buildings is becoming a priority in Portugal. It's a process that demands the full understanding of the state and behaviour of the materials and structural elements that constitute these buildings. Among these elements, timber walls made of vertical and, sometimes, diagonal boards, and referred to *tabique* walls (TW), are present in most of the buildings built till the 40s-50s of the last century in Portugal and represent a very important constructive and cultural element. In spite of that, these walls are often seen as secondary replaceable elements with no significant mechanical value, a belief that makes research and technological development on the assessment and rehabilitation of TW to be still quite limited. Most of the research already done consists on the assessment of the different layouts and components of TW from buildings located at the Northern part of Portugal. In particular, this research involved the evaluation of the dimensions of timber boards, laths, lintels, braces and the way they are jointed (nailed) and linked to floors and ceilings, and the assessment of their materials and/or mechanical characteristics. Recent studies have simulated numerically the mechanical behaviour of TW under vertical (considering lateral buckling) and horizontal in-plane forces, acting separately. The results estimated a performance that goes far beyond what was initially expected for a constructive element that is commonly considered to be just a partition element with no structural functions, namely that a good in-plane (vertical and horizontal) bearing capacity may be foreseen. However, these numerical results still needed

experimental support. Thus, the present research aims assessing the compression behaviour of TW through experimental testing on full scale specimens, contributing also to a higher appraisal and preservation of timber walls. This campaign was followed by the numerical simulations of the specimens using the SAP2000 software.

Research and conclusions

TWs are commonly used as interior partition walls and are often considered as non-structural and low resisting elements, having no ability to contribute to improve the overall performance of the buildings. These walls, which are quite slender (height to thickness ratio usually greater than 20), are mainly made of vertical timber boards juxtaposed with a gap of around 2cm, that may be framed and/or diagonally crossed (cutting or not the vertical boards) by thicker planks. This timber vertical structure is usually covered by a series of horizontal wooden laths nailed on the boards that improve the adhesion of the finishing layer of lime mortar or earth based render. These are the so called simple TWs, in opposition to the double TWs, which are made of two layers of boards: a layer of diagonal boards overlaid to the layer of vertical boards (see Fig. 1).

Figure 1 – TWs specimens

The compression experimental tests on these two types of walls, with 2,5cm thick boards, showed that they have a good mechanical performance under vertical compression forces. In particular, a simple TW (with no mortar finishing) is able to sustain 18kN/m, a value that, considering a 2.0 safety factor, corresponds to a design applied load capacity of 9kN/m. Moreover, this capacity can be easily multiplied by a factor of $(3{,}0/2{,}5)^3 = 1{,}7$ in case the thickness of the boards is 3.0cm, which is a very common value. On the other hand, the numerical simulation was capable of forecasting the laboratory behaviour/conditions establishing the specimens limit border conditions, i.e. hinged at the top and built in or hinged at the bottom.

Finally, the double TW, with double thickness, i.e. with half the slenderness, responded with a critical load that is only 30% higher (maximum) than the critical load of the simple TW, showing that the participation of the diagonal boards on the vertical capacity of the TW is much lower than that of the vertical boards; in the case of the cyclic tests, the critical load of the simple and double TW became quite close one to the other. Nevertheless, further investigation is still needed. In particular, this experimental campaign will include more tests on other specimens

Acknowledgements

The authors would like to thank the financial support of *Portilame* and *CS Construtora* that made this research possible. The 3rd author would like to thank the FCT (Fundação para a Ciência e a Tecnologia - Foundation for Science and Technology) of Portugal for the grant funding - SFRH/BPD/88115/2012.

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ASSESSMENT OF THE MECHANICAL CHARACTERISTICS OF TIMBER FLOORS THROUGH SIMPLE DYNAMIC IDENTIFICATION

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Keywords: Timber floors, Dynamic identification, Mechanical assessment

Abstract

The non-destructive in-situ characterization of timber floors is difficult and may involve expensive procedures, such as loading tests. Alternatively, it is possible to estimate some mechanical properties by assessing the characteristics of timber beams through sonic or penetration tests (e.g. pilodyn and resistograph); however, the existing correlations are still not very reliable. Thus, this project aims assessing the characteristics of timber floors using dynamic identification procedures, a simple and low cost technique when compared to loading tests. In particular, and through the identification of the main frequencies, this research aims estimating the mechanical behavior of timber floors, including the characteristics of the beams to walls connections.

Objectives and framework

The rehabilitation of old buildings is becoming a priority issue in Portugal. It's a process that demands the assessment of the state of conservation and understanding of the mechanical behaviour of the materials and structural elements that constitute these buildings. Among these elements, timber floors are particularly important, having a relevant participation in the behaviour of the entire structure. The floors are not only responsible for creating functional spaces, but also for establishing connections between walls, promoting a better box behaviour.

This study aims assessing the characteristics of the old timber floors through dynamic identification, i.e. by measuring the dynamic behaviour of the floors. With a small device, such as a seismograph or an accelerometer, this work seeks measuring the vibration frequencies of timber floors and analysing the results to estimate the in-situ characteristics of these elements. Using a structural analysis software, the frequencies obtained experimentally are compared to those obtained through the numerical simulation of the tested floor, allowing estimating some of its mechanical characteristics. In particular, this exploratory research foresees the estimation of the behaviour of timber floors by verifying, through dynamic identification, the influence of the various elements that constitute these floors, namely their characteristics and links. The benefits of this technique are, among others, the easy transportation of the equipment, the fast processing of the results and the low cost of the whole process. The work is based on results obtained through the application of this technique to a set of old buildings located at Porto that were undergoing renovation works, i.e.

buildings made of stone masonry walls at the contour and timber walls at the inside (although exceptions exist for both type of walls – stone masonry walls outside and timber walls inside) and timber floors and roofs. The structural system of the floors is typically made of timber beams with a span of not more than 5m and struts in between. The beams are materialized by tree trunks, either full, partially cut, or fully cut into rectangular section elements. To guarantee the horizontality of the floor, wood billets are placed between the beams and the floorboards. The boards are nailed to the beams, as well as the ceilings of the lower floors (a structure made of wooden thin laths placed perpendicularly to the beams supporting a wood and plaster covering). Fig. 1 shows some of the elements that constitute these timber floors and illustrates tests performed on the floors.

Figure 1 – Timber floors: a) timber beams and wooden floorboards; b) performed tests.

Conclusions

The results of the dynamic identification, i.e. the experimental measurement of the frequency of vibration of the floors structural elements allowed measuring the embedding characteristics of the beams in the stone masonry walls, estimating, in the case of the old floor structures of the case studies, that should correspond to only 40% of a full built in condition. The experimental results also pointed out the high participation of the struts to the global behaviour of the floor when well connected to the beams. Although the ceiling structure also contributed to the floors global behaviour, its most important effect is to decrease the vibration frequencies as result of its large participation mass.

The campaign also showed that the non-linearity of the axis of a timber beam may cause a variation of its vibration frequency above 60%. On the other hand, the border conditions can be responsible for a vibration frequency variation higher than 100%, depending on the degree of embedding of the beams in the walls. These two features are those that have greatest influence on the vibration frequency of a floor, particularly when compared to the timber class for which a variation of 100% at the elasticity modulus may change the value of the natural frequency of a beam in only around 15%.

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ROBUSTNESS ASSESSMENT OF AN ANCIENT TIMBER ROOF STRUCTURE

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Keywords: Timber trusses, Robustness, Geometric variability, NDTs

Introduction

The definition of robustness allows room for interpretation among engineers, owners and remaining involved agents. In the case of reliability-based analysis, a probabilistic assessment allows to evaluate how prone a structural system is to disproportionate collapse due to local failures. Here, the robustness indices are based on the probabilities of failure or reliability indices of intact and damaged structures. This task involves the consideration of probabilistic distribution functions for loads, as well as strength and stiffness of structural elements. These distributions can be found by consulting the Probabilistic Model Code or obtained empirically. For timber structures, it is common to use the loss of a component or reduction of strength and stiffness in elements and joints as possible damage scenarios. In this work, a robustness analysis has been carried out on an ancient timber roof structure system based on results of a full test-scale made to a truss and on the probabilistic models given in the Probabilistic Model Code for timber properties.

Description and NDT

The inherent variability of timber and its susceptibility to decay emphasize the need to carry out a characterization of the constitutive timber elements. A geometrical assessment was performed on a truss. Information on the presence of defects and mechanical properties were obtained by non-destructive testing (NDT). In Fig. 1 the structure of the collar truss is seen with at least one of the measured sections of each member mapped on the diagram. The collar truss was subjected to loading on each rafter until failure. The results of the tests allowed to define the probability distributions that were used later on the reliability and robustness analysis.

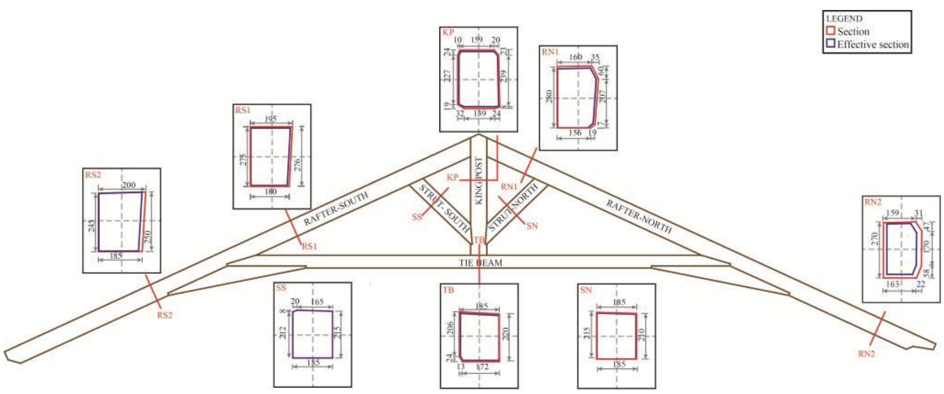

Fig. 1 - The collar truss with representative sections obtained from the geometrical survey mapped.

Reliability Analysis and Robustness Analysis of the Roof

A linear finite element model was performed in Opensees framework as seen in Fig. 2. The cross section of the truss was defined for every segment based on the information obtained from the NDTs. To allow load redistribution, the joints between the truss elements and the connection of the purlins, were initially assumed as rigid. The considered failure modes are related with the ultimate limit state verifications for bending and combined axial and shear forces on timber elements.

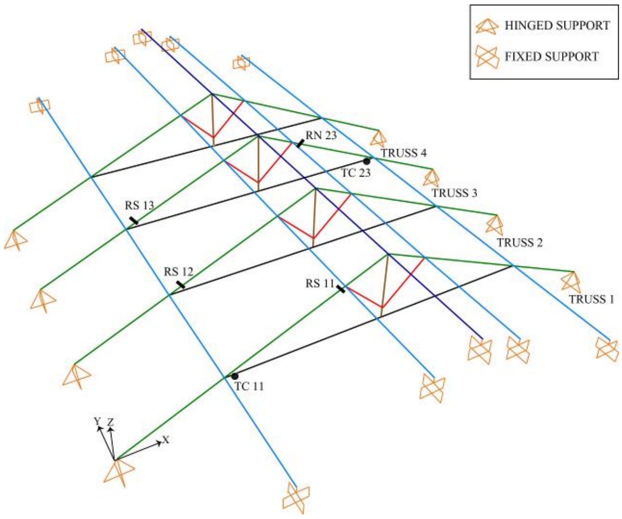

Fig. 2 – Finite Element Model of the roof structure

The main goal of reliability analysis was to assess the condition of the actual structural system comparing the reliability indices for original and residual cross sections using three different load combinations. The robustness of the system was evaluated using robustness indices related to damage scenarios that involved the loss of a component or reduction of strength and stiffness in elements and joints. A combination of permanent and wind loads was considered to perform this robustness analysis as lower reliability levels were found in that analysis. The results are presented in Table 1. It is important to stress that the reliability indices for the intact structure are high which allows to conclude that the system is robust for these damage scenarios.

Table 1 - Reliability and robustness indices for different damage scenarios

Damage scenario	$\beta_{damaged}$ (P_f)	β_R	I_{Rob}
1. Fail rafter-south of truss 2 (RS 12)	1.70 (4.4 x 10^{-2})	1.54	0.35
2. Fail rafter-south of truss 3 (RS 13)	1.73 (4.2 x 10^{-2})	1.56	0.36
3. Reduced stiffness of tie connections	4.78 (8.62 x 10^{-7})	93.5	0.99
4. Loss of bearing capacity of joint 1 (TC 11)	2.05 (2.03 x 10^{-2})	1.74	0.42
5. Loss of bearing capacity of joint 2 (TC 23)	1.98 (2.39 x 10^{-2})	1.69	0.41

Conclusions

In this work, a robustness assessment is presented for an ancient collar timber roof. The obtained robustness indices allowed to state that the structure as the ability to withstand the assumed local failure. Also, the results allowed to conclude that if the secondary system allows load redistribution the structure can also be considered as robust.

Acknowledgments

The information obtained through training school: Assessment and reinforcement of timber elements and structures (Guimarães, Portugal) within scope of FP1101 and RILEM TC 245 is acknowledged. Financial support of the Portuguese Science Foundation (FCT), through PhD grant PD/BI/52583/2014 included in InfraRisk-PhD program, is gratefully acknowledged.

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FP1101 AND RILEM TC 245 RTE TRAINING SCHOOL ON ASSESSMENT AND REINFORCEMENT OF TIMBER ELEMENTS AND STRUCTURES: THE ROLE OF THE ACADEMIC COMMUNITY IN DISSEMINATING KNOWLEDGE

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Keywords: Assessment, Reinforcement, Timber trusses, FP1101

Abstract

In the past decades, timber has been considered as a secondary construction material owing to the emergence of other materials such as concrete and steel, and as a consequence a large amount of knowledge on how to use timber has been forgotten or even lost. This has led to badly designed interventions on timber structures, which have misinterpreted the past structural solution and led to significant structural performance problems. However, the European research community has made a significant effort towards the dissemination of knowledge regarding the design and assessment of timber structures.

Within that scope, COST FP1101 had the objective of increasing the acceptance of timber in both the design of new structures, as well as in the repair of old buildings by developing and disseminating methods to assess, reinforce and monitor them. To that aim, FP1101 and RILEM TC 245 RTE in collaboration with the University of Minho (Portugal) organized a Training School (TS) on the assessment and reinforcement of timber elements and structures.

This work presents the different areas of knowledge that were scope of that training school and its main achievements on the dissemination of knowledge to young researchers and other interested groups.

Objective and Framework

The training school, to which this papers refers to, had the objective of disseminating knowledge to young researchers, as well as to others interested in wood and timber construction and rehabilitation market. The global layout of the training school is presented in Fig. 1.

During the training school, several experts provided information on the assessment of existing timber structures, visual grading, intervention on heritage buildings and on analysis, repair and reinforcement of traditional and dowelled timber connections and structures. After the initial theoretical framework, the participants were invited to participate in practical applications on a laboratory premises. The diagnosis made to a timber collar truss was presented to the participants and onsite applications of non-destructive tests were shown. Different strengthening and repair techniques with composite materials and its application were also presented. The main laboratory activities comprised on full scale tests of timber connections and of a old collar truss (original conditions and after being repaired).

