SEISMIC ASSESSMENT OF THE MASONRY "GAIOLEIRO" BUILDINGS IN LISBON. CASE STUDY AND SENSITIVITY ANALYSIS.

Author: Ana Simões

Advisors: Rita Bento (IST, Universidade de Lisboa, Portugal)
Sergio Lagomarsino (University of Genoa, Italy)
Paulo Lourenço (University of Minho, Portugal)

Motivation

• Masonry buildings were built for many centuries based on the available materials and empirical provisions.

• "Gaioleiro" buildings (19-20th centuries) is the typology with the highest structural weaknesses of the building stock of Lisbon.

Objective of the PhD research work

• Evaluation of the seismic vulnerability of "Gaioleiro" buildings based on seismic performance-based assessment procedures;

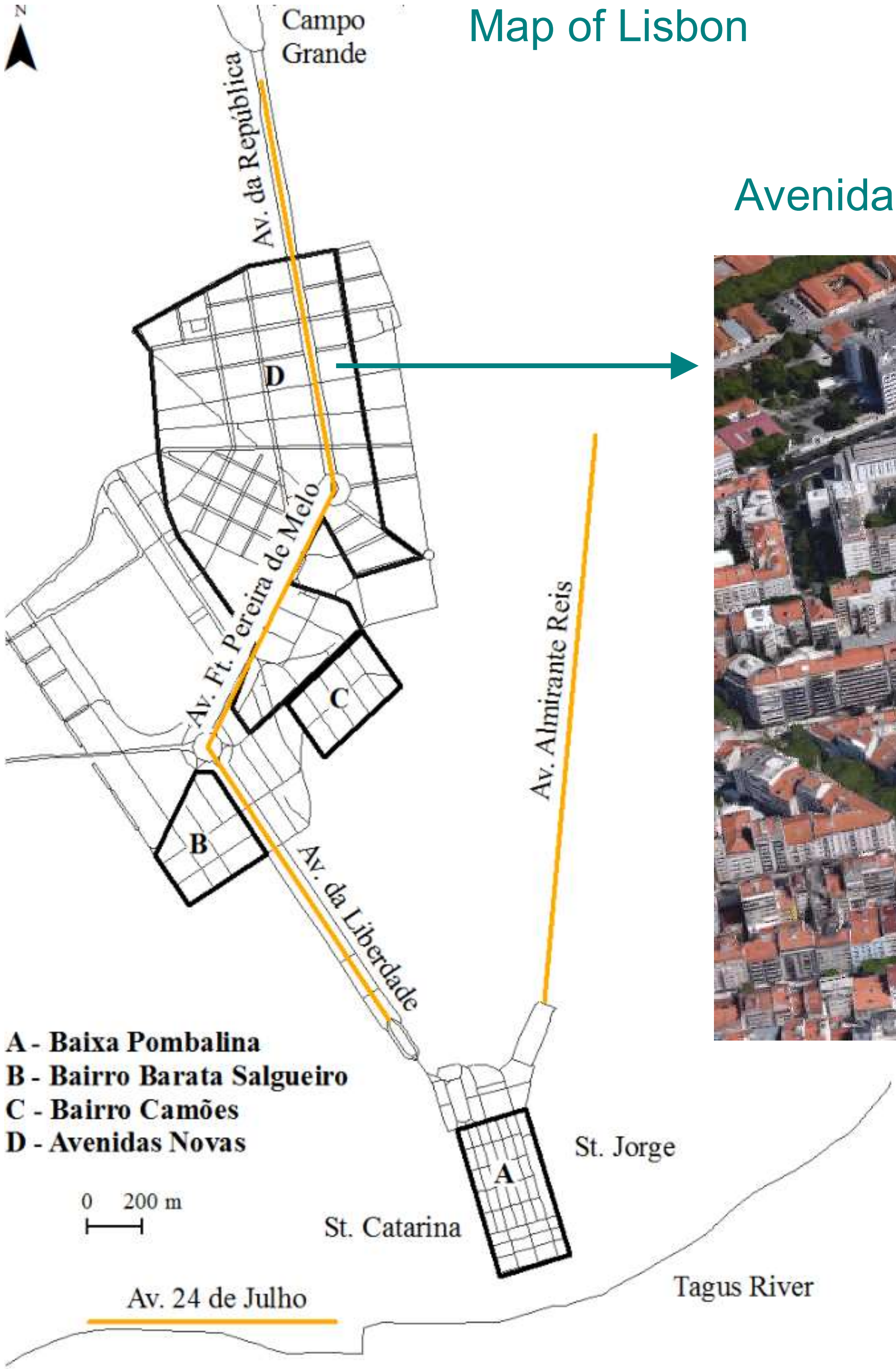
• Design of strengthening solutions for the reduction of the seismic vulnerability including cost-benefit analysis to compare the solutions;

