

World Housing Encyclopedia

A Resource on Construction in Earthquake Regions



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HOUSING REPORT

Historic, braced frame timber buildings with masonry infill ('Pombalino' buildings)

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Last Updated	
Country	Portugal
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Important

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General Information

Building Type:	Historic, braced frame timber buildings with masonry infill ('Pombalino' buildings)
Country:	Portugal
Author(s):	Rafaela Cardoso Mario Lopes Rita Bento Dina D'Ayala
Last Updated:	
Regions Where Found:	<p>This type of housing construction is commonly found in urban areas. Buildings of this construction type can be found in downtown Lisbon, in the area near the Tagus River known as Baixa. This type of building can be found elsewhere in Lisbon and in other urban areas in Portugal also destroyed in 1755, such as Vila Real de Santo Antonio in Algarve (in the southern part of Portugal). Because of its historical relevance, the building example described in this work is from Baixa.</p>
Summary:	<p>Pombalino buildings (see Figures 1, 2, 3 and 4) are historic masonry buildings that can be identified by the presence of a three-dimensional timber structure (named "gaiola pombalina"), which is enclosed in internal masonry walls above the first floor. The roofs are built with timber trusses clad with ceramic tiles and the floors are made of timber boards laid on timber joists. Ground floor walls are roughly dressed stone masonry supporting a system of vaults made of clay tiles, with stone arches. Foundations are made of short and small-diameter timber piles connected by a timber grid. These buildings were built after the 1755 earthquake when fear of new earthquakes led to the enforcement of anti-seismic provisions, such as establishing a maximum number of stories and introducing an interior timber structure called "gaiola." The buildings originally were mixed-use with commercial enterprises on the ground floor and residences on the upper floors. During the 20th century, most Pombalino buildings underwent substantial refurbishment when they were</p>

converted and occupied entirely by banks and companies. For the buildings that have maintained their original uses, the main problems result from poor maintenance. The expected collapse mechanisms due to earthquake actions are the overturning of facades (out-of-plane) or shear failure at the plane of the walls at ground floor level (global shear mechanism), leading to a global collapse mechanism. Typical seismic strengthening of these buildings includes the introduction of a concrete/steel ring beam at the level of the roof eaves. The introduction of steel elements/pre-stressed cables or of anchors connecting parallel masonry walls is also common. Steel elements are also used to connect detached timber elements from the floors and gaiola to the masonry. New techniques applying new materials like Fibre Reinforced Polymers (FRP) are also used to increase the strength of the connections of timber elements that compose the gaiola.

Length of time practiced:	More than 200 years
Still Practiced:	No
In practice as of:	
Building Occupancy:	Residential, 5-9 units Mixed residential/commercial
Typical number of stories:	4-5
Terrain-Flat:	Typically
Terrain-Sloped:	Never
Comments:	As time has passed, construction practices have changed and timber elements have progressively fallen into disuse in the three-d

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	A Pombalino building's plan is compact with a rectangular or nearly rectangular shape with symmetrical configuration (see figure 6). There are no isolated buildings as they are part of an urban block which is also symmetrical and with a rectangular plan shape (see Figure 7). A typical block has 7 to 8 buildings, usually a building at each corner and one on each side. Each block has a size of 70x25 m while the streets have width ranging from 5 to 20 m. The interior of each block includes a very small courtyard accessed only by the doors

of the back faade.

Typical plan length (meters)	8-16
Typical plan width (meters)	10-12
Typical story height (meters)	3.5-4
Type of Structural System	Other: Hybrid Systems: Other
Additional comments on structural system	<p>The vertical load-resisting system is stone masonry walls. Single leaf, irregular block, stone masonry walls. Masonry vaults at the ground floor, with ceramic regular blocks and stone arches (see Figure 11). Usually, the wall thickness of the Pombalino buildings varies from 1.0 to 1.2 meters and is the same for all floors. The Pombalino buildings built towards the end of the nineteenth century may present two or three different wall thicknesses. The usual changes are observed between the ground floor (1.0 to 1.2m) and the first floor (0.8 to 1.0m), and between the upper two floors. The thickness of the top floor may vary between 0.5 and 0.8m. The lateral load-resisting system is stone masonry walls. Masonry walls and a three-dimensional wood frame structure (gaiola) above the first floor, double braced with diagonal timber elements (see Figures 8, 9 and 10), form the lateral load-resisting system. The timber elements are notched together or connected by iron or metal ties, according to historical information about the construction techniques. The results of experimental tests performed on Pombalino panels, and of tests performed on masonry panels without diagonal bracing (Alvarez, 2000 and Lopes, 1986) showed that the gaiola exhibits ductile behavior and allows some energy dissipation. Connections between the timber elements, which sometimes include metallic (iron) elements, probably contribute to the observed ductile behavior. These results may be extrapolated to the performance of the entire structure. According to the construction process (first the entire gaiola was built, then the masonry infill and the exterior walls), there are reasons to believe that interior timber frames are connected to floor elements but these connections must be better characterized. The connections of interior timber frames between stories must also be better characterized.</p>