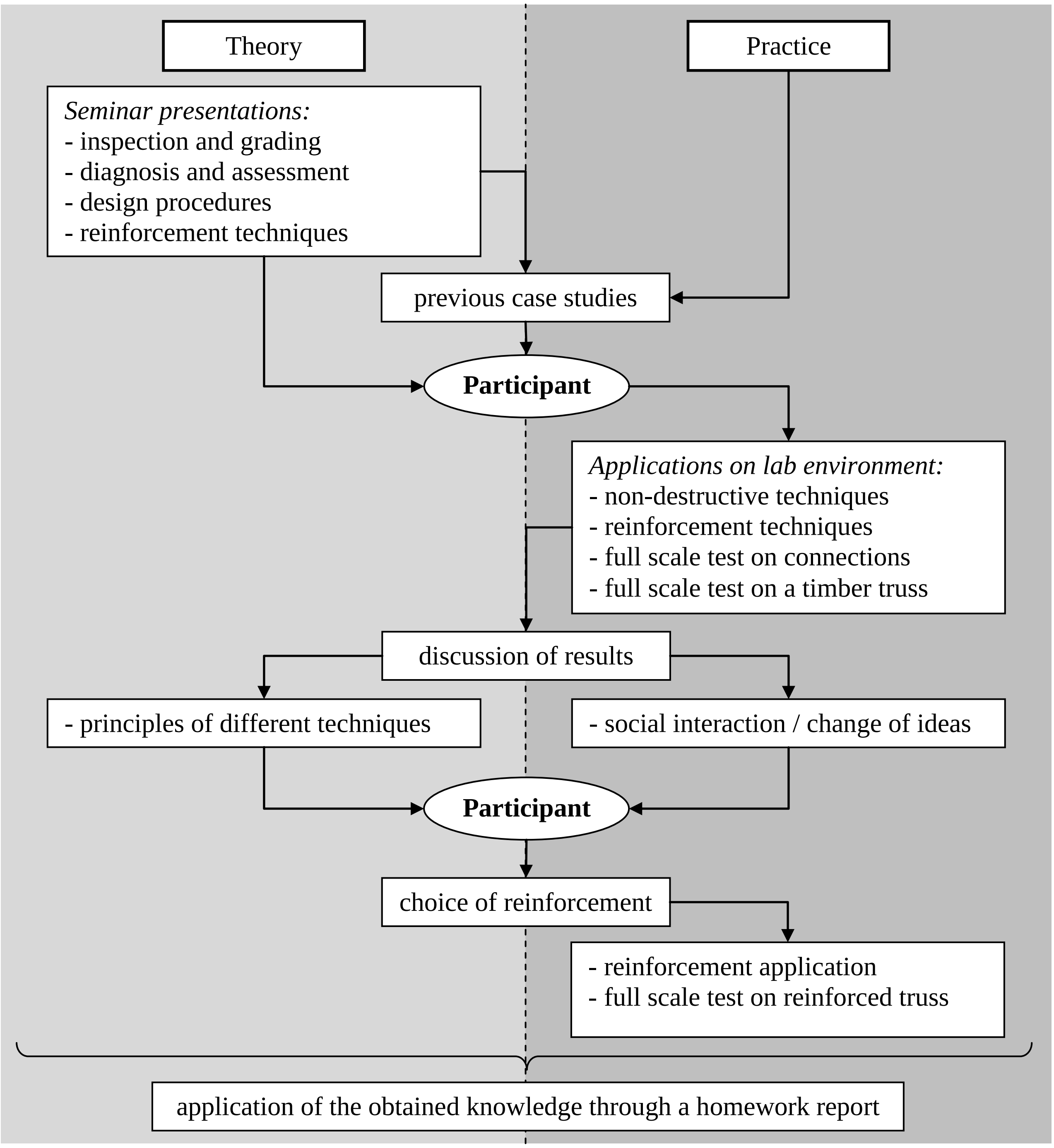

Fig. 1 – Layout and interaction of participants in the training school activities

Conclusions and the Role of the Academic Community

A holistic approach was used to transmit the main guidelines and procedures for a correct and full assessment of existing timber structures and following interventions. The training school served as an initial step for further investigation and also allowed a younger generation to obtain the necessary tools to better understand, assess and intervene in existing timber structures.

Acknowledgments

The information obtained through training school: Assessment and reinforcement of timber elements and structures (Guimarães, Portugal) within scope of FP1101 and RILEM TC 245 RTE is acknowledged. The support of the Structural Lab from University of Minho is also acknowledged. The assistance of the companies Rotho Blaas and Augusto de Oliveira Ferreira e Companhia Lda (AOF) are greatly acknowledged.

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RELIABILITY OF TIMBER FRAMED CONSTRUCTIONS IN SEISMIC PRONE AREAS IN THE PRACTICE CODES ISSUED FROM 18TH TO 19TH C

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Keywords: Earthquake, Earthquake-resistant, Timber, Frames, anti-seismic code

Extended abstract

The technical-scientific development level of a community produced in the seismic-resistant constructions, in particular in the masonry reinforced by timber frames, is directly traceable by the issuing of technical instructions for constructions and their evolution.
Provisions of the central authority, aimed in general at the reconstruction of buildings characterized by the property to withstand earthquakes, are quoted, but without actual references, in the 19th C. scientific literature, relatively in particular, to Guatemale (provisions that would have been issued in the 1541) and to Algeria (a code dated back to 1716).

The study of dynamics, as pure science or otherwise devoid of purposes applicable to the execution of buildings, is begun by Huygens and Newton in the 17th Century. During the Enlightenment Age there is a treatises development that, in addition to providing recommendations on the execution of buildings following the principles of the *workmanlike* in general, give technical instructions on earthquake-resistant constructive methods (Wolff for example).

Some of those innovative scientific trends are applied in the reconstruction of Lisbon after the earthquake that devastated the city in 1755, adopting in particular a construction model (*Gaiola*) in which, timber frames were provided in order to connect the masonry walls. The system, supported by the government with the express purpose of executing buildings resistant to earthquake, derived from the carrying out a constructive practice developed in *Casa do Risco,* coordinated by General Manuel da Maia and desired by the enlightened Marquis of Pombal, prime minister of the kingdom.

The 1783 was a tragic date for the Calabria region, numerous earthquakes with an intensity among the highest that ever hit Europe caused the almost total destruction of the buildings in the whole Calabria Ulteriore. Neapolitan engineers order the reconstruction and the buildings repair relying on *Istruzioni e Suggerimenti* (1784?) suggested by La Vega and Winspeare, works superintendents on the whole Calabrian territory and approved by the regnant of that era Ferdinando the IVth of Borbone. Such a document includes several points regarding the hygiene, urban planning and the distribution of land for new buildings, civil protection measures but above all, in order to decrease the buildings earthquake vulnerability, provide recommendations following the most innovative

ideas in the field of seismic engineering (limitation of height, decreased weight, box-like behaviour, etc.), according to constructive modalities that could be defined of good practice.

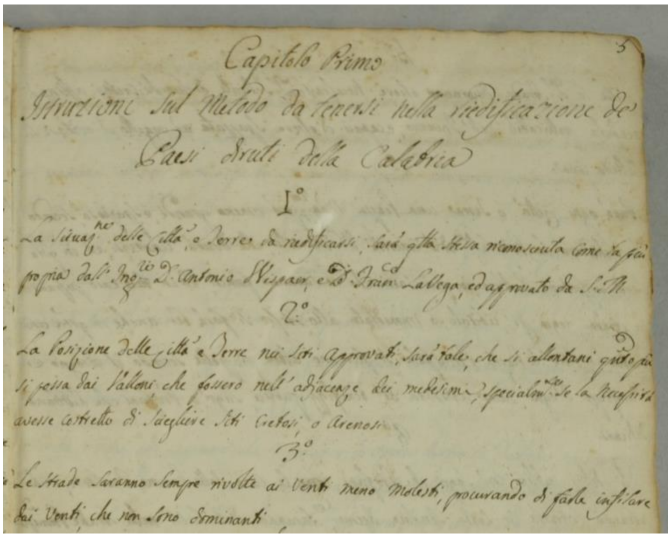
It is interesting the regulation issued in 1826 in the Greek island of Lefkas, at the time under British rule, in which it is recommended the execution of timber frames completely detached from the perimeter wall at the lower level of the building; such a timber structure, if enough rigid in the plane, also thanks to the nodes stiffened by curved elements, despite without bracings whether in wood or masonry, can be considered a safety structure that preserves people's lives in case of collapse of the exterior wall panel.

The prescriptive indications contained in the Borbone regulations will be recognised as valid and included in the regulations that the *Stato Pontificio* adopted in 1859 for the territory of Norcia and in the indications of the following earthquake that hit some municipalities around Naples in 1883 and in 1906, year of the promulgation of the Regio Decreto *Norme per la ricostruzione e riparazione degli edifici pubblici.*

The Regio Decreto n. 193 (April 18th, 1909), *Norme tecniche ed igieniche obbligatorie per le riparazioni ricostruzioni e nuove costruzioni degli edifici pubblici e privati nei luoghi colpiti dal terremoto del 28 dicembre 1908*, dates back to 1909, in which, in addition to identifying the *baraccato* structures as a proper anti-seismic system, it appears for the first time in Italy a seismic zoning map indicating municipalities, even if limited to the Sicily and Calabria region, in which there is an higher risk of earthquakes occurrence.

The difficulties in the mechanical and performance level definition of such a system thereafter entail, at least as regards Italy, the abandonment of the timber framed masonry as earthquake resistant device with the almost complete disappearance from the construction practice codes

The timber frames structures reacquire equal status to the other earthquake resistant constructive typologies only with the drafting of the Eurocodes and in particular, of the Eurocode 5 *Design of timber structures* and above all Eurocode 8 *Design of structures for earthquake resistant*.


Capitolo Primo
Istruzioni sul Metodo da tenersi nella riedificazione de' Paesi diruti della Calabria
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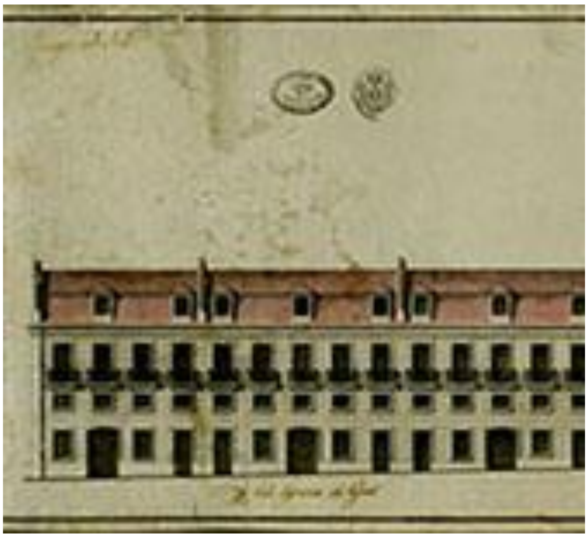

Fig. The *Istruzioni sul metodo da tenersi nella Riedificazione dé Paesi diruti della Calabria* (on the left). A Pombalino building façade (cartulario arquivo municipal de lisboa) (on the right).

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SEISMIC ASSESSMENT OF "POMBALINO" BUILDINGS

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Keywords: *Pombalino* buildings, Cyclic static shear testing, Macro-element modelling, Performance-based assessment, Non-linear static analyses, ArcGis, BIM

The heritage value of the mixed timber-masonry 18th century *Pombalino* buildings (Fig.1), built in Lisbon after the 1755 earthquake, are recognized both nationally and internationally. These buildings are characterized by the design of a mixed timber-masonry structure, known as the *gaiola pombalina* (cage) intended to withstand the horizontal seismic loads above the first floor. The cage is composed of timber floors and improved mixed timber-masonry shear walls (*frontal* walls). It was arguably the first case in history of an entire town built with the purpose of providing seismic resistance to its buildings.

Fig.1 Collection of *Pombalino* buildings, from a Lisbon downtown street, modeled in 3D-GIS [1]

Previous statistical data estimated that *Pombalino* buildings correspond to 27.2% of Lisbon existing building stock. A GIS mapping tool was developed to allow the characterization of *Pombalino* buildings in Lisbon downtown area, by combining geographical information and building attributes. This survey is an important source for further research studies of seismic risk assessment and loss estimation, at the city scale.

The performance-based assessment of a typical *Pombalino* building was carried out to assess the global seismic response of this building typology. A three-dimensional model was developed in Tremuri Program based on the equivalent frame model approach. The building was modelled using non-linear beams for masonry panels. The *frontal* walls were modelled by a macro-element model calibrated according to the previous experimental campaign [2].

The seismic assessment of the global response of the building was determined through nonlinear static (pushover) analyses. Regarding the obtained results, it was concluded that building does not fulfil the safety requirements for the ultimate limit state. Due to this fact, strengthening technique was analyzed in order to improve the seismic behavior of the building. In the Fig. 2, comparison of the obtained results between the original and reinforced building are presented. It can be concluded that this strengthen solution increase effectively the stiffness and strength of the building, especially for the Y direction, as the area of the RC walls is more representative in this Y direction. Furthermore, the reduction of damage is evident in case of the building with applied reinforced technique what is presented in Fig. 3, for ultimate displacement (d_u), for front façade and triangular load pattern.

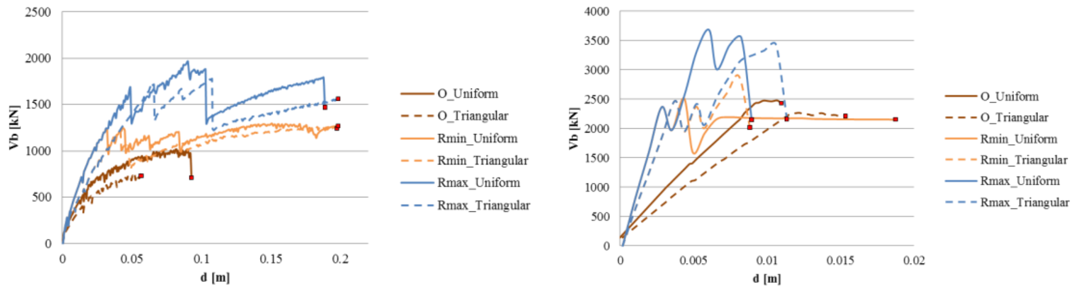

Fig. 2 Pushover curves: X (left) and Y (right)direction

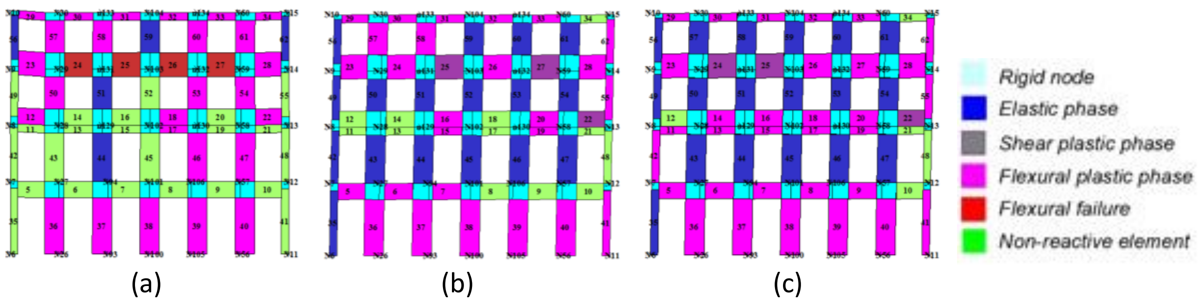

Figure 3 Damage pattern for front façade for triangular load in X direction: (a)Original; (b) R_{max}; (c) R_{min}

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THE "GOTHIC HOUSE" IN ARQUATA SCRIVIA (ITALY): COSTRUCTIVE DETAILS AND SEISMIC ASSESSMENT OF A TIMBER FRAMED MASONRY STRUCTURE

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Keywords: timber framed masonry, sensitivity analysis, seismic response

Abstract

The paper presents the analysis of the structural and constructive system together with that of the seismic response of the "Gothic house" in Arquata Scrivia, that constitutes one rare example of timber framed masonry structure in Piedmont (Italy). It is a three storey building that dates back to XIV century and is characterized by perimetral rubble stone masonry walls at ground floor, two of which are replaced at the higher levels by timber frames infilled with solid brick and lime mortar masonry; mostly of internal walls are in brick masonry. Floors are quite flexible as realized by timber diaphragms. The timber frame system presents some analogies with the French and German one (area in which it is more widespread than Italy) although it is characterized exclusively by the presence of horizontal and vertical timber elements for which a specific role in relation to the seismic response could be questionable. From 1999 to 2005 the building has been subjected to two restoration and strengthening interventions that allowed to highlight the original structural system.

