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Rehabilitation of Lisbon's old "seismic resistant" timber framed buildings using innovative techniques

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Consolidação
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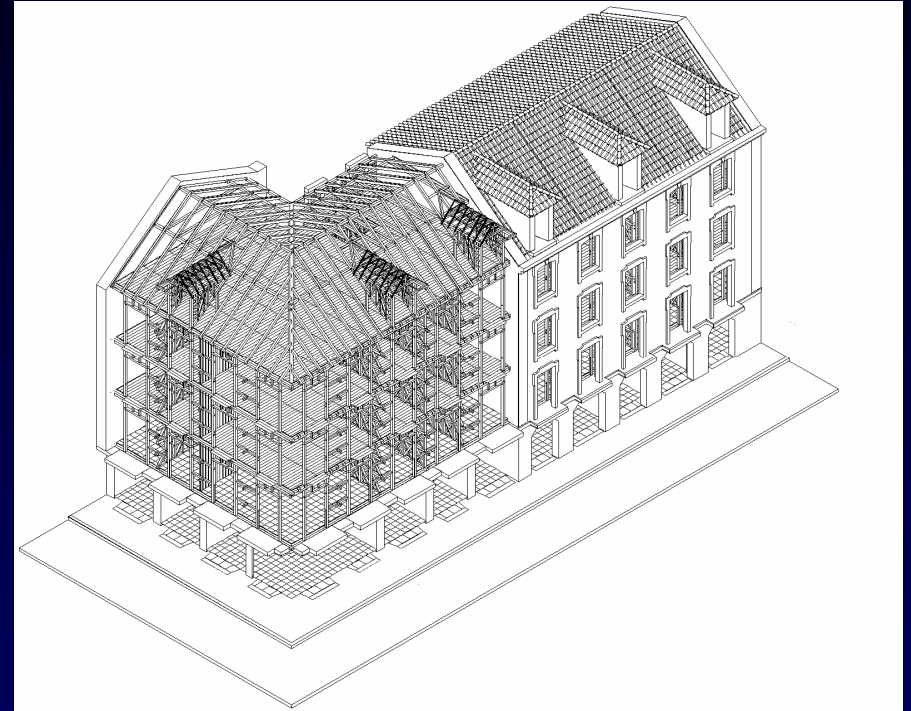
Rehabilitation of Lisbon's old "seismic resistant" timber framed buildings using innovative techniques

Topics:

1. Introduction
2. Characterisation of the "Baixa Pombalina"
3. Innovative solutions to improve the structural behaviour
4. Conclusions

1. Introduction

- Lisbon's "Baixa Pombalina", the historical downtown rebuilt after the disastrous 1755 earthquake, is composed of approximately sixty blocks, most of them rectangular and consisting in average of seven buildings.



- "Pombaline" is the term coined after the Marquis of Pombal, the prime minister at the time of the 1755 earthquake, who took most of the decisions regarding the reconstruction of Lisbon.

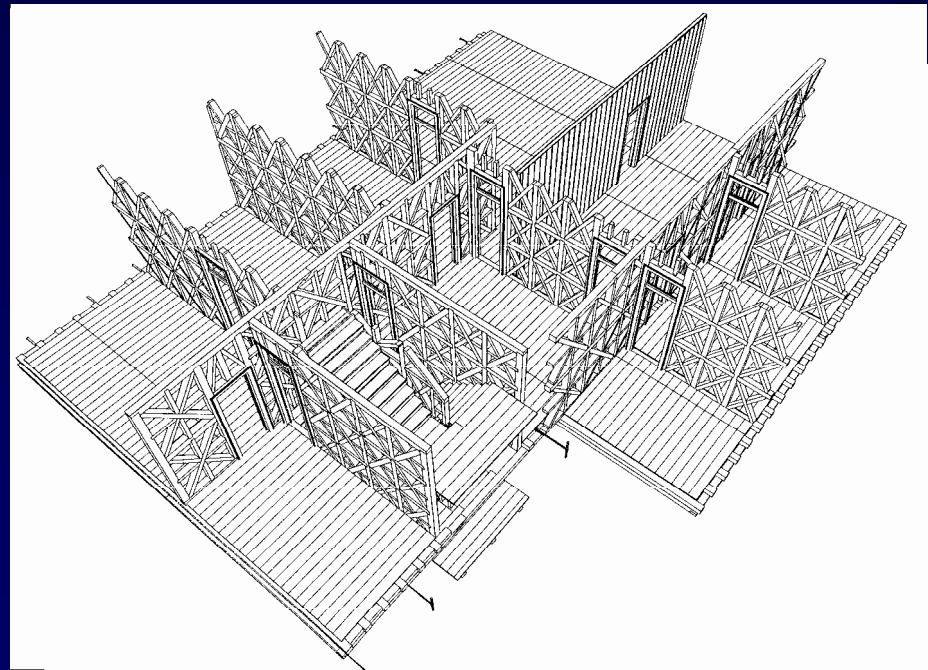
2. Characterisation of the “Baixa Pombalina”

2.1 The Pombaline buildings

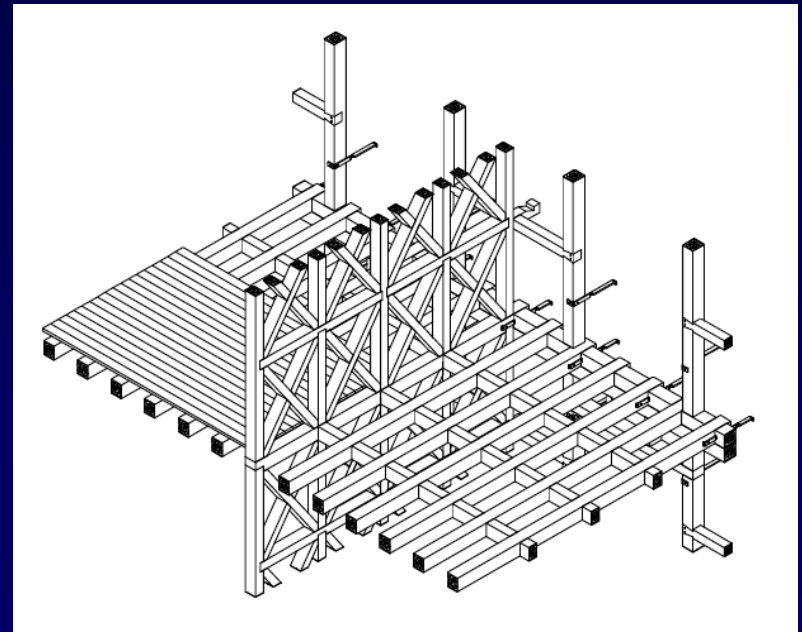
2.2 Deterioration of timber structural elements