The structural system can be divided into the

Gravity load-bearing & lateral load-resisting systems

ground floor system (masonry walls and vaults) and the gaiola system (wooden interior walls) of the floors above the first floor, described as follows: The ground to first floor level is comprised of stone masonry columns supporting stone arches and clay brickwork vaults (see Figure 11). Interior walls above the first floor are part of the gaiola. Masonry infill can be stone or clay bricks like those used at the ground floor vaults. It is usual to find both types of masonry in internal walls (see Figure 10). For the first buildings built after the earthquake, there are reasons to believe that the masonry used was rubble recycled from destroyed buildings. Other internal partitions are the wooden panels without structural function. Exterior walls (facades and walls between adjacent buildings) are stone masonry in lime mortar. Stone masonry walls (ground floor) and wooden frame with masonry infill (floors above the first floor).

Typical wall densities in direction 1

>20%

Typical wall densities in direction 2

5-10%

Additional comments on typical wall densities

Typical wall density is between 20% and 24% (both ground floor and floors above). Direction parallel to facades: 14% (ground floor) and 18% (other floors) Direction perpendicular to facades: 10% (ground floor) and 6% (other floors) All values relate to the plan area of the floor. Measurements were made considering only masonry and gaiola walls. Wall interior doors are included. The stone arches and masonry vaults at ground floor level support the interior walls of the floors above and therefore the wall density at ground floor level is smaller than at other floors.

Wall Openings

First floor openings are all of the same type (either doors with balconies or windows), depending on the importance of the street onto which the facade opens. Windows comprise the openings of the other floors. The eaves of the roof also include openings and these might be doors or small windows. The original plan called for the same dimensions and horizontal spacing of the openings for all Pombalino buildings. Main facades present a regular opening grid with clearly identified masonry piers and spandrels. The number of openings in each building or on each floor varies from 3 to 6 and depends on the area of the building plan. If the main facade of an original building has 6 openings, approximately 26% of the overall area is for windows and 38% of the overall wall surface area is utilized for doors,

measured at the floor above ground level. At the ground floor level of the same original building, the overall door area is 50% of the overall wall surface area. To prevent firepropagation between buildings, which was one of the main causes of death in the 1755 earthquake, the masonry walls between adjoining buildings have no openings and extend beyond the roofs.

Is it typical for buildings of this type to have common walls with adjacent buildings?

Yes

Modifications of buildings

The most common modification of Pombalino buildings is the addition of bathrooms. If the floors above ground are used for residences, typically the kitchen has been altered to provide for running water. It is also common to observe the insertion of larger shop windows on the ground floor, which sometimes demolishes all vertical masonry elements in the facades. Behind the buildings, the area at the ground floor level, once used as internal courtyards and free space, has been taken over by shops for their expansion needs. The most common adaptation of the old buildings for their new function is the introduction of elevators and new stairs and the demolition of interior walls (at ground floor and at floors above). The introduction of at least one floor at the top of the building is also common.

Type of Foundation

Deep Foundation: Wood piles

Additional comments on foundation

It consists of wood piles. Masonry placed over a grid of connected timber piles (see Figure 12). Timber piles are very short (generally less than 5 meters), and mobilize only lateral resistance because soil with good strength capacity is usually found at a depth of 15 meters or more. Pile diameter is small (25 cm) and piles form a regular mesh. Piles were completely under water but the current water level is becoming lower and some piles are degraded. There is no evidence of foundation soil instability and some authors maintain that pile degradation is no longer important to foundation strength capacity because the timber mesh acted as soil reinforcement at the time of construction. Baixawas rebuilt over rubble from collapsed buildings during the 1755 earthquake and the timber grid of piles would be a good measure to provide compaction. However, this is still an object of discussion and controversy.