In the paper, firstly the understanding and analysis of this latter are described in detail. They have been supported by an extensive investigation campaign that included the execution of several non-destructive tests on both masonry and timber elements. Preliminary step for setting-up the investigation plan was a sensitivity analysis carried out on an equivalent frame model of the building (realized with 3Muri program, Lagomarsino et al. 2013) by performing nonlinear static analyses. In particular, the role of the following uncertainties has been investigated: the mechanical properties of different masonry types; the stiffness of diaphragms; the stiffness of timber elements (by distinguishing the role of vertical and horizontal elements). Such sensitivity analysis has been revealed as an essential tool, firstly, to address the as-built information phase and, then, to improve the reliability of the final model to be adopted for the seismic assessment.

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NUMERICAL APPROACHES FOR THE ANALYSIS OF TIMBER FRAME WALLS

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Keywords: timber frame, traditional connections, numerical analysis, calibration, parametric analysis

Introduction

A number of numerical studies analysing the seismic performance of modern timber frame shear walls exist, while only recently the attention has focused on traditional timber frame walls, which represent an important historic seismic-resistant construction typology, particularly in Mediterranean countries. Different approaches can be taken when modelling this type of elements, varying from complicated 3D models, accurately representing joints, pegs and nails, to simplified 2D models, adopting linear and springs elements to represent timber members and joints.

Kouris and Kappos [1] performed non-linear numerical analyses on traditional half-timbered walls. The authors first performed a detailed 2-D modelling of a wall, adopting plane-stress elements and considering non-linear orthotropic properties for wood, while the contacts in timber elements was simulated adopting interface elements. Infill was not included in the model. The model was able to appropriately simulate experimental results, being able to capture the gradual softening of the walls as well as their capacity. To be able to model whole buildings in a simplified way, the authors created a simplified model using beam and link elements, while non-linear axial hinges were used for the diagonals. The application of this model to a building façade proved to be satisfactory.

Quinn and D'Ayala [2] modelled traditional Peruvian timber frame walls using 2-D beam elements and adopting semi-rigid spring elements to model the joints of the wall. The springs were calibrated based on experimental results and using the components method; preliminary results appear to be reasonably good. Another approach to the modelling of timber frame walls is the use of analytical hysteretic models calibrated on experimental results to a simplified numerical wall model [3,4].

Numerical modelling of walls

In order to simulate numerically the results obtained experimentally on traditional timber frame walls [5], a 2-D finite element model was created, adopting plane stress and beam elements. The models were calibrated on the experimental envelope curves obtained from in-plane cyclic tests.

2-D model with plane stress elements. A first model of the wall was created adopting plane stress elements and interface elements for the connections. Non-linear properties were assumed for timber and for the timber-to-timber and infill-to-timber interfaces. The numerical model was calibrated based on experimental results. It is observed that a reasonable fitting between experimental and numerical results was obtained both in terms of stiffness, lateral resistance and maximum displacement (Fig. 1) [6].

2-D model with beam elements. Considering that the plane stress model still presents some complications, particularly in terms of material properties, since non-linearities are assumed for all elements, and having as a goal the modelling of a whole structure, for which such a model would be computationally expensive, a simplified 2-D model was created. While timber was assumed linear, the link elements representing the joints were non-linear and their stiffness was calibrated using the experimental results and by applying the inverse fitting method. Comparing the numerical results thus obtained with the experimental envelope curve (Fig. 1), a good approximation was obtained with this simplified model [7].

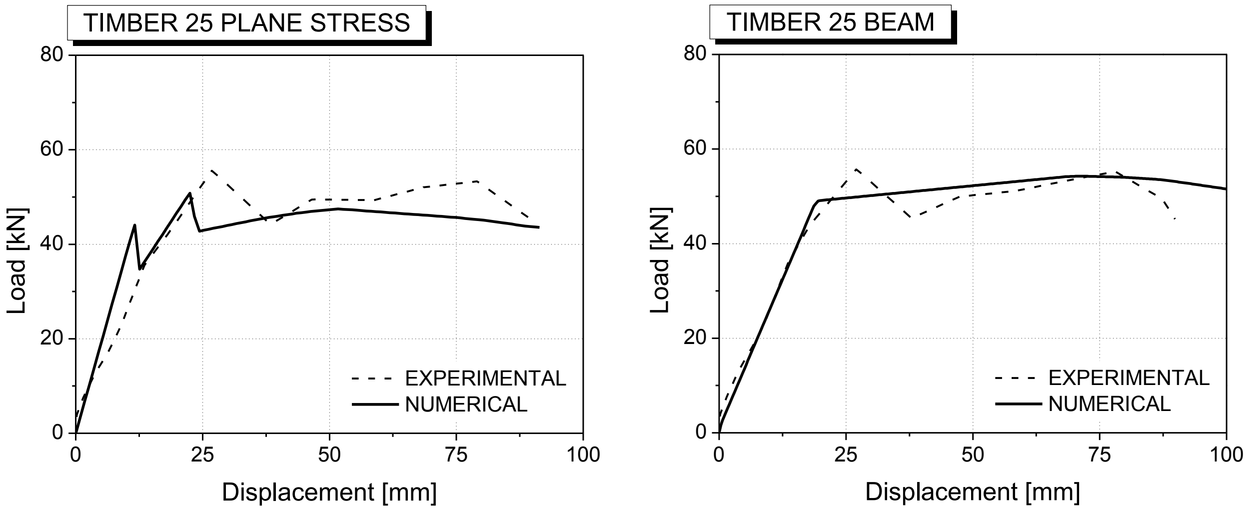

Fig. 1 Model calibration: plane stress elements (left) and beam elements (right) model results

Parametric analyses. From the parametric analyses performed, it was found that post continuity, material properties of wood and masonry as well as of timber-to-timber and infill-to-timber connections, and height-to-weight ratio all influenced the response of the wall in terms of initial stiffness, capacity and post peak behaviour [6].

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ASSESSMENT AND SAFETY REQUIREMENTS FOR EXISTING STRUCTURES

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Keywords: Eurocodes, assessment, retrofitting, existing structures, timber, masonry.

Extended abstract

Maintenance, repair and rehabilitation of existing structures have gained increasing importance in the construction industry in the last years.

The approach to safety assessment and design of retrofitting of an existing structure has much less support in codes or guidelines then the design of new structures. The construction process and subsequent life of the existing structure must be taken into account in such approach, as well as in other types of information.

Assessment of historical buildings is even more difficult because in general there is no information of the initial structure and many changes where done during its life. In addition, assessment and retrofitting must take the respect for the original character of the building into account and there is a frequent lack of knowledge of traditional building techniques and specialized workmanship.

Extending life time of structures should be supported by guidelines or technical rules. In the case of historic buildings, besides the technical, economic and social aspects to be taken into account, the historic importance may determine the level of intervention to be performed. In spite of that, the integrity of the building itself and protection for people must be safeguarded and structural safety must reach minimum levels. However, safety requirements are not always established.

Some European countries have national regulations and standards regarding assessment and retrofitting of existing structures. There is a need for harmonised European technical rules on this subject which can be broadly accepted.

Current Structural Eurocodes are primarily focused on the design of new structures. In order to develop a set of European-wide technical rules and associated standards for the assessment and retrofitting of existing structures, the Joint Research Centre published a policy support document on New European Technical Rules for the Assessment and Retrofitting of Existing Structures. Although this document is in principle applicable to all existing structures, particular aspects of historic structures are not specifically addressed.

Until April 2014, there was a lack of rules for retrofitting of existing structures in Portugal. Then, the government administration established than until April 2021 for habitational building more than 30 years old, some requirements might not be applied due to the associated costs that could make it unfeasible. So, concerning structural behaviour, there is no obligation to improve structural performance of the building, as long as its use is not modified (even with such low safety

level). This could lead to unacceptable high risk levels, particularly in earthquake prone areas, if designers and promoters do not evaluate consequences of the rehabilitation.

This presentation refers to the existing design codes and the work under way to extend them to existing structures and discusses their application and limitations regarding historic buildings.

Based on LNEC experience, an approach is also proposed concerning safety requirements applicable to heritage buildings, and the suitability of specifying different target reliability levels are also discussed. Those levels should depend on the heritage value of the structure and the consequences of a possible failure of the structure, thus linked to its acceptable use.

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BUILDING REGULATIONS AND EXISTING BUILDINGS

Setting the requirements on structural safety in Portugal

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Keywords: Building regulations, Existing buildings, Structural safety, Portugal.

Extended abstract

Building regulations set minimum requirements for safe, healthy, functional, energy-efficient and accessible buildings. The application of building regulations to existing buildings is often constrained by pre-existing site and building conditions to an extent that makes it not always viable to achieve the same overall level of performance of new buildings, within the given technical and economical envelope of each operation. Applying building regulations to existing buildings requires a sometimes delicate balance between a number of cultural, social, environmental, technological and economic factors that predominate in each society at that given period. To determine this break-even point, the opinion of different stakeholders should be taken into account. How each set of building regulations deals with existing buildings is therefore a subject open for research and debate, especially in a time when urban rehabilitation is a high priority in the political agendas.

On the basis of this framework, this paper analyses the positions expressed by different stakeholders when the requirements on structural safety for existing buildings were recently discussed in Portugal. To contextualize the analysis, the Portuguese housing stock is described and the way building regulations apply to existing buildings is reviewed. The paper proceeds then to explore the priorities of different stakeholders in a recent legislative initiative that changed requirements that apply to construction works in existing buildings, drawing conclusions for future action in this field.

According to the census of 2011, the Portuguese housing stock is relatively new and in good condition: 86% was built after 1945 and 71% does not require repairs. If we focus on the buildings prior to 1946 a different scenario arises: 42% of the stock is in need of minor repairs and 18% needs major repairs or are severely deteriorated. Buildings prior to 1946 represent only 14% of the housing stock but account for 58% of the buildings in need of major repairs or being severely deteriorated. Buildings prior to 1946 are predominantly made of masonry walls with timber floor and roof structures, while the buildings after that date increasingly incorporated concrete in their structural elements. Regarding seismic resistance, the buildings prior to 1946 have varying degrees of structural safety (many recognised as having poor or very poor performance levels) while the buildings after that date already had to comply with specific seismic safety regulations.

During the last 20 years the Portuguese regulatory framework for building has evolved positively towards better safeguarding quality of construction. Major regulatory improvements were made in the fields of energy-efficiency, accessibility and technical installations. Despite this evolution, the Portuguese building regulations are designed with the focus on new buildings. This poses a problem when public policy is switching towards the rehabilitation of the existing stock. When applying to existing buildings, the general principle found in current Portuguese building regulations is that

construction works do not have to improve on pre-existing building performance levels, only to avoid down-grading them. Building regulations on structural safety follow this general principle. Besides other considerations, this approach allows for a wide margin of subjectivity in the application of regulations and is a cause for occasional differences between promoters and permit-issuing authorities.

In 2012-2014, the Portuguese government prepared and approved a special legal regime aimed at dealing with the alleged mismatch between the current regulatory framework and the rehabilitation of the existing building stock. The government presented the special regime as a pragmatic tool aimed to eliminate unnecessary and inappropriate regulatory constraints, thus reducing the uncertainty and the cost of interventions and promoting a proactive policy of urban rehabilitation. The approach has been to exempt construction works in existing buildings of complying with a number of requirements on habitability, accessibility, acoustics, energy efficiency, gas installation and telecommunication infrastructures. In this context, additional requirements on structural safety were not favoured . The new regime thus reiterates the safeguard already laid down in the Portuguese legal framework: *"interventions in existing buildings* ***cannot reduce*** *[...] the structural and seismic safety of the building"*.

The approval of this special regime was involved in controversy, sparkling wide opposition from a number of professional and scientific associations. The structural safety professional and scientific community was particularly active in the debate. Detractors of the special regime within the structural safety community considered that improving structural safety conditions of buildings is a standing priority and see rehabilitation as an opportunity to achieve this goal. They argued that: i) most of the existing buildings do not ensure minimum levels of safety in case of an earthquake, ii) the added cost of measures to improve structural stability of buildings is small, and iii) rehabilitation without improving resilience to risk of earthquake conveys a false impression of safety to users and it is an economically questionable investment.

The view of the government prevailed at the end, with the promise that a specific legal document on structural safety of existing buildings would be subsequently prepared. That did not happen to this day, over almost two years after the approval of the special regime.

The following conclusions can be drawn from the analysis of this study-case:

- The discussion of the special regime turned into a clash between opposing positions, founded on two equally reasonable priorities: to stimulate the rehabilitation of existing building stock *versus* to improve structural safety.

- The debate ended in a deadlock. Both parts argued with their reasons and objectives but proved unable to support their points of view with indisputable facts: (i) on the government side, scientific and empirical data proving a positive direct correlation between the changes in the building regulations and the reduction of costs and increase of dynamics in urban rehabilitation; (ii) on the structural safety community side, scientific and empirical data as well as practical information on the technical solutions demonstrating their effective benefits in terms of safety and cost.

- An evolution from this point will likely be possible if the structural safety community is able to persuade the government and the society by supporting its arguments with hard facts, such as (i) technical guidelines and recommendations for structural rehabilitation of existing buildings according to their characteristics and conditions, (ii) a cost-benefit analysis of these solutions, and (iii) a practical programme of capacity building of the construction sector to implement the prescribed solutions.

- It thus seems right to conclude that more applied research is needed. This should go along with a better dissemination of the associated technicalities within the construction sector and with an informed and enlightened debate among relevant stakeholders (government bodies, research and technical community, building and real estate sector, and citizens associations).

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THE ROLE OF TERRESTRIAL LIDAR FOR MECHANICAL AND SAFETY EVALUATION OF HISTORIC TIMBER TRUSSES

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Keywords: Timber floor, LiDAR, safety

Introduction

The paper describes an activity conducted by a multi-disciplinary research group (architecture, civil engineering, technology, geomatics) for the mechanical evaluation of a timber floor belonging to a historic residential building located in the city center of Torino.

The floor was made of trusses of solid wood and wooden boards and presented a mid-span deflection. Since the floor structure was hidden by a suspended ceiling, the difficulty was to determine with precision all the geometrical characteristics of the main truss and its creep with the aim of verifying its mechanical resistance and stiffness.

Through an accurate application of laser-scanner technique, it was possible to carry out a precise assessment of the structure.

Although the majority of historical buildings belonging to the Turin center have been restored to account for changes of the performance requirements, many of them are still lacking proper seismic improvement. Therefore, a detailed geometrical survey must be complemented with non-destructive analyses and structural assessments. This approach has been adopted analyzing the historical flat that is considered in the following, where the survey of the geometry is combined together with both static and dynamic load assessment in order to provide a reliable evaluation of the safety margins.

One of the major difficulties is certainly due to the presence of suspended false ceilings which hide the structure above, together with the fact that the flat was occupied by the people living there during the intervention. The present study reports the geometrical survey, the diagnostic and the preliminary structural analysis.

Thanks to the LiDAR (Light Detection and Ranging) survey it was possible to prove that the central beam of the floor, which is the most loaded, is affected by inelastic deformations that are not compatible with any of the prescribed values of the standards. The diagnosis of the timber beam was performed with the Resistograph, which revealed the good quality of the wood (Larch). On the contrary, the homogeneity of the material was poor, and voids at the extrados of the beam midspan have been detected. The accounting for the detailed geometry obtained with laser survey and void location provided by Resistograph® analysis allowed for a proper simulation and assessment of elastic and inelastic deformation. The structural assessment was conducted according to the Italian standards (NTC 2008), calculating both the maximum bending stresses and the maximum initial and long-term displacements, under the effect of dead weights and serviceability loads. As a result, although the strength limit was verified, the displacements were well above the limit prescribed by the standard. Finally, it is worth noting that in a seismic event, vertical acceleration spectra must be considered together with horizontal ones, which directly emphasize the beam deflections. In this view, a retrofitting of the beam is necessary in order to improve the bending stiffness both with respect to static and dynamic loading.