2.1 The Pombaline buildings

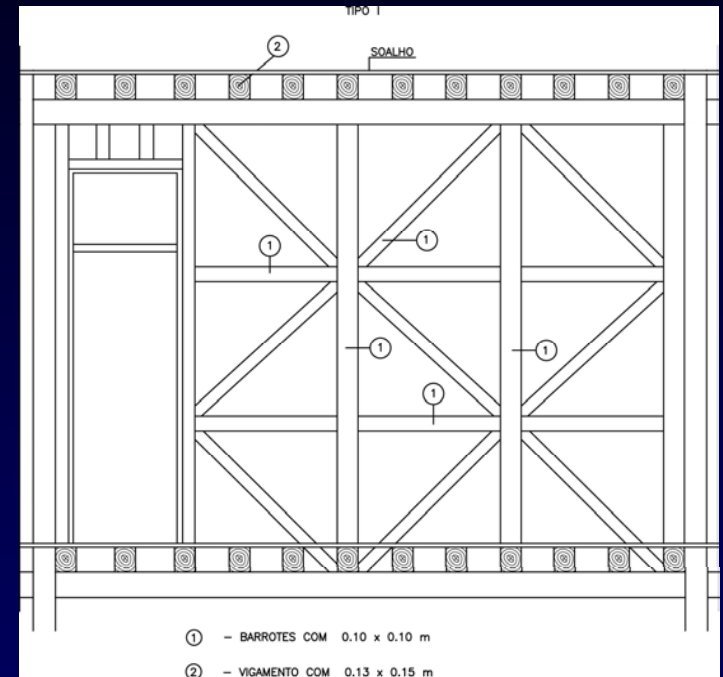
- The new buildings during the first decades of reconstruction after the big shake incorporated a set of features intended to provide them with adequate seismic behaviour, enabling them to resist horizontal loads and to dissipate substantial amounts of energy.
- The “gaiola” designation was adopted because the building seemed like a big cage, with the carpentry work high up in the air.



- The system consists of a set of timber members embedded along the inner face of the main stone masonry façade walls. To these members and to the ashlar around the openings, an internal timber grid was connected by means of iron cross ties.
- Further bracing was provided by the timber floors, whose diaphragm action was enhanced by iron ties, bolted to the floor beams and deeply embedded in masonry main walls.

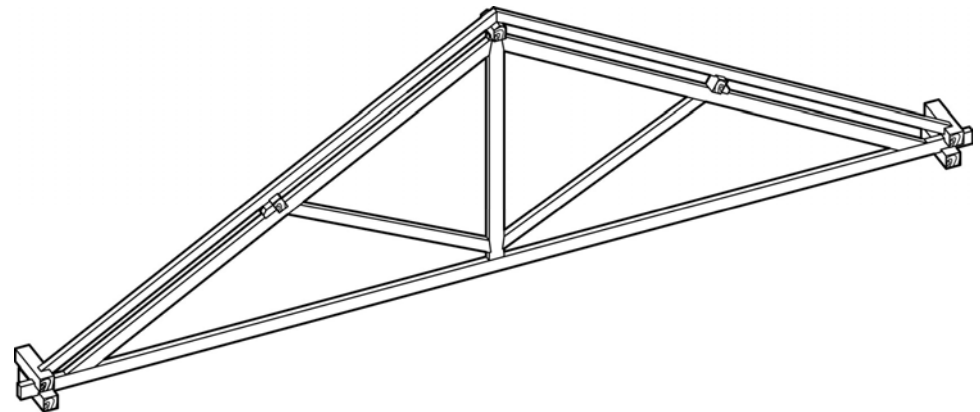
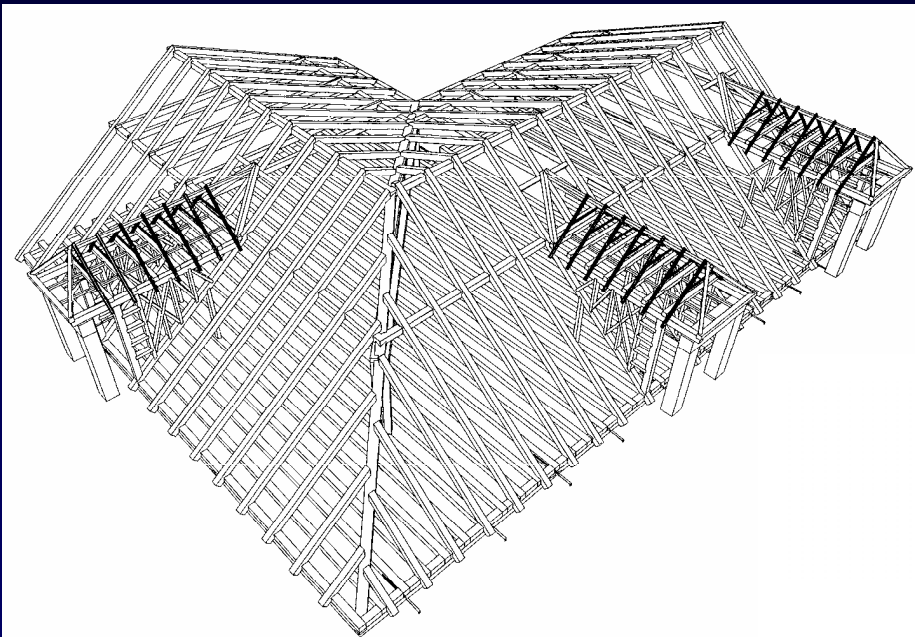


- Several basic configurations of timber-masonry load-bearing walls have been identified in the old Lisbon buildings.



- Timber species used in these buildings and their cross-section dimensions also presented some variation. The empty spaces of the walls were filled with rubble masonry made of small stones and ceramic elements assembled with lime mortar.

- Example of a representative roof structure: a set of king post trusses. Jointed timber elements form the triangular frame. The king post is the central vertical timber.



2. Characterisation of the “Baixa Pombalina”

2.1 The Pombaline buildings

2.2 Deterioration of timber structural elements

2.2 Deterioration of timber structural elements

- Buildings in “Baixa Pombalina” have undergone successive and occasional modifications until quite recently.
- Main changes have been the construction of extra floors, inadequate widening of existing façade openings and removal of walls and pillars, notably on the ground floor, and addition of steel and reinforced concrete elements.
- The introduction of new materials, with mechanical behaviour considerably different from the original ones, resulted in uncontrolled changes in the original structural system, possibly decreasing its strength and capacity to dissipate the energy associated with seismic actions.

- Overloading and modifications on the buildings, on the one hand, environmental effects, insect damage, mould, and biological damage, on the other hand, can severely compromise the integrity and performance of wood structures.
- Decayed zones, significant reduction of section and excess of deformation are the most frequent anomalies that have been detected on the timber elements.



- Many structures are in need of some kind of rehabilitation due to the deterioration they have undergone with time.
 - The rehabilitation methods used so far, resorting to current technologies based on the intensive use of cement and reinforced concrete, due to their strong invasive character, are not at all suitable in the case of the “Baixa Pombalina”, given its historical and architectural value.
 - Current repair methods are often intrusive and lead to the waste of good material.
- Therefore, there is room for low-invasive strengthening solutions, that will simplify interventions.

3. Innovative solutions

- New materials and techniques can play an important role in the rehabilitation of the "Pombaline" buildings compound, by improving the structural behaviour of: the original timber floors, the connections between the timber floors and masonry walls, the original timber braced walls, and the connections between the timber framed walls and the main masonry walls.
- Together, these improvement solutions are capable of enhancing the global strength, ductility and energy dissipation capacity of the buildings whilst respecting their original structural concept and, therefore, their authenticity.