• Definition of fragility curves before and after strengthening.

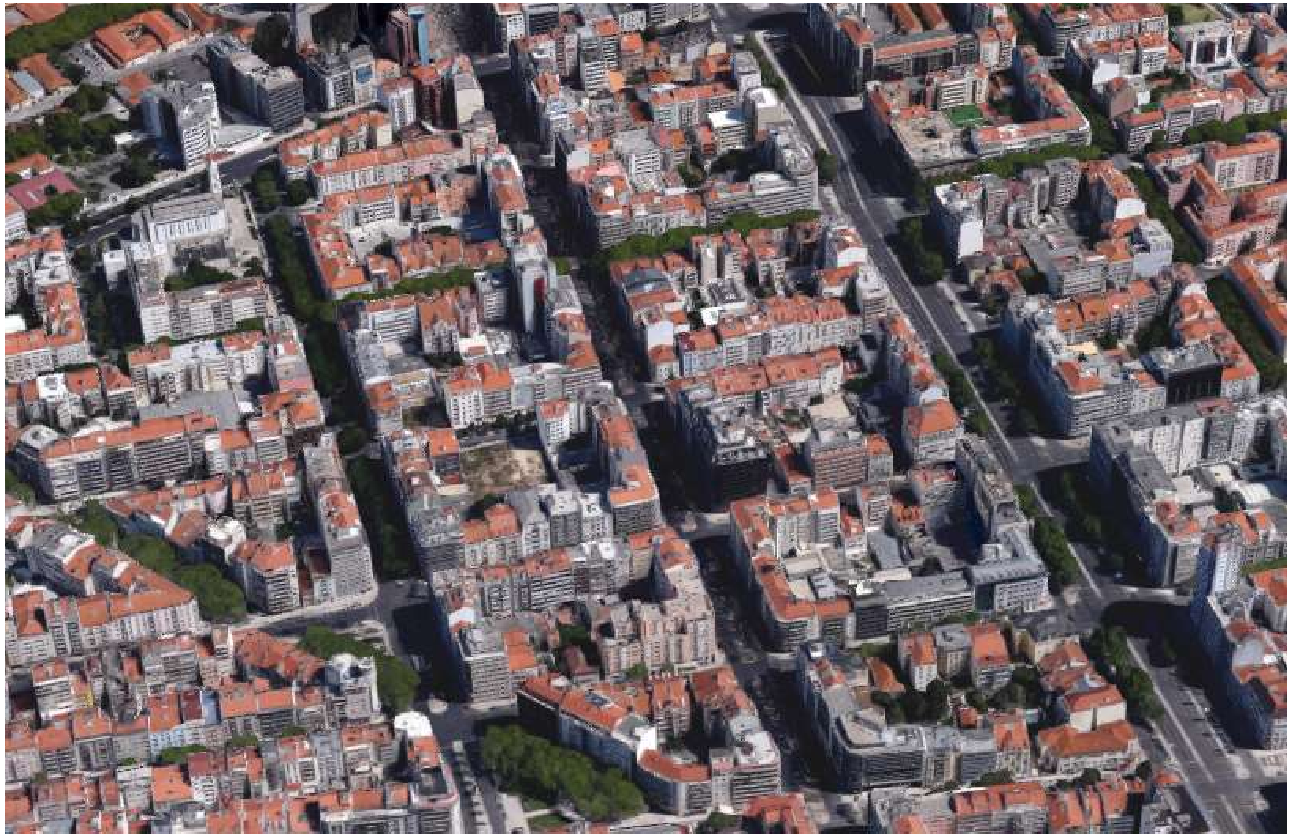
Outline

- The “gaioleiro” buildings
- Definition of the case study
- Analyse of uncertainties
- Sensitivity analysis
- Final comments