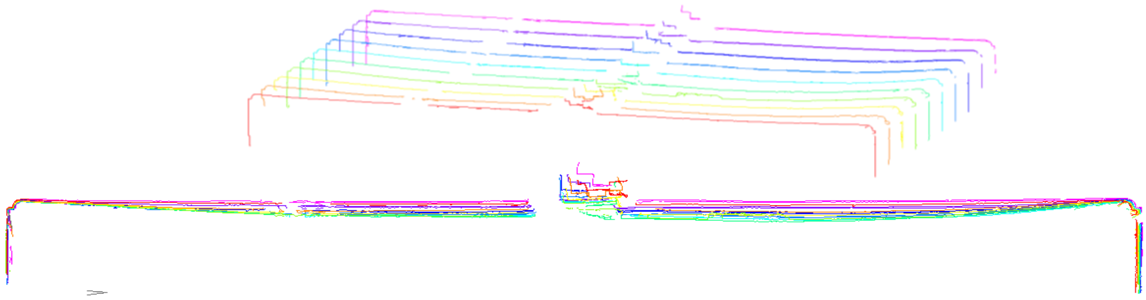

Fig. Progression of cross section through ceiling and wooden structure, in a 3D spatial view (top) and a planar view (down) in which it is visible the depression of the wattle dropped ceiling surface.

Conclusions

From the survey it appears that the wooden elements observed were is in a good state of conservation. However, the creep is 24 cm, therefore the beam is not acceptable in terms of current standards. This result requires a necessary reinforcement intervention for the safety of the elements and of the building.

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THE MASONRY TIMBER FRAMED LOAD BEARING STRUCTURE OF THE *PALAZZO VESCOVILE* IN MILETO (ITALY)

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Keywords:1783 earthquake; Borbone anti-seismic code; Masonry reinforced with timber frames; Seismic vulnerability

Extended abstract

The *Palazzo Vescovile* in Mileto (Southern Italy), executed shortly thereafter the catastrophic earthquake that struck the Calabria region, emblematically represents the application of principles and technical indications recommended in the Borbone anti-seismic code *Istruzioni* and included in treatises of Eighteenth century anti-seismic engineering. That building, characterized by various constructive events that caused a construction completion delay, presents devices aimed at consciously mitigating its seismic vulnerability including the building geometry (i.e. in plan bi-axial symmetry, a front elevation regular development and a height limited to only one storey) and constructive solutions regarding the nature and the organization of materials and resistant elements forming the load bearing structure.
The vertical structural system is represented by masonry reinforced with timber frames which main function is to bond the building intersecting walls with the aim of obtaining a box behaviour of the *Palazzo Vescovile* under earthquake excitations. On that purpose the particular arrangement and morphology of the members nodes, often with the addition of metallic devices, contributes to transfer stresses to a three dimensional system of orthogonal walls.
In addition to the vertical load bearing system the inter-storey floor also plays a key role in influencing the building anti-seismic response. In fact, the presence of notches strengthening the node beam to wooden ring, improves, together with the latter, the resistance to out-of-plan actions. Furthermore, the floor is characterized by a moderate deformability, thanks to the narrow

spacing and geometric features of the beams, useful for redistributing horizontal forces to the shear walls.
The roof structure, constituted by king post trusses ensuring the absence of outward thrusts, benefits of the presence of saint Andrew crosses arranged orthogonal to the structural unit with the purpose of preventing the trusses stacking under horizontal loads and in general of ensuring a roof longitudinal stiffness.
Moreover the document devotes its attention to the behaviour of the *Palazzo Vescovile* in Mileto under gravitational actions, analysing the wooden frame contribution to the compression resistance of the whole constructive system.

The theoretical and practical reconstruction process of the Calabria region villages, after the 1783 earthquake, beyond the well known framed constructive system, included a more complex set of technical and technological anti-seismic measures.
The research of a *box-like* behaviour, mass reduction, symmetry in plan and in front elevation, limit of the height and increase of the inter-storey floors and roof stiffness, represent fundamental principles and criteria to pursue, in accordance with the Italian 18th century treatises hence with the *Borbone Istruzioni*.
A combination of constructive devices, analysed through the case study of the *Palazzo Vescovile,* were perhaps applied for the first time in a such systematical, complex and aware way in order to reduce the building seismic vulnerability.

Fig. Timber frame emphasizing alternated notches at the ring level (on the left) roof Saint Andrew crosses (on the right)

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CHARACTERIZATION OF TIMBER MASONRY WALLS WITH DYNAMIC TESTS

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Keywords: "Pombalino" buildings, "frontal" walls, timber-masonry walls, shaking table tests

1 Introduction

Most of the Lisbon 18th century timber-framed masonry "Pombalino" buildings currently need seismic rehabilitation due to: (i) natural degradation with aging; (ii) need for adaptation to new serviceability requirements, generally involving higher loads and consequent structural changes; (iii) former interventions with elimination or damage of structural elements, affecting seismic resistance and (iv) noncompliance with the present seismic codes.

The research presented in this paper aimed at experimentally evaluating the seismic vulnerability of the "Pombalino" buildings and at proposing a strengthening technique to reduce it by reinforcing their timber framed "Frontal" walls. The experimental program was based on extensive dynamic testing on prototype representative of the current characteristic of "Frontal" walls.

The results of the dynamic tests carried out at LNEC 3D shaking table are presented regarding the two types of tests performed: (a) seismic tests, in which the seismic action was applied with increasing amplitude in one direction; (b) dynamic identification tests, aiming at evaluating the decrease of the mechanical properties of the models. A comparison of the performance of the non-strengthened and strengthened tested prototypes is also presented.

2 Shaking table tests setup

The shaking table tests were performed at LNEC (*Laboratório Nacional de Engenharia Civil*, Lisbon) at NESDE department (Earthquake Engineering and structural dynamics Division). The tests were performed unidirectional along the shaking table lateral axis, since the purpose of these tests was to study the plan response of the "frontal" walls.
Three models, representing the "frontal" walls, were built: "Model 0" consisting of timber frames without masonry infill (Fig. 1(a)); "Model 1" consisting of a timber frames with masonry infill

(Fig. 1 (b)) and “Model 2” consisting of a timber frames with masonry and reinforced cross-halving joints (Fig. 1 (c)).

a) b) c)

Figure 1 – Models: a) Model 0; b) Model 1; c) Model 2

3. Conclusion

This paper intended to provide useful information on the dynamic behaviour of traditional timber-framed masonry walls, typical of the Portuguese *Pombalino* buildings and thus intending to contribute to the state of the art on the matter, given the scarce results available in literature.
The experimental analysis was carried out on three distinct models (Model 0, Model 1, and Model 2). From the experimental campaign carried out it was possible to observe that:

- The masonry increases the rigidity of the model, having the disadvantage of increasing the mass of the structure. In the first modal identification test, it was observed that in all modes the frequency is lower in the model without masonry.
- The damage in Model 1 is highly concentrated at the connections between floors resulting in the large deformation of the walls that presented a maximum damage of 39%.
- The modal frequencies increased in the reinforced model due to a stiffness increase.
- By analysing the evolution of frequencies during the dynamic test, it is shown that the strengthened model has a good behaviour to seismic test, presenting a maximum damage of 14%.

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SEISMIC ASSESSMENT PROCEDURES FOR FLEXIBLE TIMBER DIAPHRAGMS

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Keywords: Flexible timber floors, diaphragm in-plane behaviour, seismic assessment.

Extended abstract

A review of the available procedures and guidelines for the in-plane assessment of existing timber diaphragms in unreinforced masonry (URM) buildings is provided. Most of the provisions that concern flexible wood floors and that are valid for URM, can as a matter of fact be adopted for historic masonry buildings reinforced with timber frames.

Recommendations from the most recent international standards like ASCE 41-13 “Seismic Evaluation and Retrofit of Existing Buildings” [1] and NZSEE 2015 “Assessment and improvement of the Structural Performance of Buildings in Earthquakes” [2] were thoroughly analysed.

ASCE 41-13 [1] is the updated version of the ASCE 41-06 [3] which is mainly based on FEMA 356 “Prestandard and Commentary for the Seismic Rehabilitation of Buildings” [4]. The research background is mainly represented by the experimental program carried out by ABK and published in the Topical Report TR03 back in 1981 [5].

The roots of the diaphragm assessment procedure contained in the original version of NZSEE (NZSEE 2006 [6]), are derived from ASCE and FEMA and consequently the focus will be on NZSEE 2015 [2] which updates chapter 10 of [6]. The experimental background for the changes introduced by [2] lays mainly in the research work recently carried out at the University of Auckland (see Giongo et al. [7] for detailed reference).

Table 1 Default expected strength values for wood diaphragms [1]

Diaphragm Type		Shear Stiffness (G_d)		Expected Strength (Q_{CE})	
		[lb/in]	[KN/m]	[plf]	[KN/m]
Single straight sheathing		2000	350	120	1,75
Double straight sheathing	Chorded	15000	2627	600	8,76
	Unchorded	7000	1226	400	5,84
Single diagonal sheathing	Chorded	8000	1401	600	8,76
	Unchorded	4000	701	420	6,13
Straight sheathing over diagonal sheathing	Chorded	18000	3152	900	13,13
	Unchorded	9000	1576	625	9,12
Double diagonal sheathing	Chorded	18000	3152	900	13,13
	Unchorded	9000	1576	625	9,12
Panel overlay on sheathing Unblocked	Chorded	9000	1576	450	6,57
	Unchorded	5000	876	300	4,38
Panel overlay on sheathing Blocked	Chorded	18000	3152	-	-
	Unchorded	7000	1226	-	-

Particular attention was given to producing a step-by-step practice-oriented guideline that provides background information which helps understand better the procedure framework and also gives suggestions for alternative interpretations when multiple choices are possible.

Table 2 Shear stiffness values [kN/m] for straight sheathed vintage timber floor diaphragms [2]

Direction of loading	Joist continuity	Condition rating	Shear stiffness (G_d)*
Parallel to joists	Continuous or discontinuous joists	Good	350
		Fair	285
		Poor	225
Perpendicular to joists**	Continuous joist, or discontinuous joist with reliable mechanical anchorage	Good	265
		Fair	215
		Poor	170
	Discontinuous joist without reliable mechanical anchorage	Good	210
		Fair	170
		Poor	135

* Values may be amplified by 20% when the diaphragm has been renailed using modern nails and nail guns
** Values should be interpolated when there is mixed continuity of joists or to account for continuous sheathing at joist splice

The main approach-differences that are discussed in the paper, can be synthetized as: 1) diaphragm demand is based on the elastic shear stiffness in ASCE [1] (**Table 1**) while NZSEE [2] employs the secant stiffness at 100 mm midspan deflection (**Table 2**); 2) unlike ASCE, NZSEE regards diaphragm in-plane behaviour as orthotropic; 3) different static scheme are assumed for the evaluation of the diaphragm period; 4) direct limitation to diaphragm deflection is prescribed only by NZSEE for linear procedure. An extensive diaphragm modelling work was undertaken by the authors, the results of which are currently being analysed and will be reported in the near future. Preliminary results seem to suggest that factors like the aspect ratio and the diaphragm size might have a significant influence on the diaphragm response and on the definition of diaphragm properties. Therefore, in order to compare and correctly evaluate different diaphragm assessment procedures, the specific background conditions behind each procedure should be accounted for (e.g. details about the experimental background, assumptions on diaphragm/building behaviour that are based on aspects common in the country where the standard has originally been applied).

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ASSESSMENT AND DIAGNOSIS OF TWO COLLAR TIMBER TRUSSES BY MEANS OF VISUAL GRADING AND NON-DESTRUCTIVE TESTS

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Keywords: Timber trusses, Visual grading, NDTs, Damage maps

Abstract

The main objective of the present work is to evidence the importance of the inspection and diagnosis phase on the assessment of existing timber structures through visual grading and non-destructive testing (NDT), especially for old structures with historical importance. To that aim, two collar timber trusses (trusses T1 and T2) were inspected and assessed.

The first part of this work presents the visual grading procedure complemented with NDT. During that part, all the elements of the trusses were visually inspected with consideration of its geometric characteristics, its defects and critical sections. NDTs, such as impact penetration, ultrasound and drilling resistance tests, were carried out in order to characterize the level of conservation of the elements at its present condition. The combination of the results of all NDTs allowed for a more substantiated grading of the segments and consequently of the elements. The results are presented through damage maps. In the second part of this work, a comparative analysis between the two trusses is made considering the prior results of the NDTs and the performance of the trusses on the full scale tests. To that aim the results of the visual grading and NDTs are correlated to the sections were failure of the segments was visible.

Results of Inspection and Diagnosis

From the analysis of the visual grading and damage maps obtained through the NDTs it was observed that one of the trusses had higher percentage of elements in lower classes. The different NDTs provided an important insight to the conservation condition of the timber trusses. The results of NDTs efficiently evidenced the segments where higher decay was present. The overall results allowed to determine that the critical sections were found in the rafters, mainly in the supports and on the connections with the tie-beam and post, consistent with visual grading. Nevertheless, the correlations between quantitative results obtained by section (for impact penetration tests and drilling resistance tests) were low.

Comparative Analysis

Truss T1 was able to sustain a higher level of load compared to truss T2 . In terms of visual grading, truss T2 had higher percentages of lower grades and also evidenced a higher level of degradation confirmed by NDTs. It was also possible to verify that failure of the elements took place on segments that were initially considered as possible weak sections accounting their lower visual grade. Taking as example truss T2, three main failures were found during the mechanical test, namely failure of both rafters on sections near the connection with the tie-beam and failure near the connection of one rafter with the post. Those failures coincided with sections with lower visual grades as presented in Fig. 1.

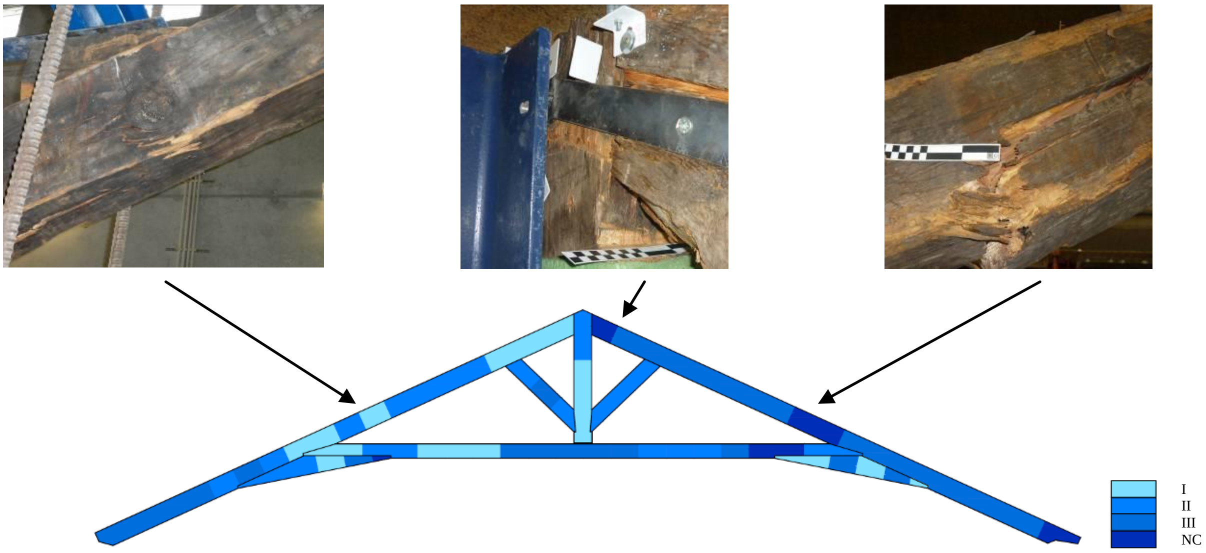

Fig. 1 - Visual grading of truss T2 with details of the failure of the rafters and of the post-rafter connection.