3. Innovative solutions

3.1 FRP reinforcement

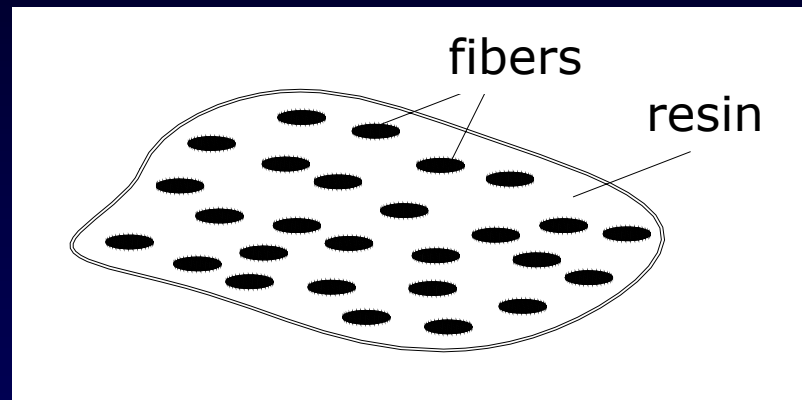
3.2 Low intrusion restoration techniques for timber structures

3.3 Improving the connections between the timber floors and masonry

3.4 Strengthening of the original timber braced walls

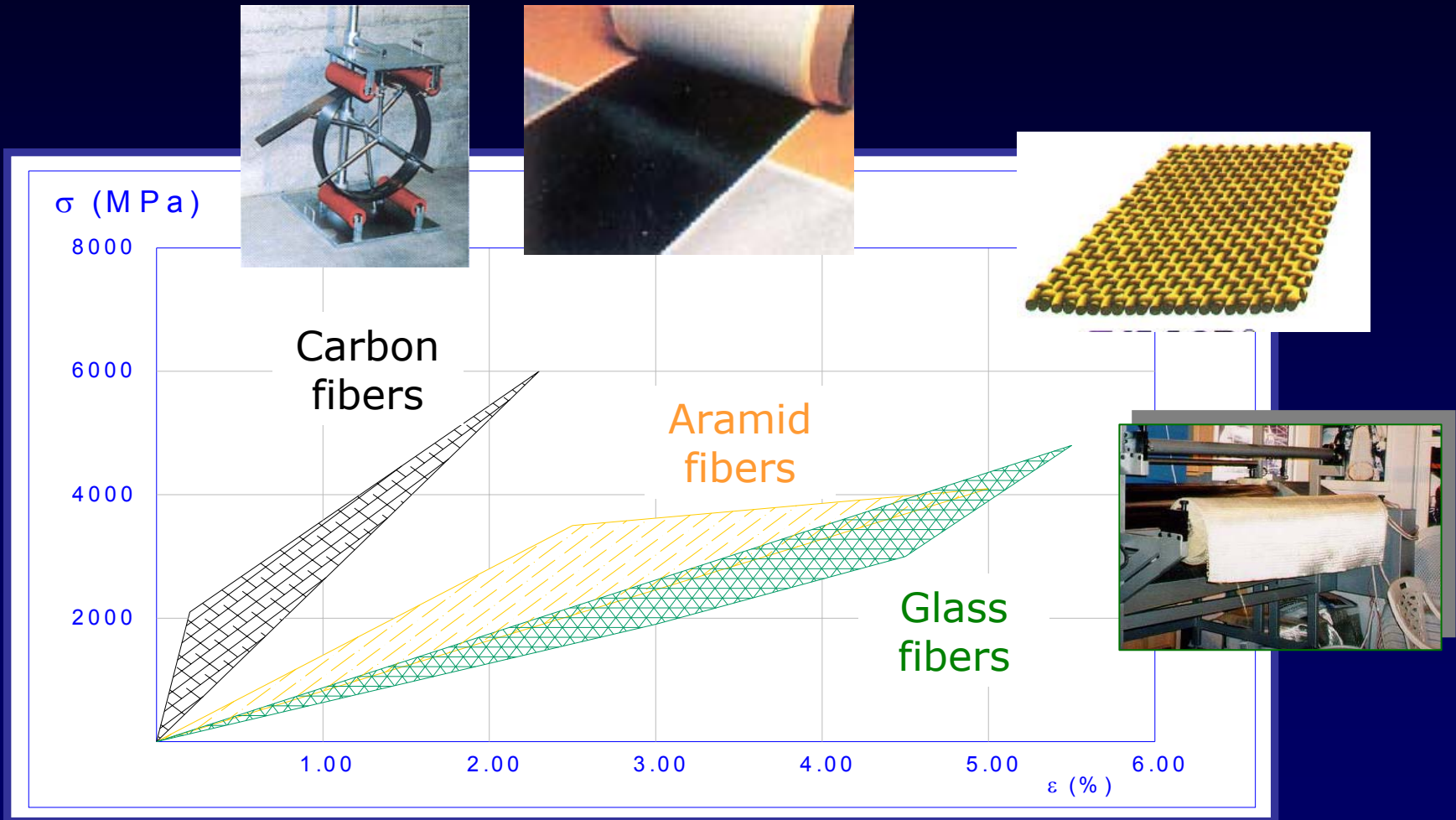
3.5 Improving the connections between the timber framed walls and the main masonry walls

→ FRP (*Fiber Reinforced Polymer*) belong to the family of composite materials of polymeric matrix (resin) reinforced with fibers



- FRP composites combining high resistance fibres and a resin have a wide variety of industrial applications.
- The widespread use of FRP in the aerospace and defence related sectors, sporting goods industry, etc, has given rise to their application in the civil engineering sector and are currently viewed as highly promising materials in the construction industry.

Comparative Diagram of Tensile Strength of principal types of fibers: carbon, aramid and glass fibers

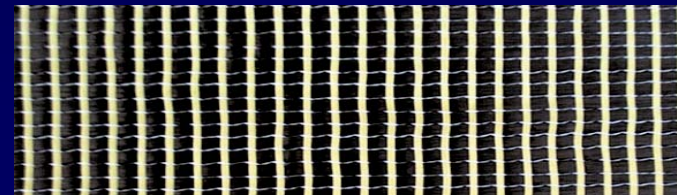
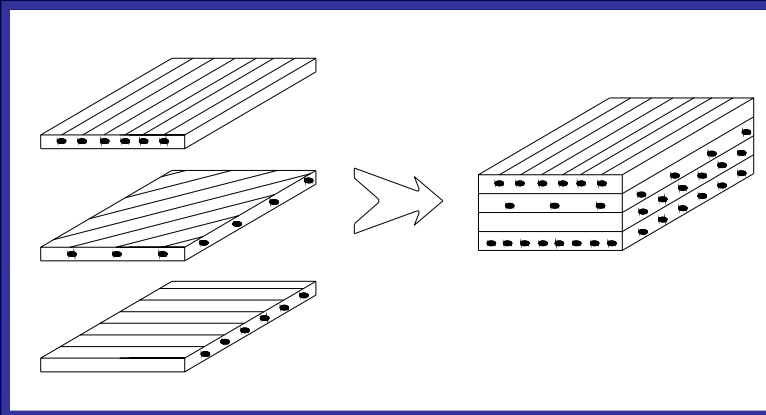


- Key advantages of FRP are:

- high strength/weight and stiffness/weight ratios, which significantly exceed those of conventional civil engineering materials;
- free-form and tailored design characteristics;
- ease of handling and versatility;
- corrosion and fatigue resistance and a high degree of inertness to chemical and environmental factors.