Type of Floor System

Plywood panels or other light-weight panels for floor

Additional comments on floor system

Wood floors can be considered as a flexible diaphragm. The roof timber structure depends on the top floor of the building because it may include windows openings within the timber frame.

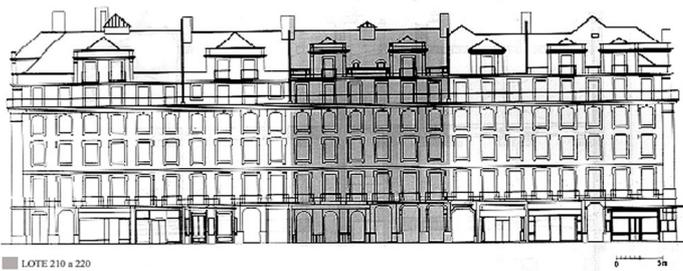
Type of Roof System

Roof system, other

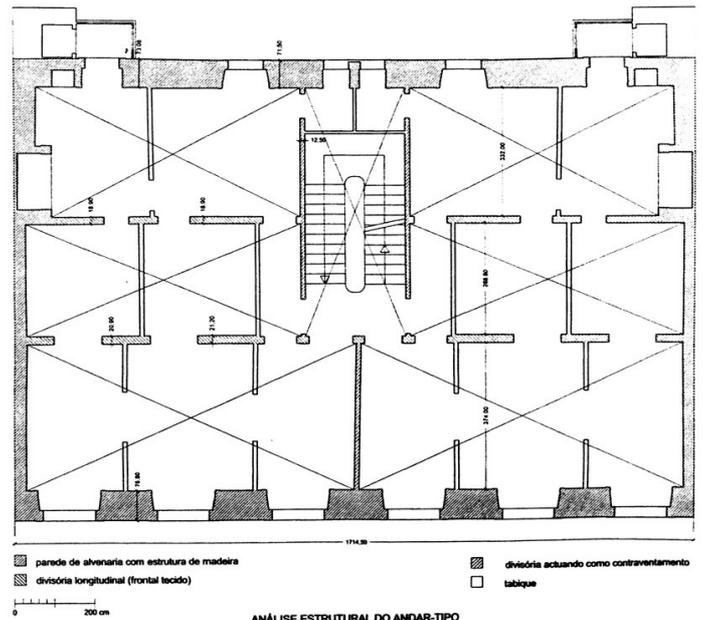
Additional comments on roof system

The number of pitches of the roof depends on the kind of window, which is associated with construction practices at the time the building was built. Connections between timber elements and masonry walls may have metallic elements like anchors. In the absence of these elements, connection forces are transmitted only by friction effect. The characteristics of the connection must be analyzed case by case.

Additional comments section 2



Plan of the facades of a typical block of buildings (Santos, 2000)



Plan of a typical building (Santos, 2000)



***Aerial view of Lisbon
Downtown showing similar blocks of
'Pombalino' buildings***

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Irregular blocks of calcareous masonry set in lime mortar	Low tensile and shear strength characteristics, values not known precisely (see Cardoso et al., 2001)
Foundations	Short and small diameter timber piles (pine)	Strength values not known (see Alvarez, 2000)
Floors	Timber elements (pine and oak)	Strength values not known
Roof	Timber elements (pine and oak)	Strength values not known
Other		

Design Process

Who is involved with the design process?	Engineer Architect
	Engineers and architects had a very important role

Roles of those involved in the design process

in planning the reconstruction of the city. The plans included not only the new urban layout but also functional and architectural aspects. Structural features were also examined and seismic considerations were a main concern as the introduction of the gaiola in these buildings shows.

Expertise of those involved in the design process

The idea of using timber frames for the gaiola and for the connections between timber elements was inspired by ship construction, in which the Portuguese had great expertise.

Construction Process

Who typically builds this construction type?