Conclusions

The first step of the assessment of an existing timber structure is its diagnosis accounting the results of visual inspection and non-destructive tests. This step is crucial to identify possible weak sections and thus for a better understanding of the mechanical performance of the structure. The results taken from it, are also extremely important for the calibration of more complex analysis or numerical models.

In this work, the results of visual grading and of non-destructive tests on two old collar trusses were considered for identification of their weak sections and to understand their overall state of conservation. To that aim, damage maps considering visual grading, impact penetration, drilling resistance and ultrasound results were made and analyzed. Also, correlations between tests were made, concluding that a qualitative analysis may be used to sustain the initial visual grading.

Finally, the results of the diagnosis was compared with the results of full-scale tests, and it was observed that visual grading allied with the results of non-destructive tests may efficiently identify possible weak sections, as well as serve as a means of comparison between the two tested trusses.

Acknowledgments

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DEVELOPMENT OF DISSIPATION PANELS FOR SEISMIC RETROFITTING OF HISTORIC BUILDINGS

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Keywords: Seismic retrofitting, energy dissipation, dissipation panels, innovative technology.

Introduction

In the reconstruction of Lisbon after the devastating earthquake of 1755, an innovative structural solution was implemented. The historic timber framed masonry walls represented then a key structural element regarding seismic action [1]. As often as not the buildings that incorporated these seismic resistant walls require interventions in respect of their original structure, re-establishing or enhancing the seismic behaviour.

Innovative Dissipation Panels for seismic retrofitting are under development. The design of the Dissipation Panels was based on the role of the historic timber framed masonry walls as well as on the incorporation of the quite recent seismic protection system, which reduce damage and limit losses more effectively than the traditional approach. The new technology was designed to improve the energy dissipation capacity of the buildings associated with seismic actions whilst respecting their original structural concept and, therefore, their authenticity.

Full scale prototypes of the developed Dissipation Panels were produced and tested in order to characterize its cyclic behaviour. The prototypes were subjected to cyclic tests performed at the Laboratory of Structures and Strength of Materials of Instituto Superior Técnico (IST).

Experimental setup

In the concept design of the experimental prototypes, allowance for good cyclic behaviour was addressed. Basic conception of the Dissipation Panels corresponds to an articulated supporting frame with an embodied dissipative damper. The Dissipation Panel was designed to exploit the dissipation behaviour of the embodied damper, which for this study has hysteretic properties. First studies are hence related to an Hysteretic Damper made of steel with a very simple geometry. The Hysteretic Damper, as the main and central body of the Dissipation Panel, was designed to take advantage of the plastic behaviour of steel. Testing and validation of other types of dampers are included in the scope of this research study.

The experimental program comprehended two main parts. The first part corresponded to the mechanical characterization and hysteretic capacity assessment of the Hysteretic Dampers alone – Fig. 1. The second part of the experimental program aimed at determining the cyclic behavior of the Panels – Fig. 2 – and evaluating the energy dissipation capacity as a main criterion of its efficacy.

Results

Damper

The mechanical properties of the Hysteretic Dampers were obtained by means of cyclic tests that were carried out in an universal Instron testing machine as shown in Fig. 1. Physical models of the dampers were subjected to tensile-compression tests.

The hysteretic diagrams that resulted from testing the Hysteretic Dampers present growing displacements amplitudes from one cycle to the next cycle. As the damper plasticizes, energy dissipation occurs due to inelastic hysteretic response.

Dissipation Panel

Full scale models of individual prototype units of a complete Dissipation Panel were produced and tested in order to characterize its cyclic behaviour. The Dissipation Panels were subjected to cyclic quasi-static tests performed in the reaction wall at the Laboratory of Structures and Strength of Materials of Instituto Superior Técnico (IST) as presented in Fig. 2.

The experimental diagrams of the prototypes of the Dissipation Panels show good capacity to dissipate energy, both in tension and in compression. The energy dissipated in each cycle corresponds to the area enclosed by the load-displacement curve.

Figure 1 – Experimental setup for testing the Hysteretic Dampers.

Figure 2 – Experimental setup for testing the Dissipation Panels.

Conclusions

Design of the Dissipation Panels is based on the role of the notable historic timber framed masonry walls that were used in the reconstruction of Lisbon after the catastrophic earthquake of 1755. This similarity allows for the interventions in the buildings to be compatible, reversible and low intrusive thus respecting and preserving the existing structure. Additionally, the incorporation of seismic protection systems in the conception of the Panels provides energy dissipation in view of reducing damage and limiting losses more effectively than the traditional approach.

A series of full scale cyclic tests to evaluate the performance of prototypes of the Dissipation Panels were carried out. Experimental characterization of the dynamic behaviour of the conceived prototypes show good energy dissipation capacity. Optimization of the behaviour of the Dissipation Panels is in progress seeking to respond effectively to the constant search for economical and technical competitive solutions.

Acknowledgments

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RETROFITTING ASSESSMENT AND NUMERICAL MODELS FOR THE HISTORICAL TIMBER ROOF STRUCTURES OF THE TOWERS OF VALENTINO CASTLE IN TURIN

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Keywords: Earthquake-resistant, Timber roof, Assessment, Reinforcement intervention, LiDAR survey, 3D modeling.

Abstract

The paper analyses a reinforcement intervention conceived by one of the authors (C. Bertolini) and performed on the historical timber roof structure of the Valentino Castle in Torino (Italy) some thirty years ago. The timber roof of the towers, dating back to 17th century, is a three-dimensional frame structure with a height of about 12 m. In the transversal direction four main great trusses are present, and two small trusses are placed close to the transversal masonry walls. The pitch is strongly inclined. A ridge connects the structure in the longitudinal direction of the timber roof, in addition to five series of purlins and three orders of overlaid frames with stiffening functions. This structural complex is firmly secured to the covering planks that support the tiles of black stone. The intervention was carried out with timber elements anchored to the ancient masonry walls, in order to improve their seismic behaviour. This intervention proved to be particularly innovative, since at that time the regional area where the castle is located was not yet considered a seismic area by the national standards. Laser scanning surveying, non-destructive investigations and numerical simulations are adopted in the present study, in order to assess the efficiency of the intervention and the present condition of the joints.

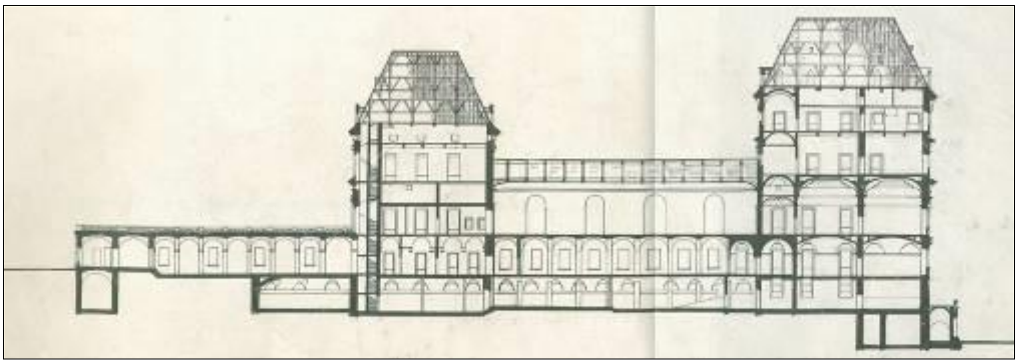

Fig. Timber roof structure of the Valentino Castle in Turin

Conclusions

The current abundance of technical and technological solutions for reinforcement interventions on timber structures requires ex-post evaluations to assess the effectiveness of interventions on historical structures. The positive assessment of the new accurate structural analysis improves and optimizes the results obtained at the time of the intervention carried out 30 years ago. This confirms the durability of an intervention performed with minimally invasive techniques due to the tri-dimensional behaviour of the structure. The structural analyses clarified that a proper model must precisely represent the structure and must include the constraining effect of the planking system. Proper structural modeling, detailed surveying and coherent technological interventions were crucial for the preservation of this important timber roof structure dating back to four centuries ago.

Fig. The timber roof structure of the north-east tower nowadays (photo C.B.)

This experience highlighted the importance of an interdisciplinary approach in order to face similar situations. This interdisciplinary approach is effective in saving resources while improving the assessment, in particular considering the different specialized investigations that are needed in any knowledge phase.

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LOAD-BEARING CAPACITY OF TRADITIONAL DOVETAIL CARPENTRY JOINTS WITH AND WITHOUT DOWELS: COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

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Keywords: Dovetail joints, testing, analytical models, capacity

Extended abstract

Introduction. Post-disaster field studies widely suggest that historical timber structures are seismically resistant, and a growing number of experimental studies support this observation. The joints between structural members, which are the major energy dissipation mechanism within the structure, play a crucial role in the overall robustness and the way that a structure handles the seismic demand. Joints mostly fail when the timber members are still in the elastic range, therefore a thorough understanding of their behaviour under various loading schemes is of utmost importance to gain deeper insight about the overall structural performance of timber structures. This paper summarizes the findings from a series of testing carried out on dovetail joints, which is one of the most common traditional carpentry joints, during the 5th COST FP 1101 Training School, held in University of Minho, Portugal. Within this framework, a dovetail joint (with and without dowel) was tested under compression and tension (Figure 1 and Figure 2). The experimentally obtained load-bearing capacity of the joints was then compared to the capacity values calculated using analytical models, and the failure modes were further discussed.

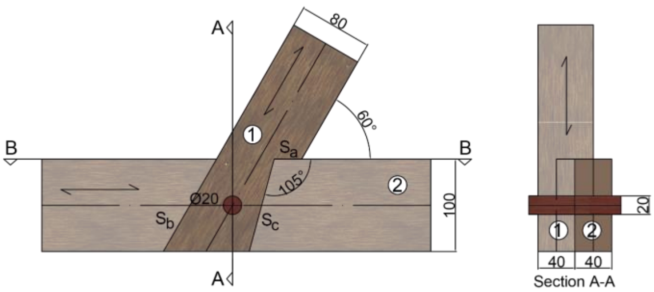

Figure 1: Geometry of tested dovetail joints with the dowel

Calculations. Calculations made here follow the Eurocode 5 (and Johansen's equations) philosophy: to every possible failure mode of the dovetail joint matches a failing load, and the minimum of all failing loads corresponds to the capacity of the connection. Those possible failure modes are (see Figure 3): (1) Failure of the dowel, (2) Splitting near the dowel, (3) Extraction of a shear plug around the dowel, (4) Excessive compression perpendicular to the grain on the horizontal element, (5) Excessive compression at an angle to the grain on the skew element, and (6) Interaction between tension perpendicular to the grain and shear.

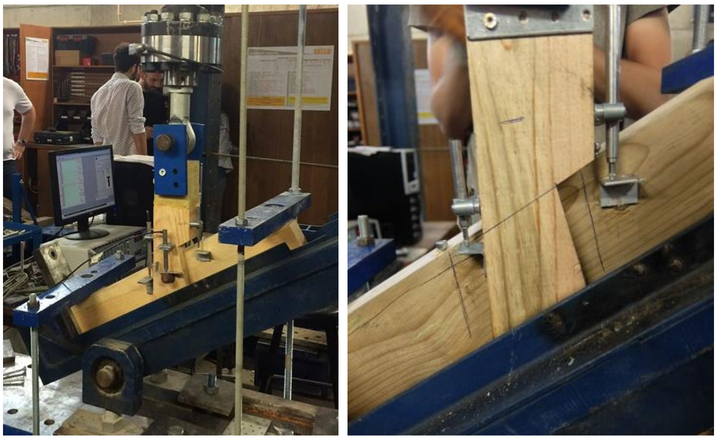

Figure 2: Dovetail joints with and without dowel during experiments

Discussion. The results showed that the experimentally obtained capacity values can be successfully reproduced and the failure mode can be correctly predicted by analytical models for dovetail joints without dowel. On the other hand, the capacity of a dovetail joint with dowel under compression or tension (i.e. the minimum value among capacities calculated for each failure mode) is always underestimated by analytical models (Figure 3). The engineers who are commissioned for the condition assessment and retrofitting of traditional timber frame structures with carpentry joints should pay utmost attention to this discrepancy. The carpentry joints are not standard, and this study clearly shows that the proposed analytical models should be further fine-tuned to reflect their load bearing capacity and behaviour under certain actions.

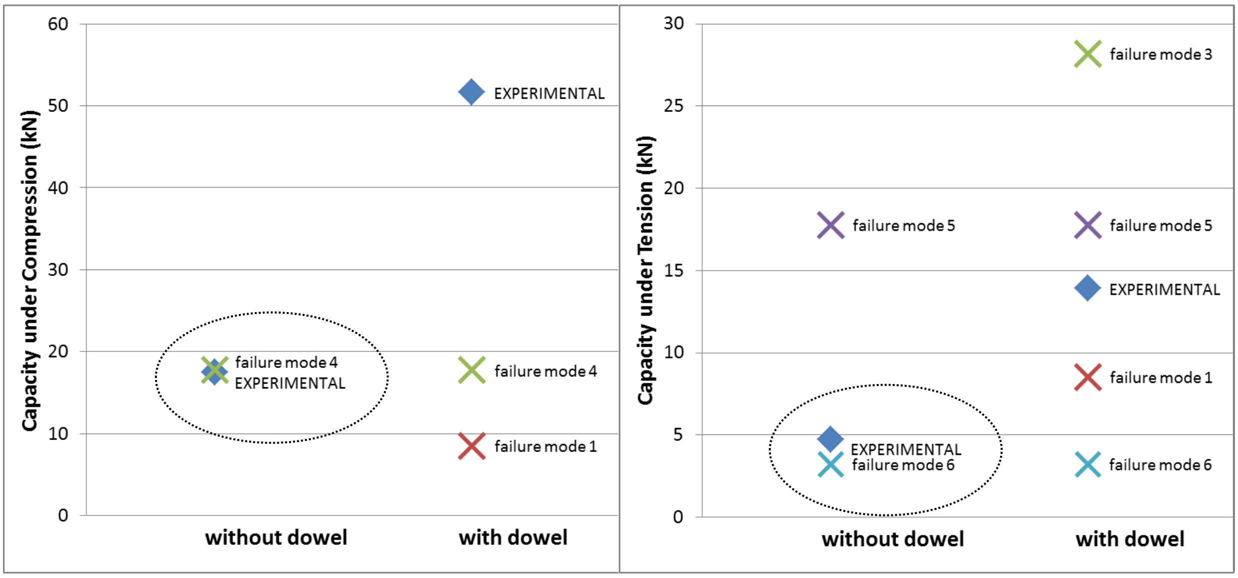

Figure 3: Experimentally and analytically obtained capacity results

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A TIMBER ROOF STRUCTURE FOR THE MILREU RURAL HOUSE REHABILITATION

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Keywords: Timber roof, rehabilitation, heritage, high seismicity, aesthetics.

Extended abstract

1. The Algarve Roman Ruins of Milreu – the historical site

The Algarve region in southern Portugal used to be a Roman province with important settlements along the main road from Silves (west zone) to Seville, Spain. Currently, it is an important leisure destination for European citizens. In the Algarve central region, near the capital Faro is the archaeological site of Milreu known for its Roman ruins with a Villa and a Water temple. In the late XIX-th Century it was extensively excavated by a Portuguese archaeologist Estácio da Veiga and recently, in the 1950's by the German Archaeological Institute under the supervision of Dr. Theodor Hauschild. Under an EU program this site was rehabilitated with a new visitor's information center, a pedestrian circuit through the masonry walls' ruins and mosaics and the rural house restoration, see Fig.1.