- Composite materials for civil engineering are available mainly in the form of:

- thin unidirectional strips and plates (laminates);
- flexible sheets or fabrics, made of fibres in one or at least two different directions, respectively;
- profiles and rods.



Epoxy resins

- in general terms, the most suitable for in-situ timber repair operations, since they do not require high pressure during their application and curing and they can be reasonably tolerant to glue line thickness variation;
- main characteristics:
 - high strength;
 - low shrinkage;
 - high durability;
 - compatibility with principal types of fibres;
 - good workability and ease of application.

3. Innovative solutions

3.1 FRP reinforcement

3.2 Low intrusion restoration techniques for timber structures

3.3 Improving the connections between the timber floors and masonry

3.4 Strengthening of the original timber braced walls

3.5 Improving the connections between the timber framed walls and the main masonry walls

- **Low intrusion restoration techniques** using structural adhesives and FRP are suitable for repairing and strengthening existing timber structures.
- The option for advanced materials aims at providing systems with such features as low mass, ease and speed of installation, versatility and structural efficiency.
- In combination with traditional carpentry methods, versatile timber restoration solutions lead to less waste of original good material, reduced visual impact and an aesthetically pleasing appearance.

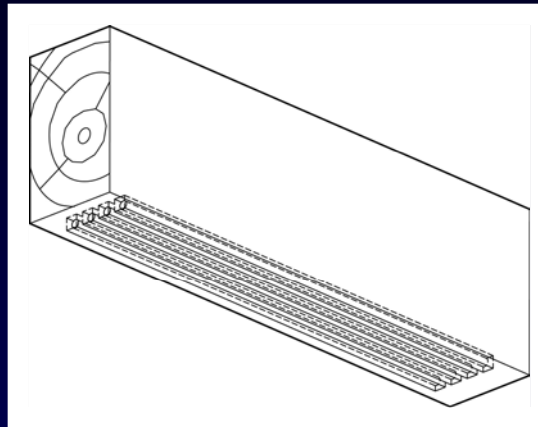
Main configurations:

- reinforcement of beams;
- modified flitch and upgrade of beams;
- beam end repair;
- upgrading of glulam beams;
- truss consolidation;
- joints.

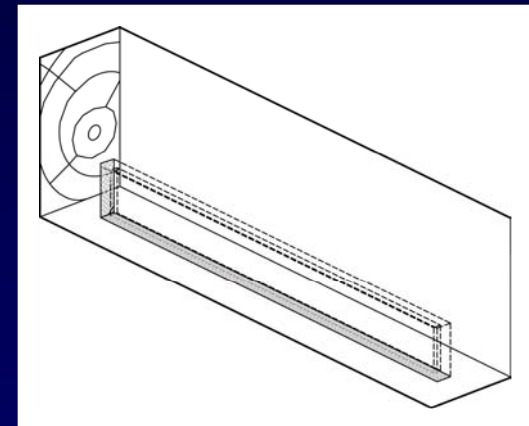
- Reinforcement of beams



*Tourand Creek
Bridge, Canada*



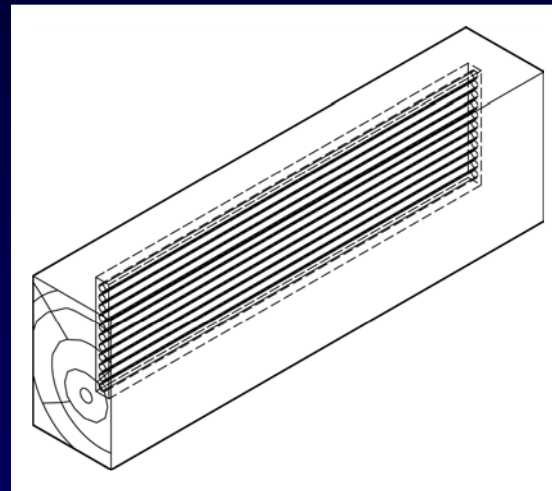
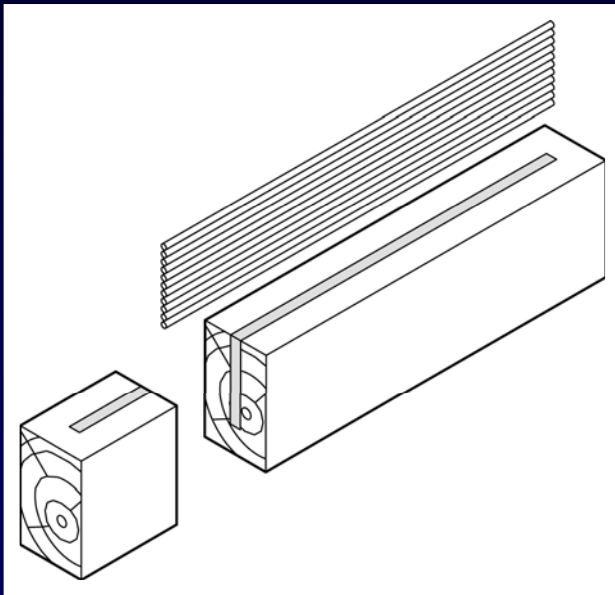
Bonded-in rods



Bonded-in laminate



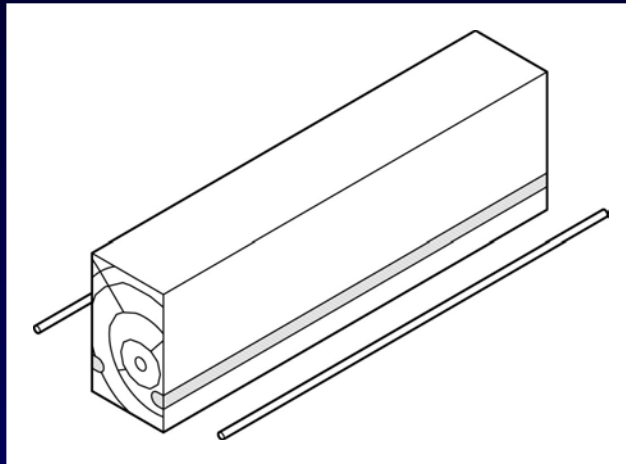
- Reinforcement of beams



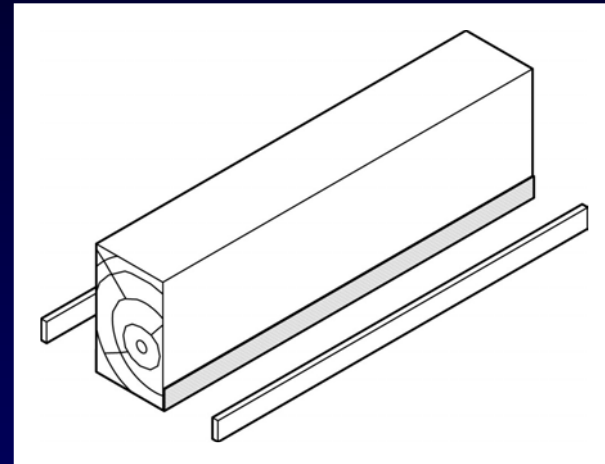
Modified flicth – rods inserted into a slot
and filled with an epoxy mortar