Builder

Roles of those involved in the building process

See details at Lopes et al. (2013)

Expertise of those involved in building process

Construction process and phasing

Due to time constraints, the construction process was highly organized. The gaiola and the entire wood structure were built first, then the masonry infill was placed at the same time as the exterior masonry walls were constructed. Finally, windows and doors stones were placed with the finishing work. This sequence allowed different specialists (carpenters and masonry workers) to do their jobs without interference. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. The reconstruction of Lisbon after the 1755 earthquake was slow due to financial and economic constraints, and it is likely that buildings in the same urban block might have been built in different years. The time gap in the construction of individual buildings may explain some of the observed architectonic variances, as seen in the roof structure and lighting for the stair wells, for example. Very often an extra floor was built at the same time as the rest of the building.

Construction issues

Building Codes and Standards

Is this construction type address by codes/standards?

Yes

Applicable codes or standards

A written document has never been found but construction rules were practiced and transmitted between carpenters and masonry workers so it is assumed that there was a code of practice. The year the first code/standard addressing this type of construction issued was 1755-1758. There is no mention of regulations for this type of construction in modern building codes or seismic codes.

Process for building code enforcement

Beginning in 1758 and during the Marquis de Pombal's governance, the penalty for failing to follow construction rules was the demolition of the building by order of the king.

Building Permits and Development Control Rules

Are building permits required?

Yes

Is this typically informal construction?

No

Is this construction typically authorized as per development control rules?

Yes

Additional comments on building permits and development control rules

Historical information indicates that the owners of the buildings which collapsed during the 1755 earthquake contracted builders, who supervised the construction. They had to respect all rules imposed by the Marquis de Pombal. Engineers and architects established these rules.

Building Maintenance and Condition

Typical problems associated with this type of construction

Water ingress through the roof system can be found in some buildings.

Who typically maintains buildings of this type?

Owner(s) Renter(s) No one Other

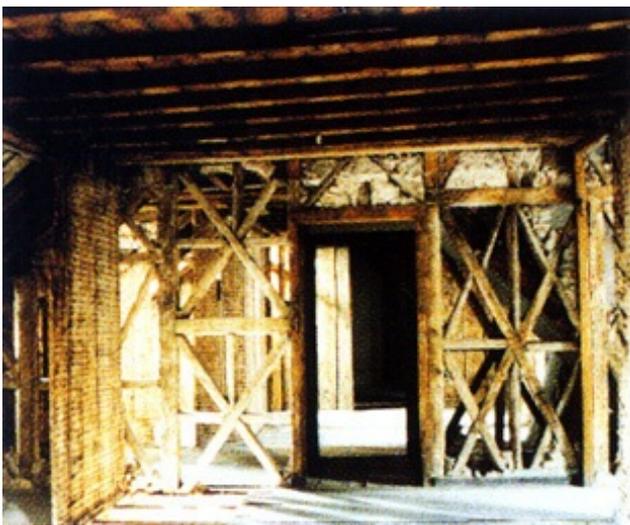
Additional comments on maintenance and building condition

See the sections corresponding to Socio-Economic Issues.

Construction Economics

Since this is a construction method that is no longer practiced, values for construction costs are not available. The actual commercial value of Pombalino buildings varies and depends on whether

<p>Unit construction cost</p>	<p>they have been abandoned or upon how difficult it would be to get authorization to perform structural/functional changes: if the building still maintains its original structure and use, the approximate cost may be from 400 to 450 euro/m² depending on the level of deterioration. If the building has been refurbished, the value depends on its current use. For residential use, values ranging from 1000 to 2500 euro/m² are usually quoted. Commercial values are not related to construction values. Infact, Baixa is located in the most central part of Lisbon and this justifies the high prices quoted.</p>
<p>Labor requirements</p>	<p>This information is not available.</p>
<p>Additional comments section 3</p>	



Wood braced frame of 'gaiola' after the removal of cover masonry (Museum of BCP, 2000)