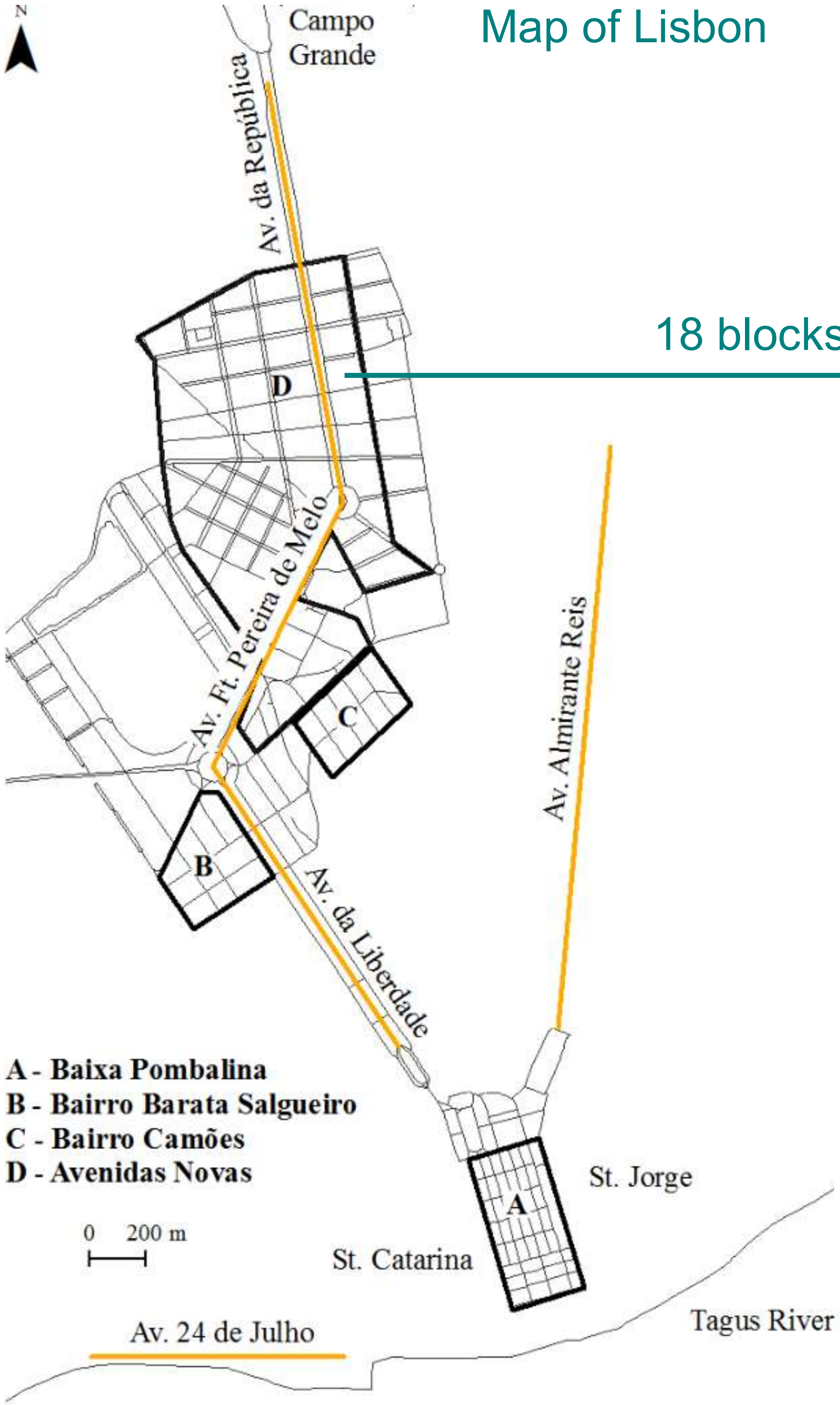
Map of Lisbon



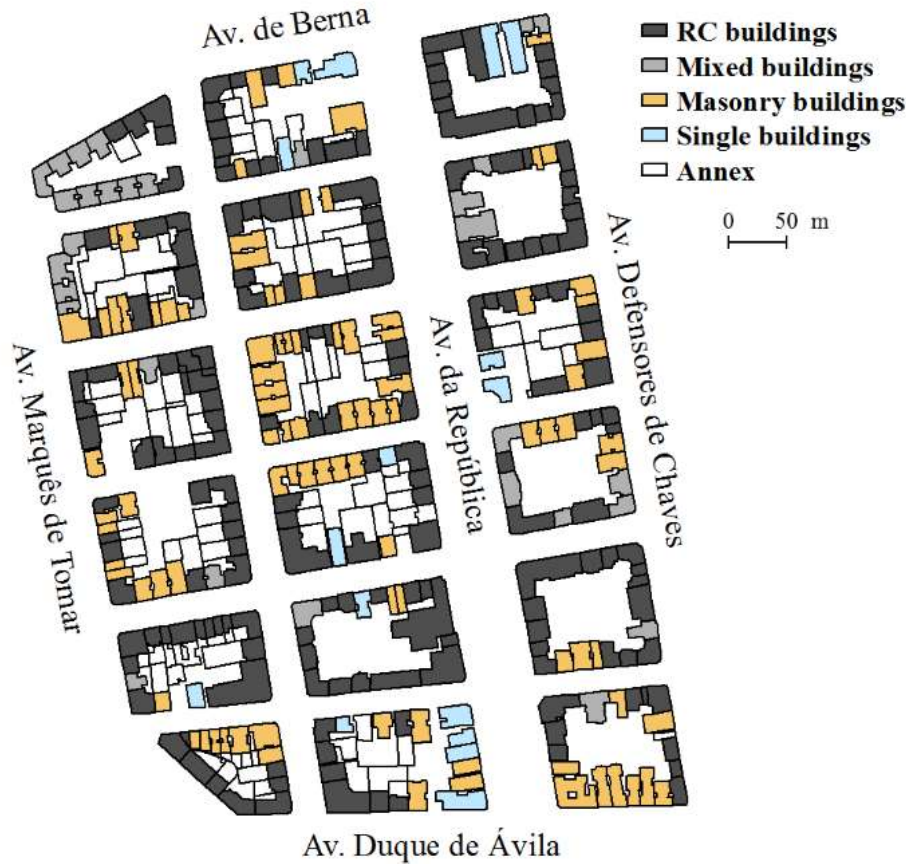
Avenidas Novas

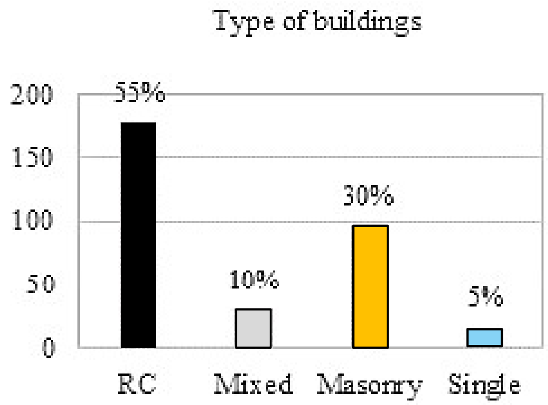


Map of Lisbon



18 blocks





The “gaioleiro” buildings

- Buildings with 4 to 7 storeys high
- External walls: rubble limestone masonry and air lime mortar
- Internal walls: solid or hollow brick masonry and air lime mortar
- Floors: timber beams placed perpendicular to the main façade walls