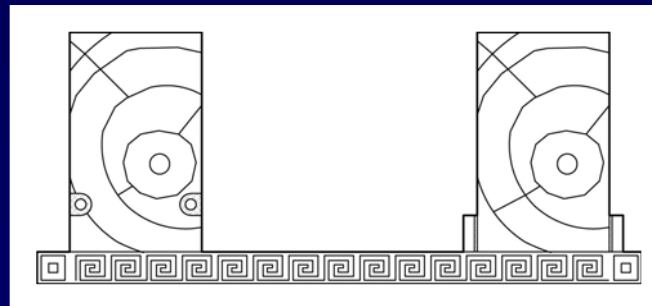
- Reinforcement of beams above decorative ceiling



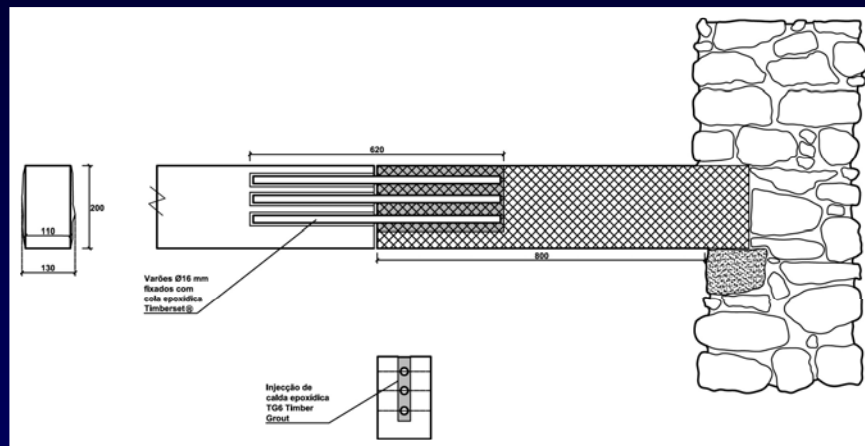
Bonded-in
rods



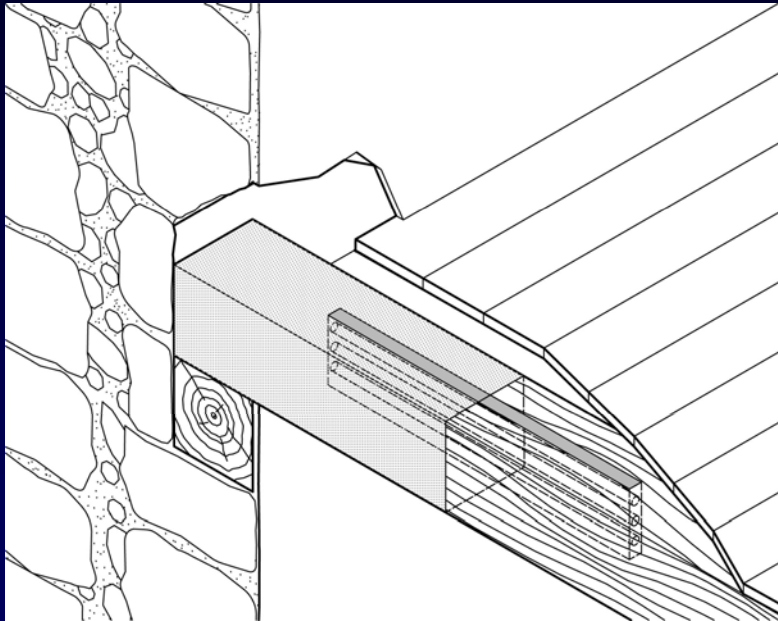
Externally
bonded
laminate



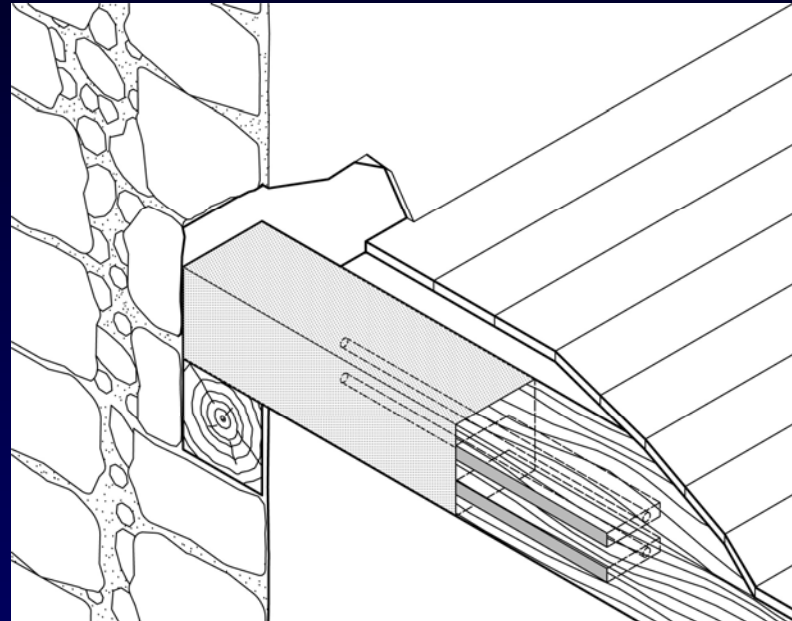
- **Beam end repair** can be repaired by drilling holes in the sound material after the decayed end has been removed. Resin is injected into the holes and the decayed part is replaced by a timber prefabricated component.



- Beam end repair



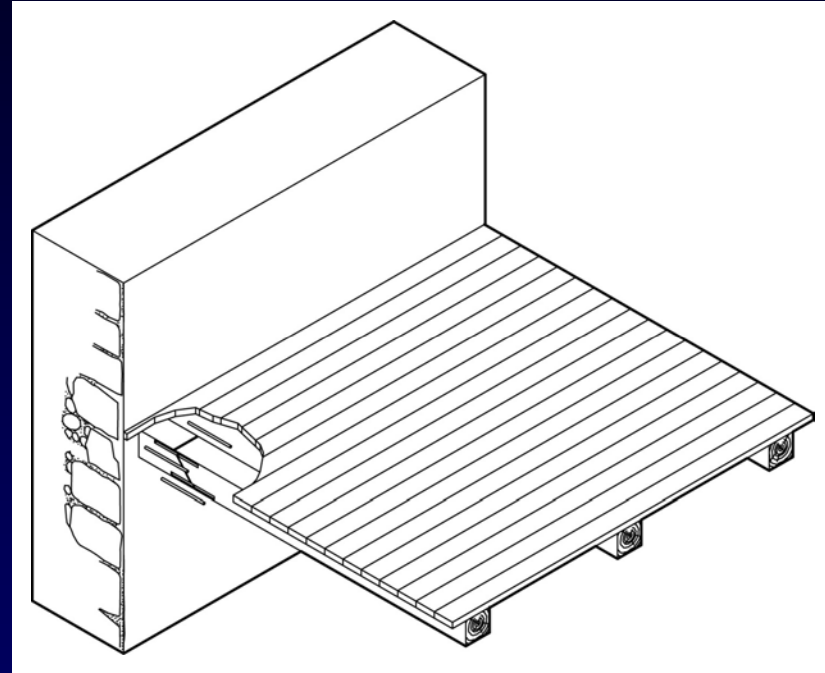
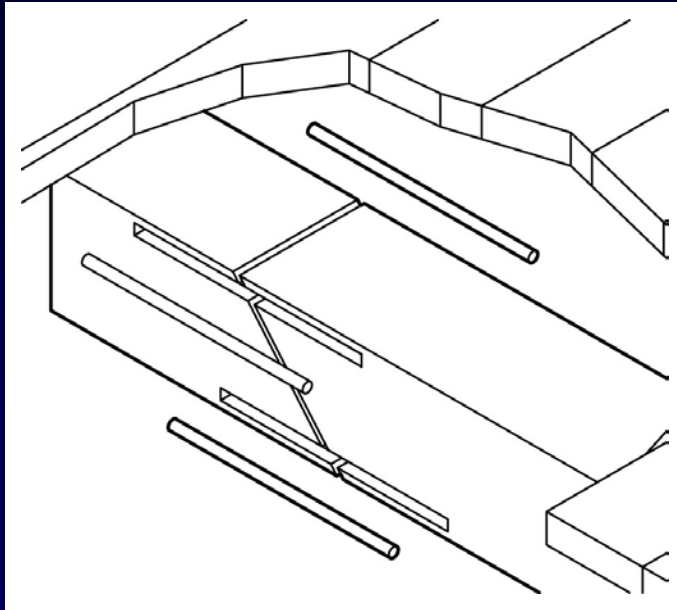
a) Top surface slot