Socio-Economic Issues

<p>Patterns of occupancy</p>	<p>One family occupies one housing unit. Each building typically has 3 to 4 or 6 to 8 housing unit(s). There are 1 or 2 units per floor on above ground floors. The number of units may depend on the area of the building plan: there is only one unit per floor if the number of windows is less than 4; if the number of windows is more than 4, there can be two units per floor.</p>
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Number of inhabitants in a typical building of this construction type during the day	>20
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	<p>The number of inhabitants in a building during the day or businesshours is more than 20. The number of inhabitants during the evening and night is less than 5. Some buildings belong to companies and banks and all floors have been adapted to new functions. In such cases, the number of inhabitants varies from a high number during business hours (40 to 50 workers and clients/costumers), to a smallnumber of inhabitants (mainly security people, less than 5) at night. If buildings were converted into commercialoutlets, occupancy might be as high as 200 people depending on time of day and the season.</p>
Economic level of inhabitants	Very low-income class (very poor)High-income class (rich)
Additional comments on economic level of inhabitants	<p>Most of the residential occupants are very poor old people who have lived in the same house their entire life. Whenthe last resident dies, the building may be abandoned or sold. The housing units are rented at low prices due tohousing rent legislation that has not been revised for more than 40 years. Because of low rent rates, these buildingshave been very poorly maintained and are often in need of rehabilitation work. Lisbon's City Council has specificprograms to finance rehabilitation work and these are being gradually applied throughout the city. The rehabilitationof recently purchased buildings depends of the new owners. Building functions may change but, where residential useis maintained, housing units are adapted to provide good conditions and then rented or sold to wealthy tenants orowners.</p>
Typical Source of Financing	Small lending institutions/microfinance institutionsCommercial banks/mortgagesInvestment pools
	<p>Originally, mainly financed by private developers, perhaps with some governmental contribution. Presently, most ofthe work for rehabilitation and reuse are financed by banks or by the owners. The nature and cost of the work depends of the intended use of the building. Small lending institutions and</p>

Additional comments on financing

microfinance institutions finance the work of small offices and the rehabilitation of residential rented units. If the building is going to be adapted for companies or for completely new apartments, refurbishment is more expensive and financed by commercial banks and mortgage lenders. There is a large variation in the costs depending on the degree of intervention: they can vary from 75 euros/m² for small interventions (wall painting and repair, waterproofing), to 400 euros/m² for other kind of interventions (floors replacement, bathrooms and other refurbishment). These prices do not include structural interventions, which are more expensive.

Type of Ownership

Rent
Own with debt (mortgage or other)
Units owned individually (condominium)
Owned by group or pool
Long-term lease

Additional comments on ownership

Buildings adapted for banks and for other organizations that occupy entire buildings are owned by a group or pool. Ground floor shops are usually held by long-term lease. Commercial functions at the ground floor sometimes occupy the first floor. The floors above are residential units or small service offices (doctors, lawyers, specialized shops, etc), rented or owned individually.

Is earthquake insurance for this construction type typically available?

Yes

What does earthquake insurance typically cover/cost

For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Until 2001, earthquake insurance was available. Now companies avoid this type of insurance, but this may be a temporary situation caused by the redefinition of policy in this sector. It is part of a group of risks related to housing that optionally may cover damage caused by earthquakes. Insurance cost depends on seismic zone, age, and the number of stories in a building.

Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?

No

Additional comments on premium discounts

**Additional comments
section 4**

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1856	37.10 -10.50 (Atlantic Ocean, Southw est of Portugal)
1909	38.95 -8.82 (Benavente (Centre of Portugal)
1969	35.99 -10.81 (Atlantic Ocean, Southw est of Portugal)

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	The 1909 earthquake was felt in Lisbon and caused light damage to buildings in Baixa, mainly crack openings and the fall of chimneys and external plaster. The intensity shown in the table for this earthquake is the epicentral one, inBenavente, some 40 km from Lisbon. On the basis of damage observed in Pombalino buildings and in ordinary masonry structures, it is not possible to conclude whether the Pombalino buildings performed better because all theobservable damage was light. For the other earthquakes shown in the table, with epicentres either in continental Portugal or in the Azores Islands, there is no record of significant damage to buildings in Lisbon, due to the longdistance from the epicentre.
Additional comments on earthquake damage patterns	-Some crack openingsand fall of externalplaster. No detailedinformation available.In poorly connectedfacades, out-of-planemechanismexpected. (Walls) -Mainly fall ofchimneys. Nodetailed informationavailable. (Roof/Floors)