Type I

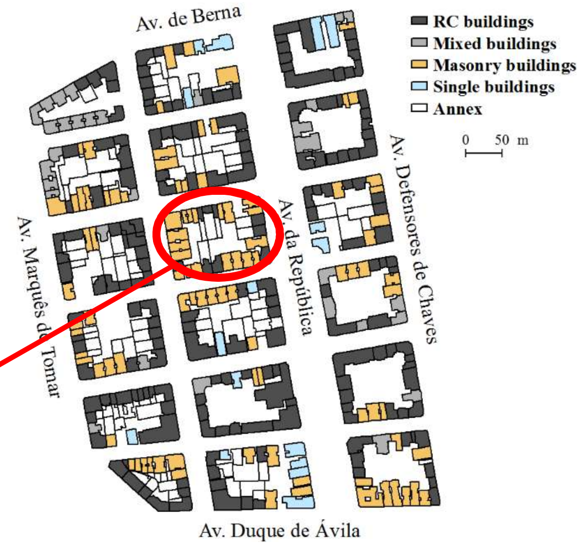
Type II

Type III

Type IV

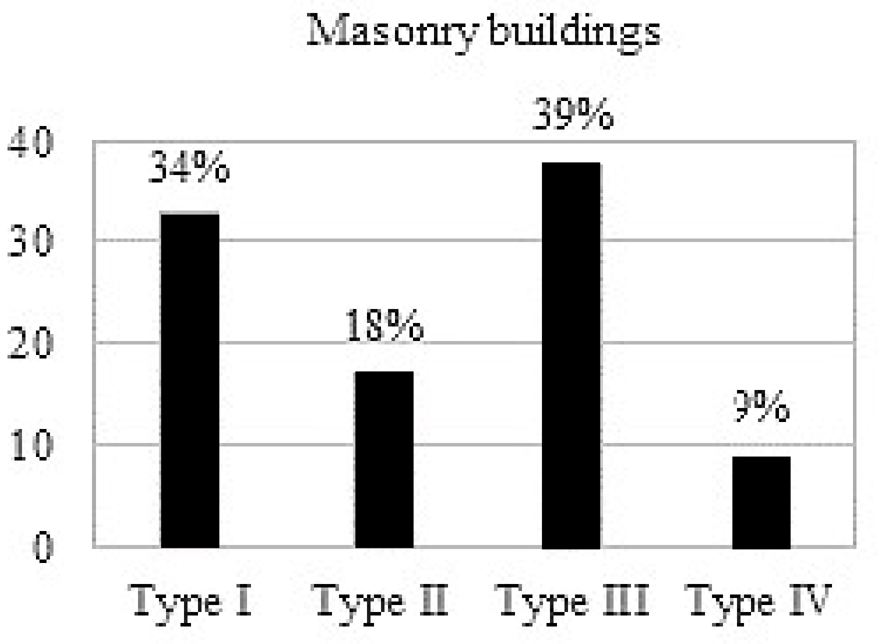
Simões, A. G.; Appleton, J. G.; Bento, R.; Caldas, J. V.; Lourenço, P. B.; Lagomarsino, S. (2016). Architectural and structural characteristics of masonry buildings on the transition between the 19th and 20th centuries in Lisbon, Portugal. International Journal of Architectural Heritage (under review).