b) Lateral slots

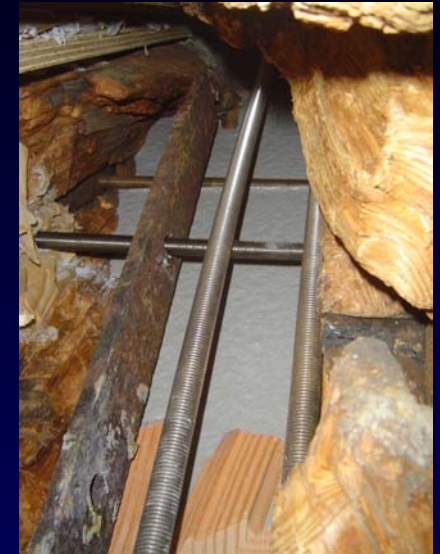
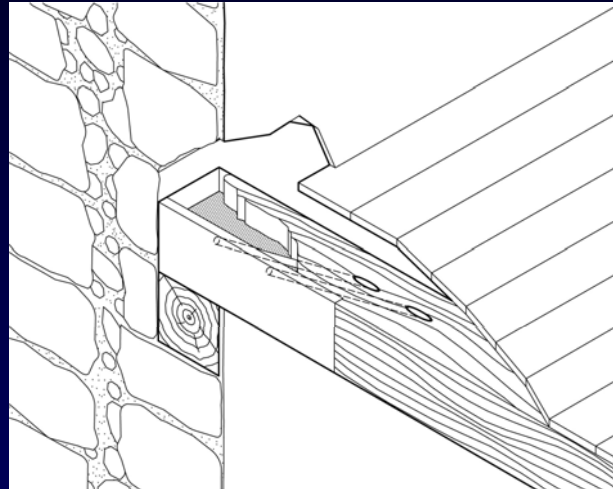
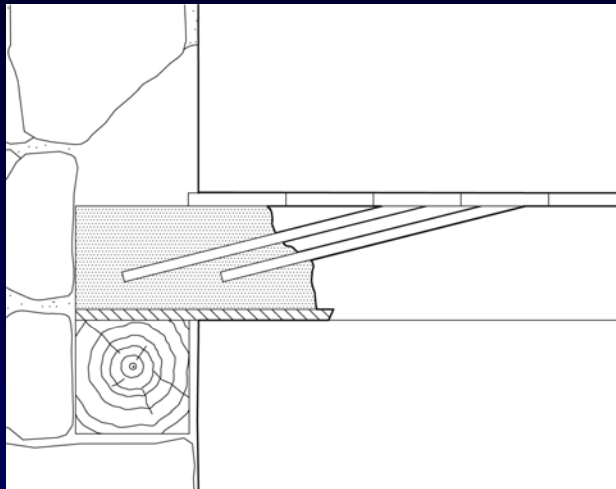
Installation of prefabricated timber components.
Injection and filling of holes and slots with epoxy resin.
Encase of rods in holes and slots in sound timber.

- Beam end repair



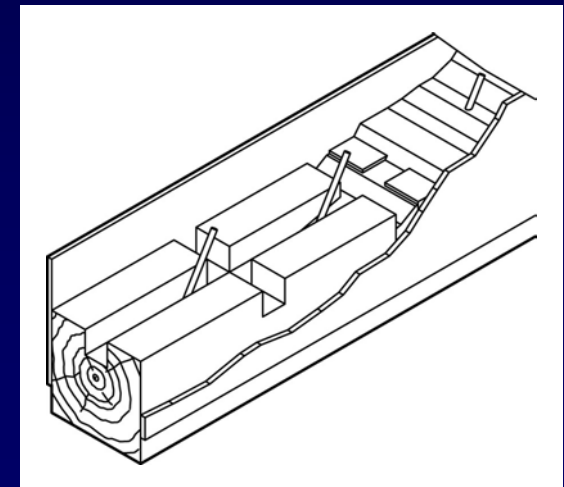
Installation of prefabricated timber component.
Injection of slots with epoxy resin and encase of rods.

- Reconstruction of sections

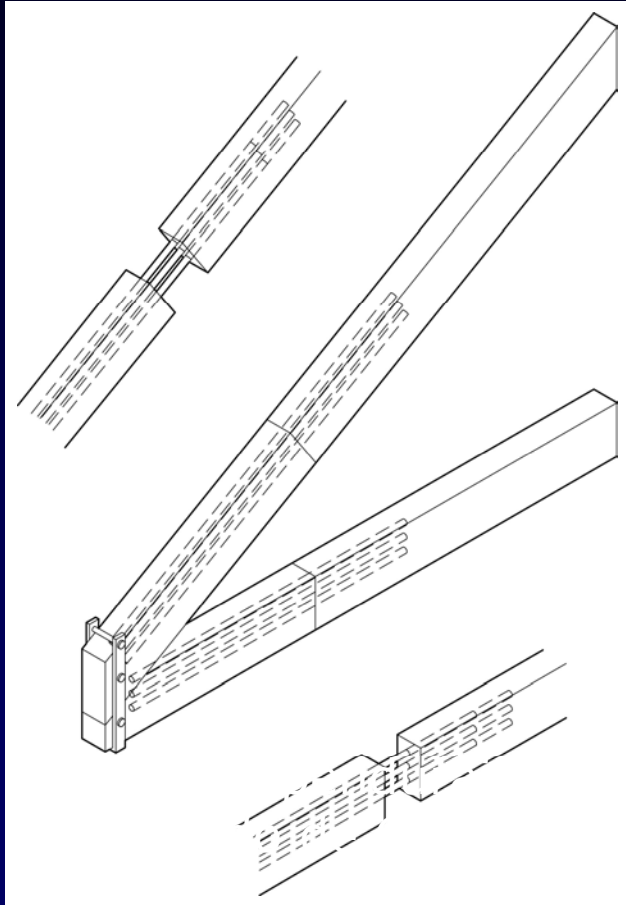


Reconstruction of sections with epoxy mortar.