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 "Handbook for the Seismic Evaluation of Buildings-A Pre-standard", Federal

Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than $\frac{1}{2}$ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than $\frac{1}{3}$ of the distance between the adjacent cross walls; For precast concrete wall structures: less than $\frac{3}{4}$ of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	TRUE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	FALSE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	FALSE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	TRUE

Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doveled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	N/A
Wall Openings		TRUE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance

The original conception of the gaiola was to resist seismic actions and this supports the prediction of a good response for this type of building. The ground floor (masonry walls) may be a weak point for the seismic behavior of these buildings due to its lower strength due to the absence of the gaiola. The presence and performance of metallic (iron) elements at the connections between timber elements and masonry walls in the roof and floors are not entirely clear. In fact, some cases were found where the connection between timber elements and masonry depended only on the length of the joist seat inside the masonry. In that case, the strength of the connection depends only on the friction between the materials and would be smaller if there was a metallic element. The uneven quality of the original masonry or the construction of different walls at various times also led to poor strength and stiffness properties. Construction practices were not the same for buildings built in the same period, which might indicate that the quality of workmanship was not the same. As an example, it is possible to find different geometries of gaiola in the same building and there are several gaps in the connections between timber elements, which may or may not have nails. The quality of workmanship also decreased over time, as the first Pombalino buildings show better quality than those built in the nineteenth century. Like all masonry buildings, the presence of large openings reduces the lateral stiffness and load capacity of facades. Another significant uncertainty is how important a role the structural interventions had on buildings because the exterior may look original but the interior can be completely modified. Removal of internal gaiola walls greatly increases the seismic vulnerability of Pombalino buildings.

Vertical irregularities typically found in this construction type

Other

Horizontal irregularities typically found in this construction type

Other

Low resistance to out-of-plane seismic effects (overturning of facades) and collapse of the roof;
Low resistance of connections between facades and perpendicular masonry walls due to bad quality of masonry at corners, that can be associated to construction of connected walls at different times.

Seismic deficiency in walls

construction of connected walls at different times; possibility of formation of a global collapse mechanism due to masonry low shear strength; Large openings reduce lateral capacity of facades. Connections between 'gaiola' walls and masonry walls may have low strength connections if there are no metallic elements; timber decay due to water ingress.

Earthquake-resilient features in walls

Three-dimensional braced structure that reduces out-of-plane horizontal displacements of facades, contributing to reduced seismic vulnerability of Pombalino buildings; it displays ductile behavior (Cardoso et al, 2005; Kouris et al, 2014).

Seismic deficiency in frames

Earthquake-resilient features in frame

Seismic deficiency in roof and floors

Low strength connections between timber elements of roof and floor and masonry walls; timber decay due to water ingress.

Earthquake resilient features in roof and floors

A good connection between roof/floor timber elements and masonry walls may reduce seismic vulnerability because they can contribute to reduced out of plane horizontal displacements.

Seismic deficiency in foundation

Timber pile damage due to water level changes may cause building settlements.

Earthquake-resilient features in foundation

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines](#)

	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class	-	o	-			



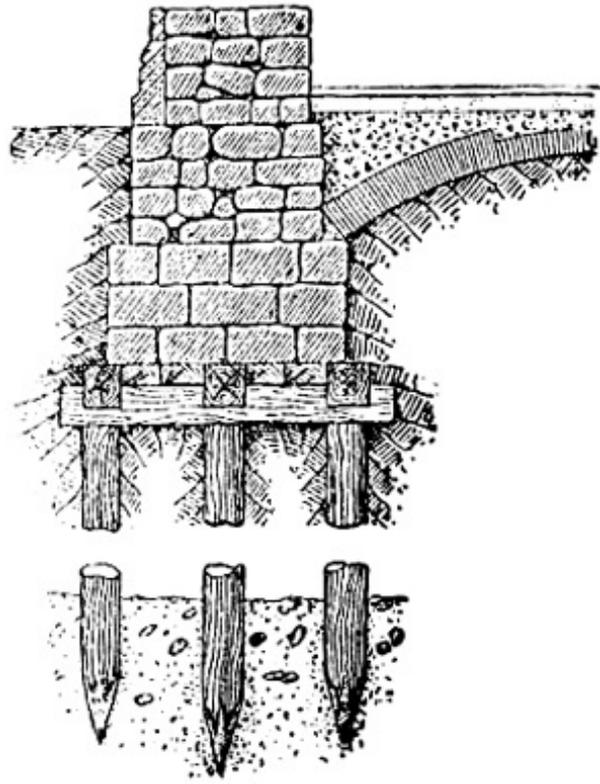
***Timber structure enclosed in
interiormasonry wall***