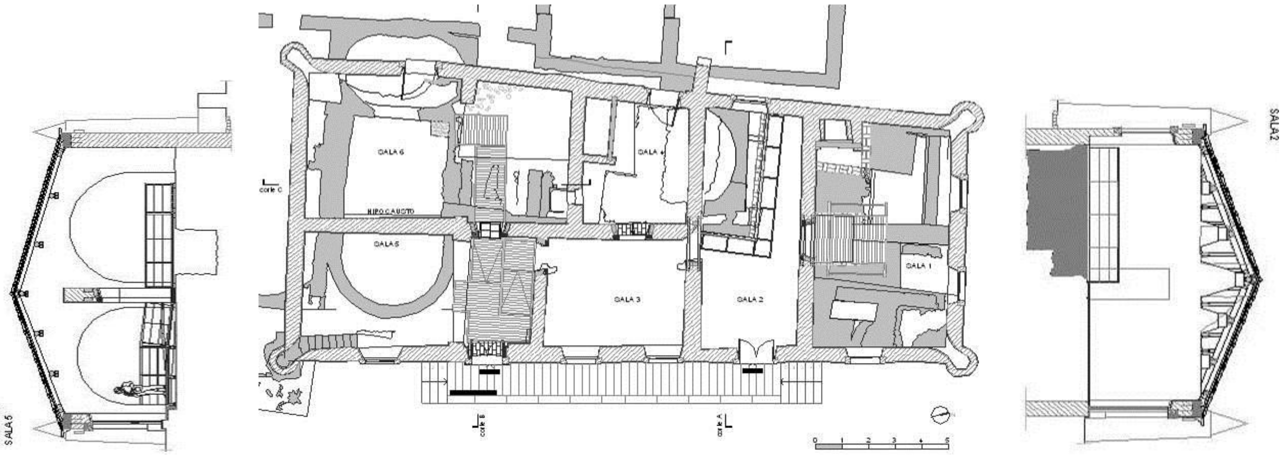

a. Existing building (1970's)


b. Rehabilitated building (2000's).

Fig. 1 – The Milreu archaeological site – the XVI-th. Century Rural House.

2. The rehabilitation process - a timber roof design solution for a high seismicity zone

This unique Rural House building construction goes back into the XVI-th. Century. It is sitting on the top of the existing roman ruins and it experienced successive extensions until the XIX-th. Century, see Fig. 2. This ancient construction must have caused a strange impression on the Portuguese Nobel prize winner José Saramago because he mentioned in his book "Journey in Portugal", as a singular abandoned building where the shepherds and their flocks slept under the same roof.



a. South section b. Building plan with the Roman ruins. c. North section.

Fig. 2 – The building survey and structural design proposal.

The building was “rehabilitated” in the 1970’s with a heavy precast prestressed concrete roof cover, with hollow ceramic infill blocks and a cast “in-situ” concrete top layer. During some decades, small displacements were observed in the masonry walls, followed by increasing cracks, which prompted the Portuguese Heritage Agency to initiate an intervention. Several major problems had to be solved, in particular, the structural concrete roof system removal, to bring this building to the adequate conditions to be visited by the public. The design proposal to reduce the equivalent seismic action at the roof level required the removal of the structural concrete roof slab, with an estimated total dead load (DL) of 120 tons. A new timber roof system made with maritime pine replaced the existing roof, decreasing the total DL more than 2/3 to 40 tons., see Fig. 3.

Fig. 3 – The timber roof structure with the short masonry pylons supports.

This solution had several advantages: (a) better aesthetics; (b) improved seismic response reduced DL mass; (c) improved comfort levels (ventilation, temperature, insulation). The final result was highly praised by the owner and the visitors.

3. Final Observations

The rehabilitation process was extensive and costly owing to the lack of experience of the local contractors in using traditional materials: timber members and assemblages; lime mortar wall finishing; and limestone masonry. In-situ training was required to achieve the desired final results and meet aesthetic requirements. The impressive timber roof system was one of the best adopted design decisions. The final cost was within the budget estimate of Euro 250.000.- and the final result was excellent. This solution can be recommended for other local public rehabilitation works.

DESIGN AND MAINTENANCE FOR A LONG-SPAN TIMBER ROOF

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Keywords: Timber roof, rehabilitation, heritage, low seismicity, aesthetics

1. Introduction

In the 1990's, a design proposal was submitted for the rehabilitation of a horse-riding school (the "manège") located in the historical Citadel of Almeida. A new heritage restoration policy – the "Aldeias Históricas" (Landmark Villages) had been implemented by the Portuguese Government, through European Union (EU) funding, to develop the hinterland regions and attract new populations. In the first phase of this program, the horse-riding school building was the largest restoration work in value. The Almeida house façades, the fortress walls were also rehabilitated and, with the horse-riding school they became a major tourist attraction in this unique landmark Portuguese village. The construction constraints and the degree of isolation the Citadel of Almeida, near the Spanish border, the lack of technical human resources, and the high-level of abandon that this location showed during the past decades, increased this restoration process challenge, Fig. 1.

Fig. 1 – The Citadel of Almeida (1990's) and the *Manège*, Beira Alta Province, Portugal.

2. The Design Proposal – Low Seismicity Zone

A structural timber roof system was proposed, after comparing with different material design options including steel, reinforced concrete and glulam, because of highly aesthetics and visual appearance.. Due to the relatively small size of this indoor space (13.50m x 40.50m) a scissor's truss was adopted to increase the available height and improve the spatial conditions. The timber members were made out of southern yellow pine with 12,0m long pieces that were cut to the proper size members. The building plan was slightly tapered with a 1.40m difference in the span length from both ends and, fourteen different plane trusses had to be designed individually, for the entire building length. Steel custom designed supports were used: the fixed hinged support topped the "giant" granite masonry columns and the other support had a sliding neoprene rubber pad to allow for horizontal movements (temperatura, humidity; creep) Seismic loads were reduced as compared with therequired larger design code values for snow actions.

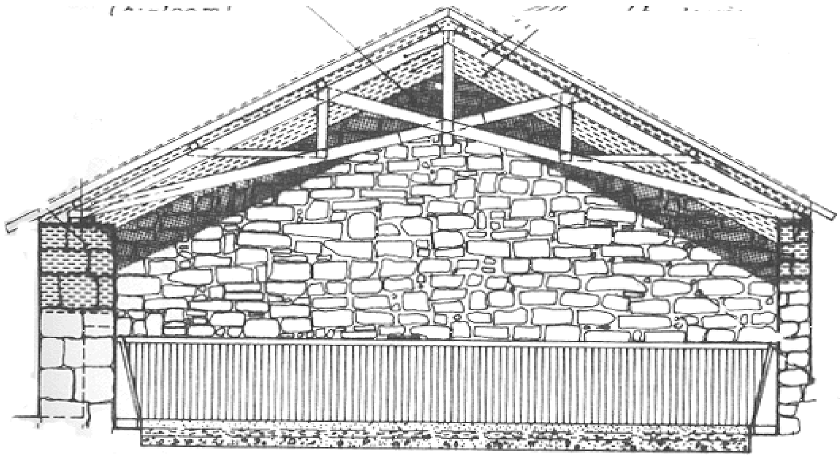

Fig. 2 – A 14.60m span scissor's timber truss for the horse-riding building.

3. Conclusions and Recommendations

This building rehabilitation process was one of the most successful projects, for the EU "Aldeias Históricas" (Landmark Villages) program (Phase I), sponsored by the Portuguese Heritage Office (IPPAR) due to the excellent craftsmanship and the use of structural timber. In this solution the structure is completely exposed to the public view and detailing plays a major role, see Fig. 3. Low maintenance and a simple technical assistance to the contractor's team deserves to be mentioned.

a. South façade with "giant" columns. b. Interior view towards west end wall.

Fig. 3 – The Citadel of Almeida *manège* rehabilitation project.

Seldom major structural timber structures are designed in current Portuguese practice for heritage rehabilitation works. The Almeida *manège* results from a highly motivated research work and a team effort to promote the use of a noble material – wood, in the historical landmark buildings. In these buildings extra care and personnal efforts (innovation, original designs, careful detailing) are required as they are subjected to extensive public scrutinity.

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HISTORIC EARTHQUAKE-RESISTANT CONSTRUCTIVE TECHNIQUES REINFORCED BY WOODEN LOGS IN ALGERIA

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Keywords: Earthquake-resistant, Timber Frames, Algiers, Miliana, Batna, Algeria

Abstract
Algeria has experienced in the past several moderate seismic events that caused loss of human lives and damage to property in different regions, Algiers (1365, 1716), Cherchell (1732), Dellys (1731), Oran (1780), Blida (1825, 1857), Jijell (1856),Constantine (1858) and Biskra (1869). What architectural elements and structural techniques did the local population use in their constructions to protect themselves against earthquakes? Many techniques are the results of a continuous of a learning circle of trial and error process which gradually improved along time to adapt and resist to the changing requirements of the physical seismic environment. The structural failure of historical buildings during earthquakes has often led to a better understanding of their performance and improvements in their design. Among the traditional seismic preventive techniques highlighted in many region in Algeria, we identified the traditional historic timber frame that made eventually theses buildings resist such several earthquakes in northern and eastern Algeria. This paper presents the historical resistant masonry system and constructive aspect used in historical masonry reinforced by wooden frames in Algiers, Miliana, and Batna (Menaa and Amenthane) such as seismic isolation foundation, reinforced arches, reinforced masonry walls, links between orthogonal walls. These constructive techniques represent today the Transferable Indigenous knowledge in seismic area in Algeria.

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TRADITIONAL TIMBER HOUSING STRUCTURE IN ZEYREK

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Keywords: Traditional housing, Timber Structures, Integrated Conservation, Zeyrek.

Abstract

Zeyrek, as a World Heritage Site and one of the important residential areas of the old city of Istanbul, has an significant number of historical timber houses belonging to late 19th - early 20th century. Due to its topographical, climatic, social, economic and cultural features as well as its nearby wooded environment, local materials and traditional technology, Zeyrek has reflected a precious architectural pattern consisting of many of timber-framed buildings for a long time.

This paper examines traditional architecture, presents and promotes the experimentation with timber housing restoration in Zeyrek, Istanbul, aiming to analyze the existing wooden housing pattern in the area and to investigate the restitution and restoration project of a traditional timber house in detail. The proceeding of conservation and restoration in traditional timber housing structure meanwhile maintaining these buildings extracted positive lessons in history. In this context, the classification of physical characteristics commonly found in these timber housing settlement has been done considering the method of construction, the facade proportions of the elements, plan schemes, articulation of different forms, the conservation and restoration projects in the site.

The present study follows methodological principles of historical research about Zeyrek. A case study about traditional timber house structure consists of field surveys and documentation. According to observation and analysis of the traditional housing settlement, the main classifications were obtained, along with photographical survey showing the current situation of the timber housing characteristics of the site. All of these documents are demonstrated by a case study; a timber house structure in Zeyrek. The paper focuses on this transformation by putting forward integrated conservation approach.

This study consists of 5 main chapters including introduction and conclusion. The first part, which is introduction includes general information about Zeyrek World Heritage Area. In the second part of the study, the aim of the study and a brief history of conservation of the site will be explained. The third part includes survey, restitution and restoration of the traditional timber structure in Zeyrek World Heritage Area and the fourth part includes integrated conservation works related to the area.

History of Conservation in Zeyrek

One of the most famous and symbolic settlements of the Turkish era, The Fatih district originally developed around the first large mosque and imaret of Istanbul. In the southwest it is connected to Aksaray with the Etmeydanı and Horhor quarters. To the east it is circumscribed by Saraçhanebaşı, Şehzadebaşı, and toward the Golden Horn Zeyrek, Çarşamba and Sultan Selim and in the Edirnekapı direction. The area where the quarter is located has retained its status as a religious symbol since the foundation of the city.

The quarter was devastated by the fire in 1908, while thousands of buildings in the region were consumed by the Cibali fire of 1918. In the perion prior to World War I small-sacle, two or three-storey apartment houses gradually began to replace the wooden ones based on a grid-iron plan.

Zeyrek is located at a key point in the histories of both the Byzantine and the Ottoman Empires.
Zeyrek is situated on the fourth hill of Historic Peninsula. One of the most significant example of Byzantion Architecture, Pantokrator Monastery founder by Empress Eirene in the 12th century and timber houses of Ottoman Architecture gives the unique identity to Zeyrek.
Zeyrek's historical legacy, unique architecture and well-preserved neighbourhood helped it gain an Urban Conservation Area status in 1975; in 1985, it entered the UNESCO World Heritage Project list. Needless to say, the district had survived many a catastrophe until then. Fires that started in the workshops at the Golden Horn shores spread through, fuelled by the North winds, causing immeasurable damage in the wooden buildings, creating the need for reconstruction. These fires impoverished the residents, changing Zeyrek's texture and architecture.

Fig. 1 *General view of Zeyrek Conservation Area (Akcabozan, 2015)*

As quoted from the Istanbul Project: Istanbul Historic Peninsula Conservation Study, the opportunities of the area and contribution to the conservation of immovable cultural beings. Zeyrek Conservation Area boundaries were first determined in 1974 and ratified by General Statute in 1987. A total of 469 buildings are surveyed in the study, that 51% of them are listed. 86% of the listed buildings, are defined as civil architecture. Molla Zeyrek Mosque is one of the most important monumental structures in the region, and the most symbolic of it [1].
Although many public and private institutions have made great efforts to emphasize the importance of the issue, the conservation of cultural beings is an ongoing problem in Turkey. Zeyrek World Heritage Area is analysed in detail in terms of conservation problems threats and potentials. Effective conservation and integrated conservation approaches are necessary to enhance the environments and to create better income opportunities or the people living in the area by re-functioning regulations along with residential use.
In Zeyrek, attempts are presently directed towards upgrading the surroundings of the Pantokrator with the intention of raising awareness for the preservation of the area and attracting the attention of investors or sponsors. Vernacular timber housing in Zeyrek quarter was recognized as vulnerable at the time of incription. Despite the threat of pressure for change, many efforts have been carried out in order to conserve and strengthen the timber structures within the site.
Therefore, changes of the social structure in the area have also affected the use of those structures. Loss of historical monuments, architectural integrity of the city, traditional materials and techniques. Additionally, socio-economic reasons and high costs of restoration can decelerate the conservation process. By the integrated conservation process; social groups and property owners may collaborate and all timber houses in the Zeyrek World Heritage Area could be saved. The revival of the Zeyrek quarter is a long term Project which demands a detailed process of cleaning, conservation and restoration.
The aim of this study is to analyze the existing wooden housing pattern in the area and to investigate the restitution and restoration project of a traditional timber house in detail. The proceeding of conservation and restoration in traditional timber housing structure meanwhile maintaining these buildings extracted positive lessons in history.

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POMBALINE BUILDINGS - CONSEQUENCES OF SOME REHABILITATION INTERVENTIONS

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Keywords: Pombaline downtown, seismic vulnerability, rehabilitation.

Introduction

The Pombaline buildings of downtown Lisbon have undergone some forms of adulteration across time with a greater impact in recent years due to an increase in tourist activity.
After the great earthquake of 1755, this area has been rebuilt according to an innovative, enlightened urban plan. The buildings have been built in a short period of time using a standardization and prefabrication system and also an innovative anti-seismic technique - the "Pombaline cage" - which was an unparalleled Portuguese contribution to construction technology and anti-seismic engineering.
The recent conversion of historic buildings in hotels has led, in many cases, to total internal demolition while maintaining the facade in its original condition. This solution is not recommended in the case of historic centres because the maintenance of the internal structure and original materials of buildings is crucial to protect its authenticity. It may also undermine the performance of buildings throughout the quarter in the event of a major earthquake.
There are also other situations in which the buildings undergo major changes that may impair their performance in case of earthquake, such as for example the construction of basements, the erection of additional floors and the increase of structural rigidity.
This paper is based on literature review and previous research work carried out by the authors. It describes the original structure of a Pombaline building and the major alterations that these buildings have undergone as well as the implications on their overall performance in the event of an earthquake.