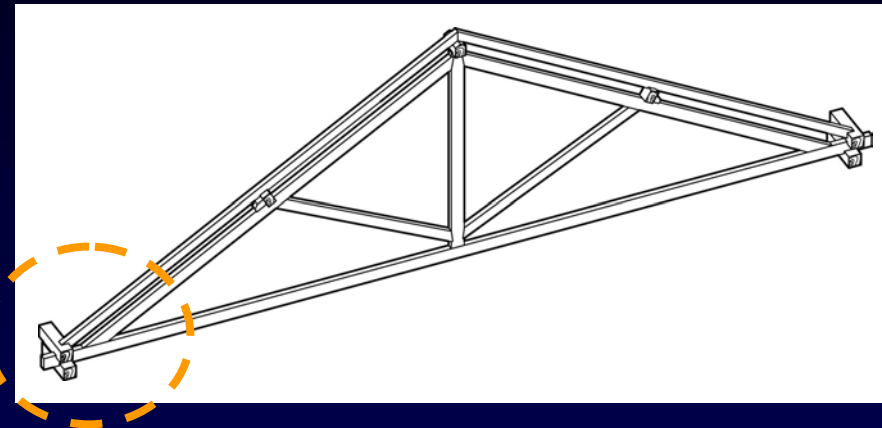
Encase of rods in order to improve the connection between timber and the adhesive.



- Truss consolidation



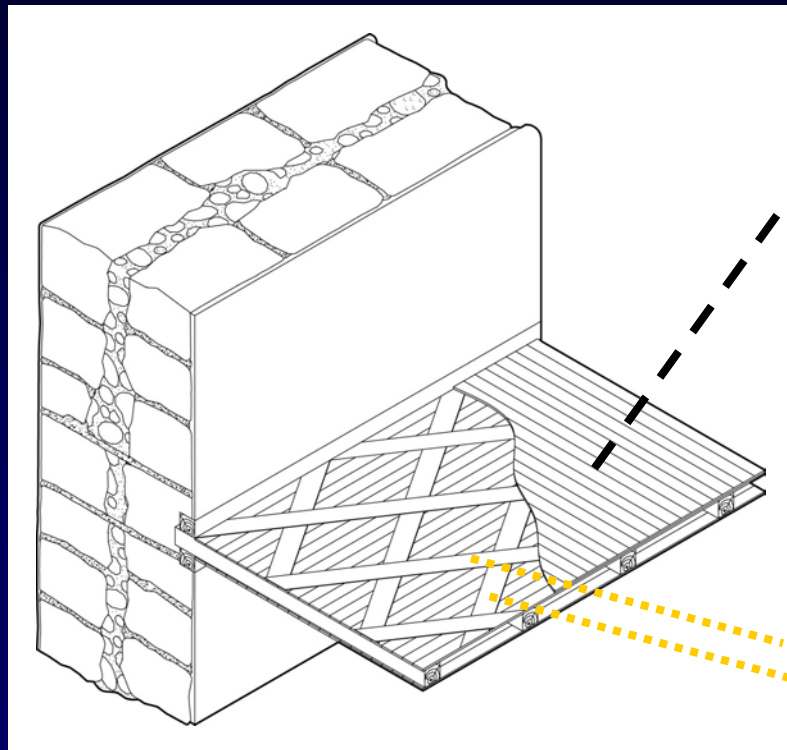
Substitution of
truss bearing



Reinforcement
of posts with
GFRP fabric



- Reinforcement of pavements

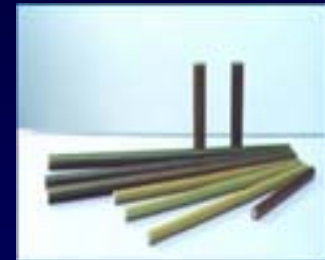


New covering

Cross FRP strips

Materials

- Reinforcing elements (rods, laminates, fabrics, ...)
 - **stainless steel** or adequately protected against corrosion
 - **FRP** (*Fiber Reinforced Polymer*)
- Epoxy adhesives
- Prefabricated timber elements



Epoxy adhesives

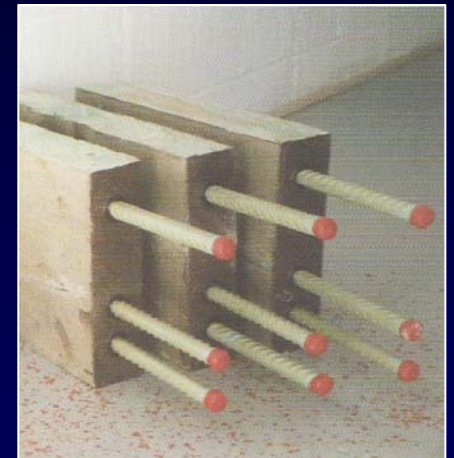
- Adhesives are usually a two or three part epoxy system which is used as the interface between the original timber and the rods or plates.
- The adhesives should be specifically formulated for timber engineering, to be used in crack injection, fixing of anchorages in timber, filling of drilled holes and slots to fix metallic or FRP rods or plates.
- After curing, mechanical properties of the adhesives should be compatible with those of timber.



- Prefabricated timber elements

- The prefabricated timber components should be of the same species of the timber to be repaired, or compatible, in terms of its mechanical properties, durability and colour.

However, if the durability of the original timber is rather insufficient regarding the particular hazard class, timber with adequate natural durability or with a selected preservative treatment may be used.



3. Innovative solutions

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3.3 Improving the connections between the timber floors and masonry

3.4 Strengthening of the original timber braced walls

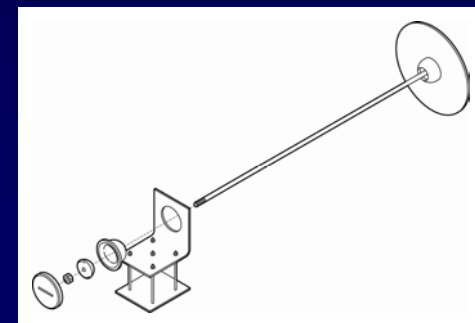
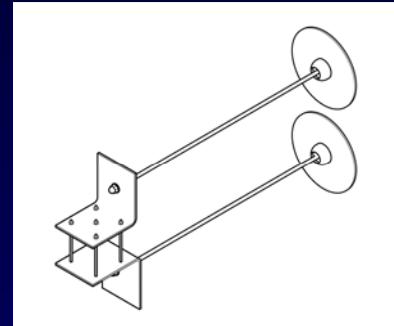
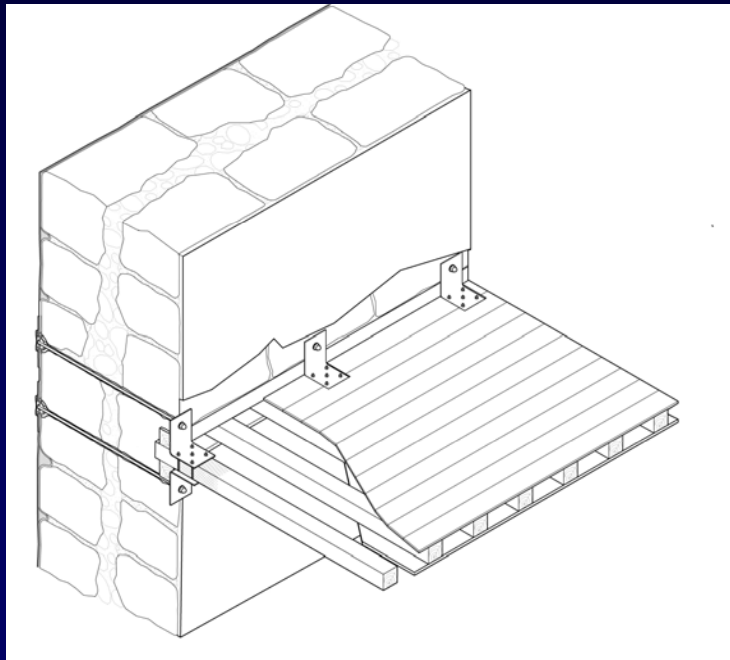
3.5 Improving the connections between the timber framed walls and the main masonry walls