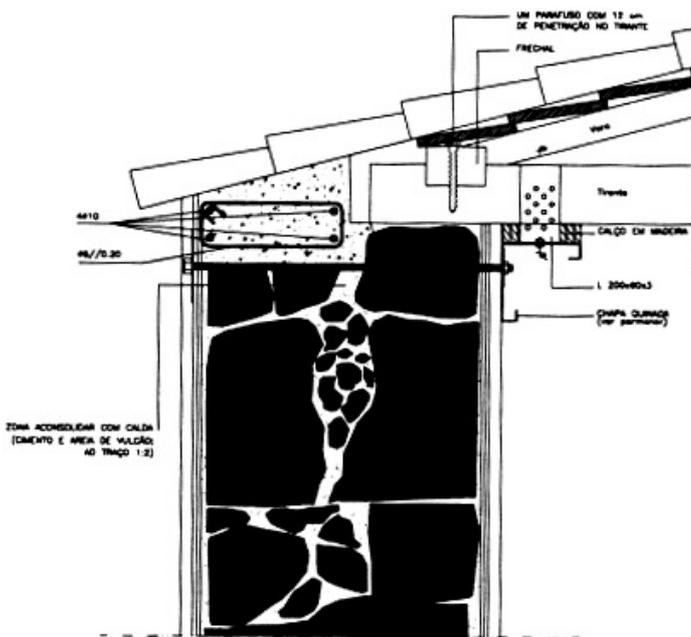
***Timber structure enclosed in
interiormasonry wall (detail)***



Masonry vaults at ground floor



Wood pile foundations (Santos, 2000)



Reinforcement of the connections between roof and masonry walls by a concrete beam (Costa et al, 2001)

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Low resistance to out-of-plane seismic effects (overturning of facades) and roof collapse; low resistance of connections between facades and perpendicular masonry walls due to the bad quality of the masonry at the connections.	Introduction of a concrete or steel beam at the top of the building, connecting the roof to walls (see Figures 13 and 14) and confining masonry. The beam is executed along the whole perimeter of the building. Sometimes, these beams are executed at the skirting board level of all floors above ground floor. Introduction of steel elements or ties (pre-stressed or not), cables, or anchors, connecting parallel masonry walls.
Masonry low shear strength may be critical to shear failure of the building due to the formation of a global collapse mechanism.	Introduction of steel mesh, confining masonry structural elements of facades (see Figure 15).
Settlement due to foundation failure	Micro piles
Low strength connection between timber elements	Use of steel rods and traditional techniques for strengthening timber element connections, such as the nails and bolts. Use of FRP in the strengthening of timber reinforced masonry loadbearing walls (see [Cruz et al., 2001]).
Low strength connection between timber elements and masonry walls	Introduction of steel elements, such as ties, which connect timber elements to masonry (see Figure 16).

Additional comments on seismic strengthening provisions	Timber damage due to water ingress, creating favorable conditions for fungi and insect attack. - Substitution or repair of broken tiles and measures to waterproof the roof. Sometimes, connections between roof and facades are also reinforced during repair. Damaged timber elements are removed and replaced with new timber elements of the same geometry.
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Has seismic strengthening described in the above table been	The usual seismic strengthening technique utilized in design practice is to improve the connections between the timber elements and the masonry walls because this is easier to perform and is cheaper than the other interventions mentioned. Another common strengthening technique is the introduction of ties which connect the facades and
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performed?

prevent out-of-plane displacements. Usually these techniques are not applied, but recently (mainly after year 2000) awareness has increased and therefore the number of rehabilitation works in which these techniques are applied has increased.

Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?

When an intervention is going to be done, seismic mitigation should be a concern but seismic strengthening is not the current practice because of the added cost and lack of awareness on the part of owners to seismic risk.

Was the construction inspected in the same manner as new construction?