Relevance of Pombaline Buildings Preservation

The Pombaline building system was created after the great 1755 earthquake. Developed in a chaotic manner, the ancient city of Lisbon was destroyed by the earthquake followed by a tsunami and a great fire in a sequence of destructive events that took place for several days.
Several technical solutions to rebuild the city have been considered but the one selected was to use the rubble debris of the earthquake. This solution would protect the city from the occasional floods originated by sea level variations and would allow a more efficient drainage.
The plan was based on a standardized building process consisting of a regular and orthogonal set of main streets and modular typology for the new buildings and their main facades. The building aspect was defined hierarchically according to the importance of the street and the type of activity it would support. The plan presented innovative concepts in terms of workability and hygiene and contained some technical solutions to prevent future calamities, including improved safety precautions against fire.

The construction was carried out under serious human and material resources constraints because it was urgent to quickly rehouse a great number of inhabitants and rebuild the city in a short time span. However, great care was devoted to the quality of construction and anti-seismic and fire safety.

Pombaline Building Characterization

Pombaline buildings are arranged in blocks of buildings. Each block is delimited by orthogonal streets creating rectangular blocks. According to the urban plan, all buildings had the same height, with a ground floor, three elevated floors and a dormer. This led to a group of buildings with identical dynamic characteristics, which provided a better seismic performance.

The Pombaline building is also characterised by its interior architecture, with a number of typical characteristics common to all buildings. The Pombaline building structure is easily identified by the existence of a characteristic wooden structure named "gaiola" ("cage"). This structure consists of a mutually perpendicular braced three-dimensional wooden frame. The buildings usually have an ample ground floor to allow the installation of trade or services.

Modifications in Pombaline buildings that may lead to different structural performance

Over time, a number of interventions in these buildings have been observed. These are usually associated with the introduction of new features and enhancements such as additional floor layers or adaptation to new uses, which completely alter the initial structural system and compromise the building's performance in the event of an earthquake. These changes can be specific, such as removing walls, widening spaces and changing the usage conditions of the floors, which is usually associated with an increase in acting loads and stresses on structural components.

A more severe type of change is related with the height of the building such as increasing the number of floors without any prior study or stability project. Another type of burdensome interventions consists of removing structural elements at ground floor level to increase door frames or to create wider open-spaces. These openings reduce the area of vertical structural elements, which causes an abrupt reduction in stiffness at this level creating hollow floors and weakening the building in an area that will be most requested during the occurrence of an earthquake. The removal of wooden elements, thus interrupting the three-dimensional cage structures, and the removal of some columns and walls on the ground floor lead to serious damage in the original structure, increasing the vulnerability of buildings to seismic actions.

Final remarks

Pombaline buildings testify to the ingenuity and expertises demonstrated in very adverse conditions and are a landmark of earthquake engineering as the anti-seismic construction techniques were applied at a city scale for the first time. Therefore, they are a valuable asset that must be preserved, cared for and transmitted safely to future generations. The original Pombaline buildings have good anti-seismic performance taking into account the technical and material constraints at the time of build. However, some of these buildings have undergone repeated interventions with the purpose of adapting them to the new demands of comfort, features and uses. Some of these interventions were carried out without taking into account the original material and techniques characteristic of Pombaline buildings, severely affecting their original structure. Today, several Pombaline buildings present great seismic vulnerability due to interventions that reduced their ability to support horizontal actions. Under the guise of "rehabilitation", some of these buildings are now completely destroyed.

The preservation of the historical and heritage value of Pombaline buildings is crucial and therefore it is imperative to preserve the Pombaline cage in as many buildings as possible in future rehabilitation interventions.

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POSSIBLE PRECURSORS OF POMBALINO CAGE

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Keywords: Pre Pombalino, Pombalino cage, Military architecture and engineering, Timber-framed structure, Treatises, Historical Earthquakes

Extended abstract

The purpose of this study is to understand which could be the precursors of Pombalino cage. The literature shows large interest in the Pombalino cage created after the 1755 Lisbon earthquake and tsunami as an engineered solution designed specifically to be resilient to earthquakes. In spite of that, this milestone in the history of earthquake engineering continues to present an unclear vision about the facts that would have led to its creation. Considering this gap, in addition to the lack of contemporary design plan elements specifically about this construction system, this paper tries to highlight facts appropriately to be assumed as relevant precursors of the Pombalino cage. For this purpose, the research analysed different levels of background knowledge on the Pombalino cage, defining the key issues that should be present in historical interpretations of its concept. Therefore, the main topics of the discussion are the following: (i) traditional timber-framed construction systems belonging to earthquake-prone regions; (ii) influential contemporary knowledge on the 1755 Lisbon earthquake; (iii) Portuguese legislation, regulations, and notices published after the earthquake; (iv) the academic education and training of Portuguese military civil engineers and architects (before and after the earthquake); (v) conclusions about the precursors of the Pombalino cage.

This research is based on in situ surveys of old buildings, documentation from several libraries (including Torre do Tombo), books, theses, ancient treatises, and previous research by the authors. The study of historical earthquakes reveals a significant number of strong earthquakes in the past throughout the Mediterranean region, although South American earthquake events were also reported in Portugal. After the Sicilian earthquake in the twelfth century, several other strong earthquakes happened in the south of Spain, Italy, Greece, and Portugal up to the seventeenth century. In all these countries, there are traditional composite construction systems with timber. Previous studies by the authors and other researchers have shown some links between these systems and between some others, including in Turkey and Kashmir. Some of the timber-framed systems contemporary to 1755 should be mentioned, namely the Spanish (central region), the Italian (Herculaneum), the Portuguese pre-Pombalino (Lisbon), the Turkish *himis* (northern region), and the Greek systems. In spite of the fast-disappearing and deep alterations of pre-Pombalino buildings, on a few of them are present nowadays parts of old structures, that this research compared with the mentioned timber-framed systems. From this concluded that pre-Pombalino buildings are a valuable multicultural heritage that could have played a part in the decision to adopt a composite system with timber. The Lisbon earthquake that affected Spain and Morocco triggered

a large number of publications, manuscripts, and debates in the scientific community (J. J. Rousseau, F. M. Voltaire and I. Kant) and society in general. From these, only information that could influence the Portuguese decision-makers was selected and it is discussed in this manuscript.

It emphasizes the role of the *Tratado da Conservação da Saúde dos Povos* by the Portuguese physician Antonio Ribeiro Sanches (1699-1783) published in 1756 in Paris and marketed in Lisbon at the same time. The relevance of this treatise shares the pragmatic background of the Pombalino cage, including putting concerns about urban control, regularity, and the improvement of security and living conditions above concerns about aesthetic values or urban speculation.

Again, the analysis of the legislation (during the reconstruction of Lisbon) stems from an interest in understanding what resources or procedures were needed to mobilise and possibly influence the characteristics of the Pombalino cage design. Particular interest show the 12th May 1758 and 12th June 1758 regulations with statements about the advantage of the new type of construction system in rebuilt areas 'benefit from fewer risks of future seismic and fire damage' and some other construction concerns. In order to understand the background of the Pombalino cage, the large number of timber constructions built during the reconstruction process should be considered.

The Pombalino cage is an engineered solution that was conceived by Portuguese skilled in architecture and military engineering. The association between military knowledge and architecture or engineering (through military academies), through military treatises (national and international), attack or defence practice is discussed in this manuscript.

The main team nominated for the reconstruction of Lisbon were mostly military technicians, both architects and civil engineers: Manuel da Maia (the coordinator of the team), Carlos Mardel, Eugénio dos Santos, and Elias Sebastian Poppe. In addition to their links to the Military Academies as professors or students, they had also worked together in relevant constructions before the Lisbon earthquake. They followed the established role for this type of technician, which involved surveys, design plans, measurements, and overseeing construction. From these experiences, this research considers their participation in the construction of Mafra convent (40.000 m^2) as specifically relevant. The construction of this great monument imposed the need for temporary housing, a hospital, and a church, all of which were built with timber. The complementary structures used in the construction of the Mafra convent (1717-1730), the 'timber island' as it was known, are a very relevant fact to include in the technicians' experience about the behaviour of timber structures. This particular fact shows common links with the Lisbon reconstruction period: the use of accessible material, with fast building methods, which were progressively standardised. Nevertheless, the technicians' knowledge of complementary timber military attack structures, as present in the Diderot Encyclopaedia regarding "Art Militaire. Fortification" should be considered due to their design and mechanical characteristics. Some other secondary military structures made of timber, such as siege towers for visual control over the enemy or to attack walls, again combined a main timber structure that needed to support the movements of the soldiers and eventual horizontal charges due to defence actions or movement in the field. Some examples of bridges made of timber, with St Andrews crosses in their lateral parts, belonging to military battery constructions and the previously mentioned structures are just a few examples of military structures that could be precursors of the Pombalino cage.

Finally, it should be emphasized the association of the military architects and civil engineers with the Academy, where a pragmatic but also an experimental approach with a deep knowledge about materials was pursued. These are valuable reasons to support the type of timber structure chosen (the Pombalino cage), which had the capacity for an approximate 3D behaviour, a main purpose of Pombalino cage.

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EXPERIMENTAL AND ANALYTICAL ASSESSMENT OF THE CAPACITY OF TRADITIONAL SINGLE NOTCH JOINTS AND IMPACT OF RETROFITTING BY SELF-TAPPING SCREWS

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Keywords: Traditional carpentry joints, single notch joints, retrofitting, self-tapping screws

Extended abstract

The joints are the most crucial parts of a timber building and determine the overall structural behaviour, load-bearing capacity and failure mechanisms. Therefore, keeping the joints fully functional is of utmost importance to ensure a desired structural performance of timber buildings under various actions. Since replacement of damaged parts of an existing structure is expensive and in many cases very difficult to perform in-situ, retrofitting to avoid failure becomes an increasingly widespread strategy. In this paper, the capacity and failure mechanisms of single notch joints before and after a simple retrofitting intervention by means of self-tapping screws were investigated. To this end, a series of tests were carried out during the 5th COST FP 1101 Training School, held in University of Minho, Portugal. The joints (Figure 1) were first tested under compression, and the load-bearing capacity values obtained at the end of tests were compared to the capacity values calculated using theoretical models proposed in German and Dutch National Annexes to Eurocode 5 as well as Swiss SIA. It was observed that all these codes significantly underestimated the capacity of the joint but the least conservative results were given by the German National Annex (Figure 2).

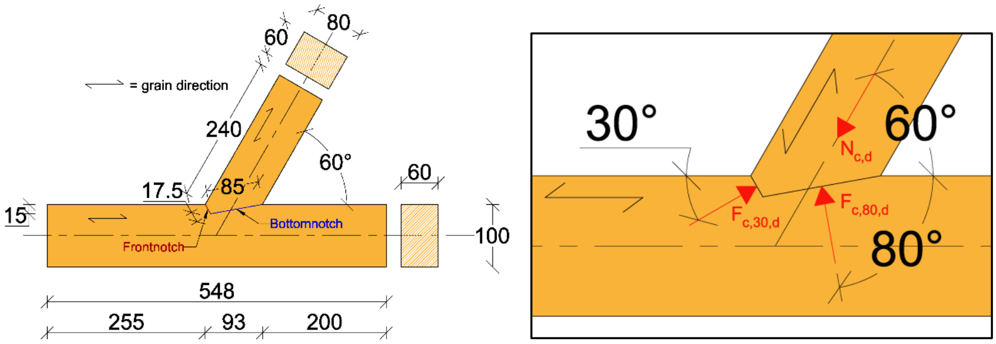

Figure 1: Single notch joint

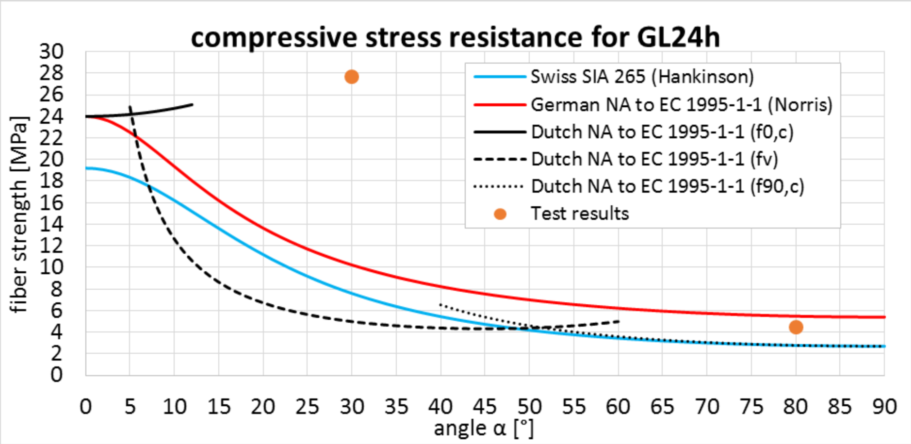

Figure 2: Test results vs. National standards

Then, tested joints were retrofitted using self-tapping screws using three different geometrical configurations and it was concluded that the efficiency of retrofitting front notch joints using self-tapping screws should be further investigated, as the tests showed that this intervention can significantly reduce the initial and overall stiffness (Figure 3). This behaviour may be caused partly by weakening of retrofitted cross-section, which was caused by preparing the surface to drill the screws to the required position and under required angle and partly that tested specimens already exhausted their elastic bearing capacity.

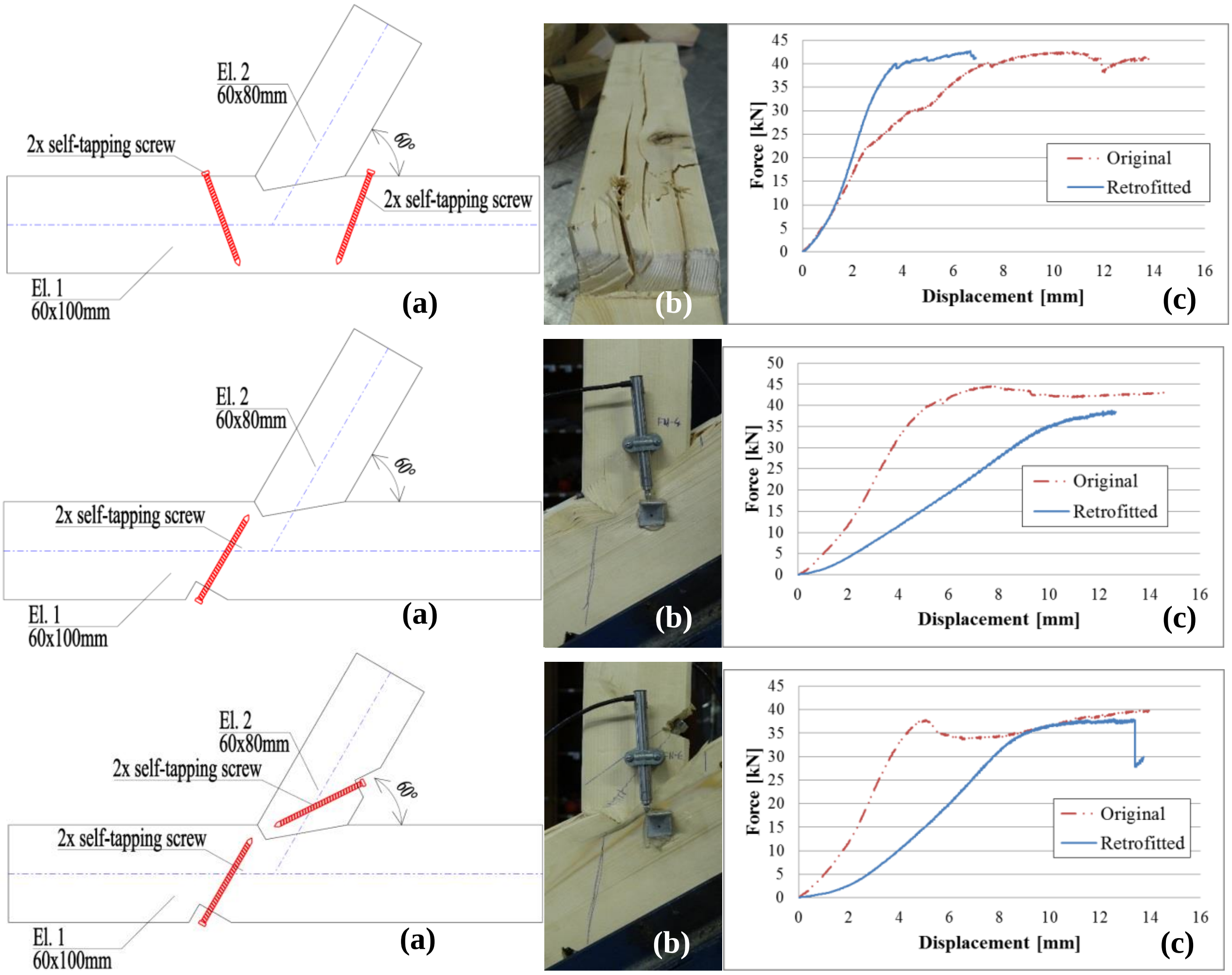

Figure 3: Retrofitting techniques 1-3 (a) retrofitting with self-tapping screws, (b) obtained failure and (c) comparison of force displacement relationship from loading cell for both original and retrofitted joint.