3.3 Improving the connections between the timber floors and masonry

- The devices that were used to connect timber floors structure to the resistant masonry walls, when existing they are usually deteriorated, thus no longer suitable to assure the connection.
- Improving the connections between the timber floors and masonry walls not only increases the resistance of the structure of the floors but also the global behaviour of the structure of the whole building, particularly in what concerns the seismic action, because of the contribution of the timber floors to the structural stability.

➤ **Low intrusive and removable connectors.**

The bars are inserted into the thickness of the walls and are anchored on the wall and on the timber beams by special devices. There are different types of connection devices either to be installed in the longitudinal or in the transversal direction of the beams.



*Connection devices between timber floors and masonry.
Longitudinal direction.*

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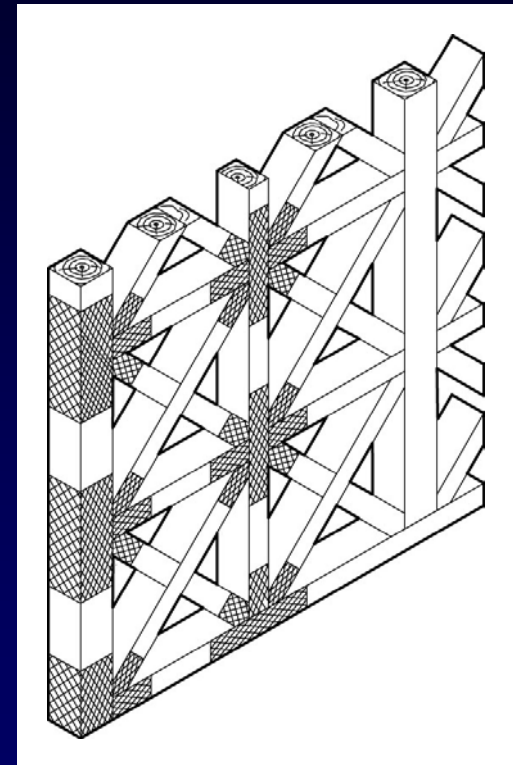
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3.4 Strengthening of the original timber braced walls

- It may be necessary to remove some parts of the timber frame, followed by its substitution with new timber. The new timber parts should be connected to the remaining sound timber by means of metallic plates and screws or using the low invasive methods already described.
- Also, externally bonded GFRP fabric may be used.



Bonded-in
dowel joints



Externally bonded
strips of GFRP fabric

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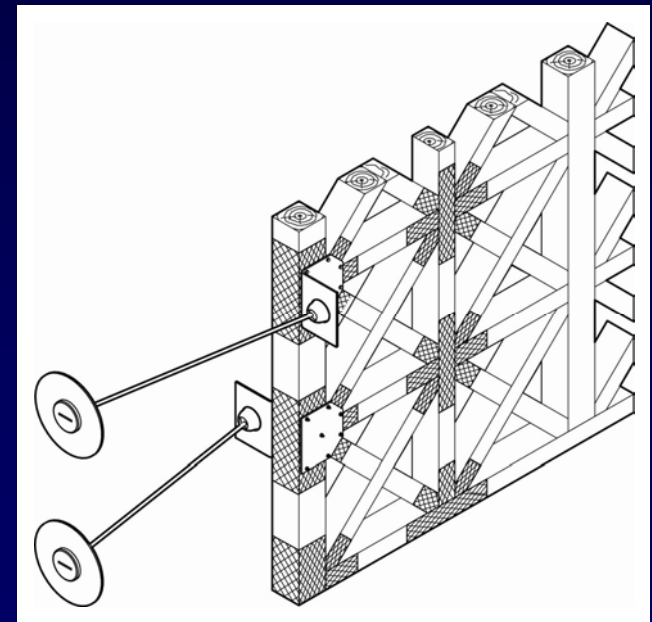
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- The internal timber grid of the original structure was connected to the main stone masonry façade walls and to the ashlar around the openings by means of iron cross ties. One of the main deteriorations of these connections is due to the corrosion of the ties, which are no longer suitable to assure the connection.
- The fundamental interventions in this kind of walls are thus related to the reestablishment and even the reinforcement of the connection conditions.

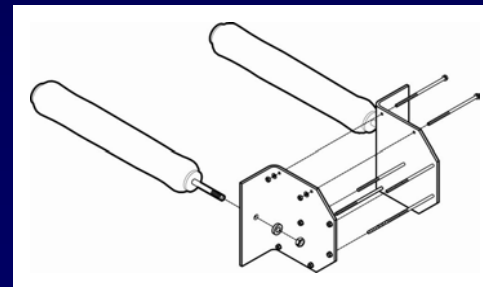
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- This can be achieved by means of the installation of a set of low intrusive and removable connectors.
- Similarly to the previously devices, the reinforcing bars are inserted into the thickness of the main masonry walls and are anchored on the timber framed wall by special devices.
- Preferably, a GFRP fabric may be put between the timber and the plate. The anchoring devices may be the semi-spherical ones.



3.5 Improving the connections between the timber framed walls and the main masonry walls

- Also in this case, instead of inserting the rods through the whole thickness of the masonry walls, sock type anchors may be used.



4. Conclusions

- ✓ The historical downtown of Lisbon, also known as “Baixa Pombalina”, comprises the most complete collection of the seismic resistant building technology, the gaiola system, which was used in the reconstruction of Lisbon after the devastating earthquake of 1755.
- ✓ The gaiola was a standardized construction system which incorporated a number of innovative methods designed to resist seismic forces. The system consists of a set of timber members embedded along the inner face of the main stone masonry façade walls.

4. Conclusions

- ✓ Innovative techniques can play an important role in the rehabilitation of the buildings in the Pombaline downtown. Whilst respecting the original structure concept and, therefore, their authenticity, these techniques are capable of improving the global strength, ductility and energy dissipation capacity of the buildings.
- ✓ Maintenance and conservation of built heritage frequently involves rehabilitation and consolidation of certain components or parts of the existing timber elements. Non-traditional materials and rehabilitation methods are capable of providing the necessary strength and durability to realize a long-term service life for timber structures.

The End.

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e Modificação
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