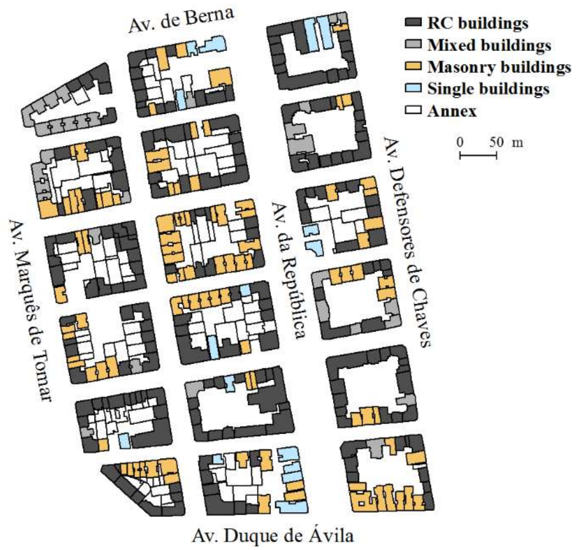
The “gaioleiro” buildings



Simões, A.; Bento, R.; Lagomarsino, S.; Lourenço, P. B. (2016). Simplified evaluation of seismic vulnerability of early 20th century masonry buildings in Lisbon. Proceedings of the 10th International Conference on Structural Analysis oh Historical Constructions – SAHC2016, Leuven, Belgium.