The materials and construction techniques are not the same anymore. Inspection of new construction to evaluate seismic vulnerability follows code provisions, whereas inspection of older buildings relies much more on the expertise of individuals and on professional advice.

Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?

At the time of the construction of Pombalino buildings, contractors performed construction according to current earthquake technical provisions. At the present time, contractors, following engineering advice, usually include some seismic strengthening in the construction. Generally, architects are involved when construction includes not only repair but also modification, which happens in most cases.

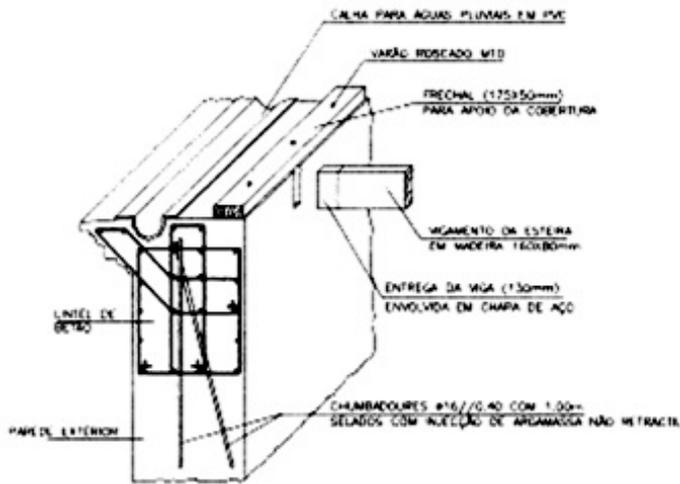
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

There is no information available about seismic performance of retrofitted buildings of this type since strong earthquakes have not hit Lisbon since 1755. Some retrofit solutions are being submitted to a homologation process so performance evaluation through laboratory testing is being done. These techniques are recent and there has been no opportunity to confirm their effectiveness. Most of them were developed after observation of damage due to recent earthquakes, such as the 1998 earthquake in Azores, Portugal, and the 1997 earthquake in Umbria, Italy. The results of numerical models of masonry buildings also provided information related to their expected collapse mechanism and they inspired the design of some reinforcement solutions (see Croci, 1988).

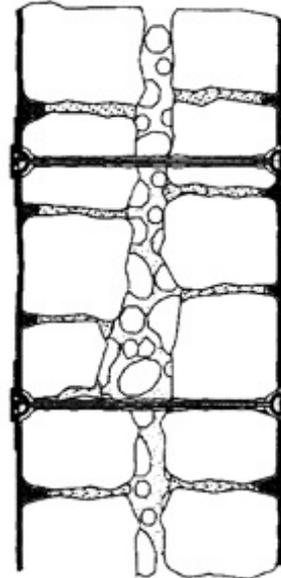
Additional comments section 6

The most common construction materials are steel, concrete and pine. Mortar mixes and proportions must be compatible with original materials. Besides the cost, efficiency, and durability of the strengthening solution, the feasibility of removing it from the structure without destruction must also be considered. The complexity level of any intervention is high because demolition is not desirable due to the historical importance of these buildings. Most

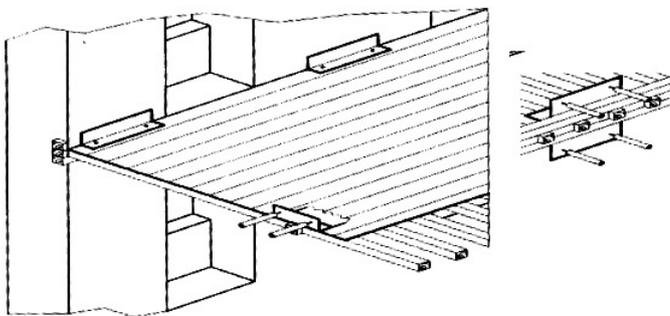
interventions must be performed in occupied buildings, thus increasing the execution time and complexity. There is little information available about the expected effectiveness of the seismic strengthening provisions listed above.



Reinforcement of the connections between roof and masonry walls by a concrete beam



Shear reinforcement of masonry structural elements using steel elements (Silva, 2002)



Reinforcement of the connections of wood floors to masonry walls by steel elements (Silva, 2002)

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