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REPAIRING OF A TIMBER TRUSS THROUGH TWO DIFFERENT TECHNIQUES USING TIMBER ELEMENTS AND SCREWED METAL PLATES

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Keywords: Timber trusses, Repair, Timber elements, Screwed metal plates

Extended abstract

Structural repairing of timber buildings may be needed due to different reasons such as change of use, deterioration, lack of monitoring and maintenance, exceptional damaging incidents or loading, later changes in regulatory specifications, or interventions to increase structural and seismic resistance.

In this work, two different techniques were considered for repair of an old timber collar truss that was previously assessed non-destructively and then taken up to failure on a full-scale test. The test was carried out by loading both rafters between the strut to failure. Linear variable displacement transducers were used to measure the displacements of the timber elements and to evaluate the entire behaviour of the truss under loading conditions. Failure of the timber truss was located in the sections of the rafters near the loading positions (Fig. 1).

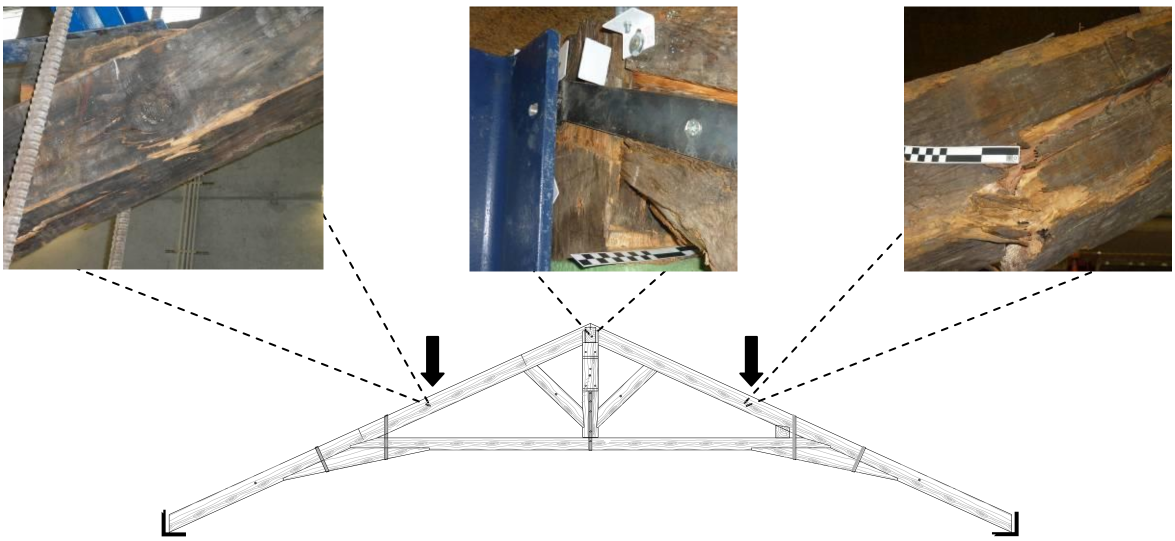

Fig. 1 - Schematic of test setup and details of the failure of the rafters and of the post-rafter connection

Repair techniques, based on the use of timber elements for one of the rafters and on screwed metal plates for the other rafter (Fig. 2), were evaluated and compared to the original un-strengthened condition.

a)

b)

Fig. 2 – Strengthening techniques with screwed: a) metal plates b) timber elements.

The repairing techniques aimed at obtaining an adequate safety level using simple traditional and current techniques. The efficiency of the combined repairing techniques was evaluated taking into consideration the structural performance of the collar truss, namely its displacement and ultimate load capacity (see Table 1).

Table 1 - Ultimate load results and efficiency of the repair techniques

Description	Property	Unit	Rafter 1 (metal plates)	Rafter 2 (timber elements)
Original	$load_{1max}$	[kN]	82.8	88.7
	$displacement_1$	[mm]	90.1	114
Repaired	$load_{2max}$	[kN]	68.1	71.4
	$displacement_2$	[mm]	97.4	97.4
Efficency	$load_{2max}$ / $load_{1max}$	[%]	82.2	80.6
	$displacement_{load2max}$ [a]	[%]	144	126

[a] ratio between the displacements of original and repaired rafters for the $load_{2max}$ value (i.e. value of displacement of the original truss corresponding to a load equal to $load_{2max}$)

In this work, the results of the experimental tests are discussed attending to the analytical calculation of the contribution of the repairing techniques. Also, the different failure scenarios, for original and repaired truss, were analyzed and compared. Both tested repair techniques showed equivalent efficiency (around 80%). However, this result was influenced by other sections (not repaired), which were damaged in the first test. When choosing which technique to use, ease of attachment and aesthetics need to be considered. Using timber elements is uniform with the materials of the old structure. Metal plates are fast to attach to the area needing repairing but tits use may interfere with the aesthetics of historical buildings and also the fire resistance needs to be considered. Finally, a careful assessment of the failure and of the effective residual timber section is important for choosing the most appropriate repair technique.

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STIFFNESS OF PROSTHETIC REPAIRS FOR HISTORIC TIMBER BEAMS

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Keywords: Timber, Glued-in rods, Repairs, Historic buildings, Stiffness of connections, FEM

Extended abstract

Stiffness of connections in a wood structure is highly important because, since most timber frames are statically indeterminate structures, they may significantly influence the distribution of forces into the structure. Moreover, when dealing with old timber structures, connections are always semi-rigid ones.., When doing repairs or reinforcements, the closest attention should be paid to the prediction of stiffness of the proposed interventions. Otherwise, they can lead to unexpected and damaging changes in the distribution of forces between the members of the frame.

Glued connections, and especially glued-in rods, are widely used in timber construction as reinforcements or repairs. If numerous guidelines exist to evaluate their axial load capacity, there is still no prescription on how their stiffness should be predicted. Moreover, a glued-in rod stiffness depends on many parameters, such as the type of rod, type of glue, thickness of bondline, diameter of rod, anchorage length,…

The aim of this research is to compare the stiffness of different solutions for an intervention made of glued-in rods, with varying parameters (i.e. number of rods, anchorage length, rod diameter and type of rod), to evaluate to which extent those parameters impact the stiffness of each glued-in rod and thus, of the connection. This paper is limited to connections only loaded with axial tension, with the aim, in the long-term, of studying connections loaded with bending moment, shear and axial forces. The intervention thus studied here is a typical repair for timber trusses: replacement of the decayed part of a tie-beam (straight connection, in tension). These parts of a truss are indeed often decayed since they are connected to masonry walls, and therefore subject to high moisture content. Different configurations of glued-in rod connections exhibiting the same strength as the original beam are proposed and studied, using a FE model based on cohesive surfaces in order to predict the axial stiffness.

Those multiple glued-in rod connections stiffness is predicted by combining single glued-in rods strength or stiffness (obtained thanks to the FEM) to account for the multiple glued-in rod connection. It is thus assumed that there is no interaction or reduction of efficiency between glued-in rods since the minimum rod spacing is respected.

Method used to first determine the different glued-in rod connection configurations studied and then predict their stiffness is:

(i) Knowing the minimum edge/rod spacing, three configurations (i.e. number of rods and diameter of these rods) are possible.

(ii) On the assumption that the connection tensile strength has to be at least equal to the initial tie-beam strength, the minimum capacity (target strength) of each rod of the multiple glued-in rods connection is assessed.

(iii) For each type of rod (steel, CFRP,GFRP,Aramid and Nylon rod), the minimum anchorage length that the glued-in rod (knowing other parameters described above) must have to exhibit the target strength is determined. This minimum anchorage length is found numerically using the cohesive-based FEM. Same types of rods with a higher anchorage lengths would obviously reach the target strength but this increase of length makes no sense (increase of the cost for non-necessary gain of strength), and therefore those configurations are not studied.

(iv) Seven configurations of connections (and therefore seven types of single glued-in rods) are thus identified. Corresponding type of single glued-in rod (with different rod diameter, type of rod and anchorage length) is modelled in order to obtain its axial stiffness. Thanks to the symmetry of single glued-in rods set in a wood block, the finite elements model is axisymmetric. The *wood* is modelled as a homogeneous elastic orthotropic material; *rods* main properties are the material Young modulus and tensile strength; *glue* is supposed to be Pliogrip®7779, a 2C polyurethane structural adhesive, which is modelled through a ”cohesive surface” (a non-thickness element taking into account all successive behaviours happening during the adhesive failure, i.e. the traction-separation laws in tension and in shear)

(v) Knowing the stiffness of each glued-in rod, we can evaluate the stiffness of the whole connection constituted of n rods by using a spring model.

The stiffness of the connection for the configurations studied are shown below on Fig.1. Depending on the configuration, stiffness of the multiple glued-in rod connection ranges between 197 kN/mm and 437 kN/mm. Results thus show that two connections of glued-in rods having the same strength can exhibit stiffness which vary in a ratio from 1 to 2,2!

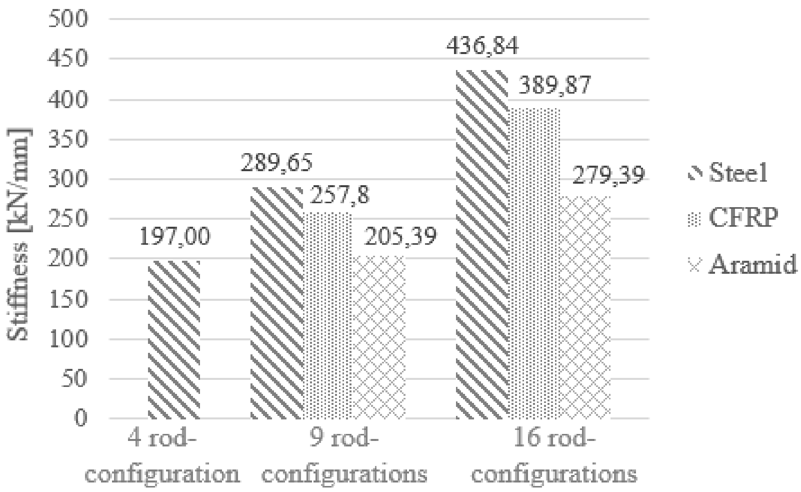

Figure 1 : Stiffness $K_{n\ connection}$ of multiple glued-in rod connections[kN/mm]

Further studies will use this prediction of stiffness to make recommendations (based on real cases) regarding the connection that best fits the initial structure, i.e. whose stiffness best respects the initial static scheme of the timber frame. The Finite Element Model dedicated to glued-in rod should also be validated on experimental results. Then, prediction of stiffness of glued-in rods connections using FEM should be extended to the study of other types of interventions on historic timber trusses, loaded not only with axial forces but also shear and bending moments, such as repairs of moment- carrying connections.

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CONSOLIDATION OF A COLLAR TRUSS WITH A STEEL CABLE SYSTEM

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Extended abstract

A full-scale historical timber truss has been deeply analysed during an experimental campaign conducted by the authors. The purpose of the investigation was the study of the application of a post-tensioned steel-cable system for the retrofitting of existing wooden structures. Such a type of consolidating technique has been used throughout the years by several authors, giving encouraging results, but still little is known from a scientific approach about the system behavior.

For this reason the specimen, carefully dismantled from an ancient industrial nave, has undertaken a detailed pre-analysis phase, during which it has been fully characterized from a geometrical, material and conservative point of view. All the part that compose the truss have been accurately measured and graphically represented. Later on, with the help of different inspecting tools, a decay map have been drawn, and the degraded areas have been identified. The wood specie and the values of density and Modulus of Elasticity have been derived through comparative experiments on similar timber elements, belonging to the same original source. After the characterization of the truss, it has been reassembled according to the initial configuration. Almost no modifications were necessary during the assemblage, with the exception of the metal elements tying together the carpentry joints. New steel insertion were made, resembling the original layout.

The truss has been tested in its original condition, without any reinforcement. To avoid certain and sudden rupture, the final parts of the rafters were cut out due to their advanced decay state. The test has been design to respond both to the ongoing scientific research and the facility constrains. The total span of the timber structure was 15 meters, with a height of 5 meters, and this precluded many experimental options that could have better resembled its original condition. For ensuring the safety during the testing process, the supports were firmly anchored to the laboratory floor slab, and the out-of-plane rotation was inhibited with coupled steel profiles, distributed all along the truss. A quasi-static loading pattern was chosen, with an initial input of 20 kN to close the assembling gaps, and then a constant loading until rupture. The displacement-controlled hydraulic jacks allowed to stress the structure with a constant speed of 0,05 mm/s. The behavior of the truss was continuously checked by a consistent distribution of LVDTs all around the structure, placed in the most significant locations. The set-up allowed a total displacement of 150 mm, and the totality of this movement was necessary to reach a considerable level of damage.

Although some minor damages, the truss broke as expected under the loading points. In spite of the laboratory set-up, a slight out-of-plane deformation was registered, but it was completely

reabsorbed during the unloading. It is important to notice as an historical timber structure, dismantled for safety issues, was capable to stand a total load of 269 kN, divided in 142,5 kN for the North jack, and 126,5 kN in the southern one. After the first test was possible to start the second part of the experimental campaign, regarding the realization and actuation of the post-tensioning retrofitting technique. Although the intervention is theoretically suitable for any timber structure, the design has to be tailored for the specific case. In this particular layout was decided to act only on the upper part of the truss, mainly due to testing constrains.
A d14mm steel cable was laid on top on the structure, and few steel pulleys helped in transmitting the prestressing loads to the timber elements. All the pieces used for the retrofitting were easily available and their realization was effective both in terms of cost and time. The intervention was in fact conceived to be fast, light and effective. Another fundamental point of the repair was the control of the post-tension applied to the cable system, and this was achieved with a dynamometric key and a combination of steel rods and nuts. Once the retrofitting was completed, the truss was re-tested under the same loading conditions. The second test gave successful results in terms of load carrying capacity, but was not possible to bring the truss to the total failure, due to safety issues.
Comparing the final stress applied by the jacks, the structure regained the 82% of its initial strength. The displacements were still considerable, but what is mostly interesting is the change in the overall behavior, shown by the LVDTs results. The truss has been reacting in a different way, showing how the retrofitting system has activated the residual capacity of the timber elements, allowing reaching such high resisting values.