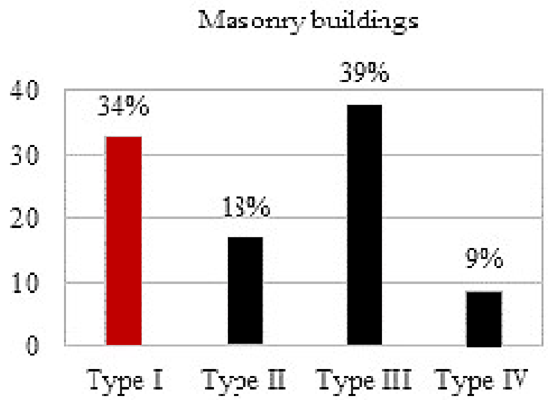
Definition of the case study

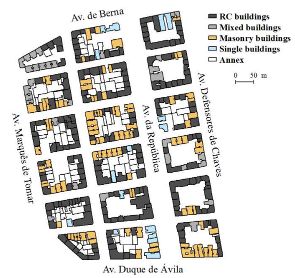


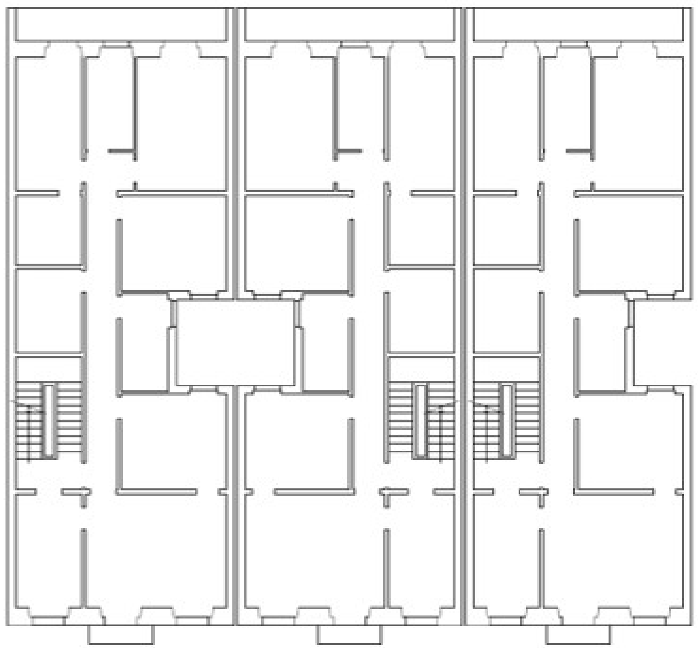


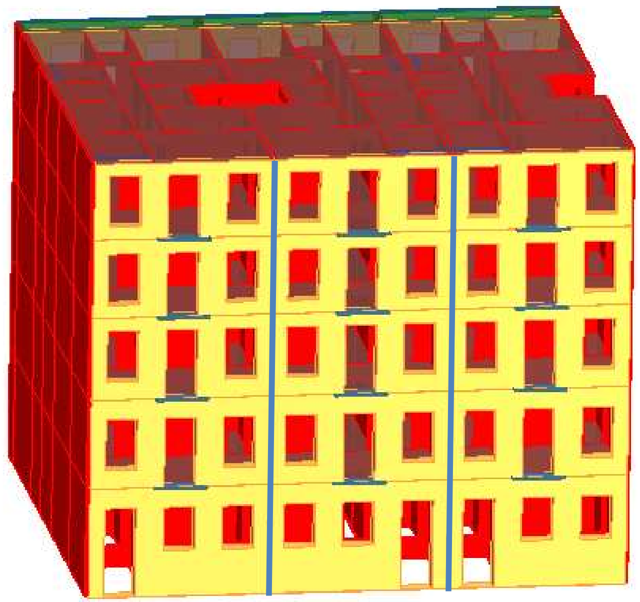
Definition of the case study

- Building type I: asymmetric structure.
- Model with 3 buildings to analyse different boundary conditions.
- Numerical model defined in Tremuri Program according to the equivalent frame model approach.

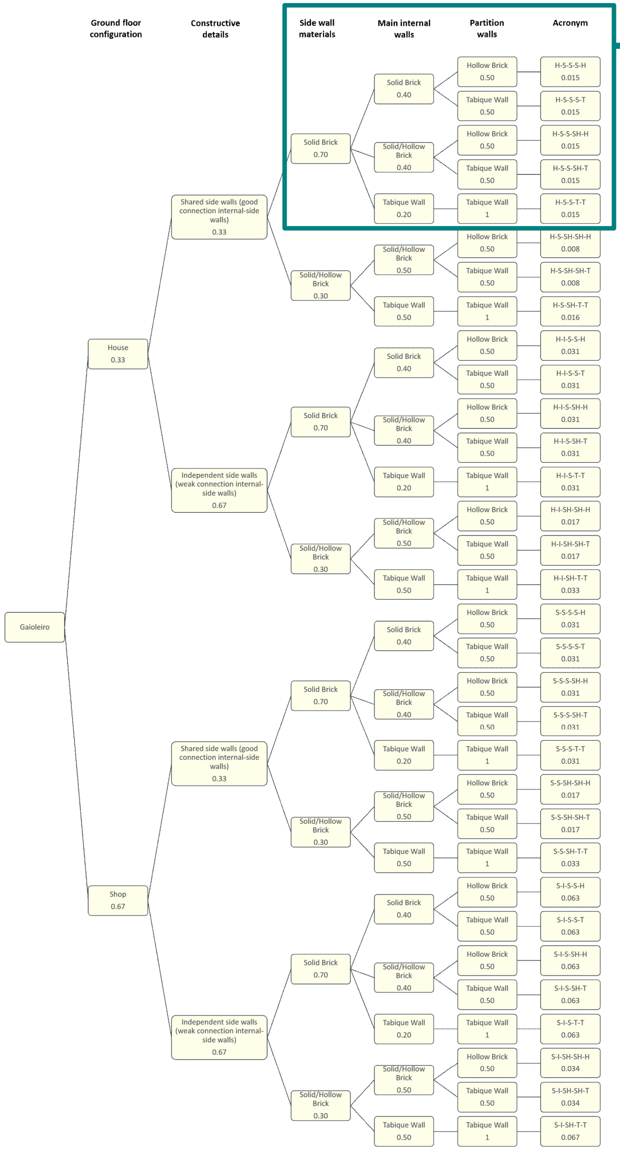




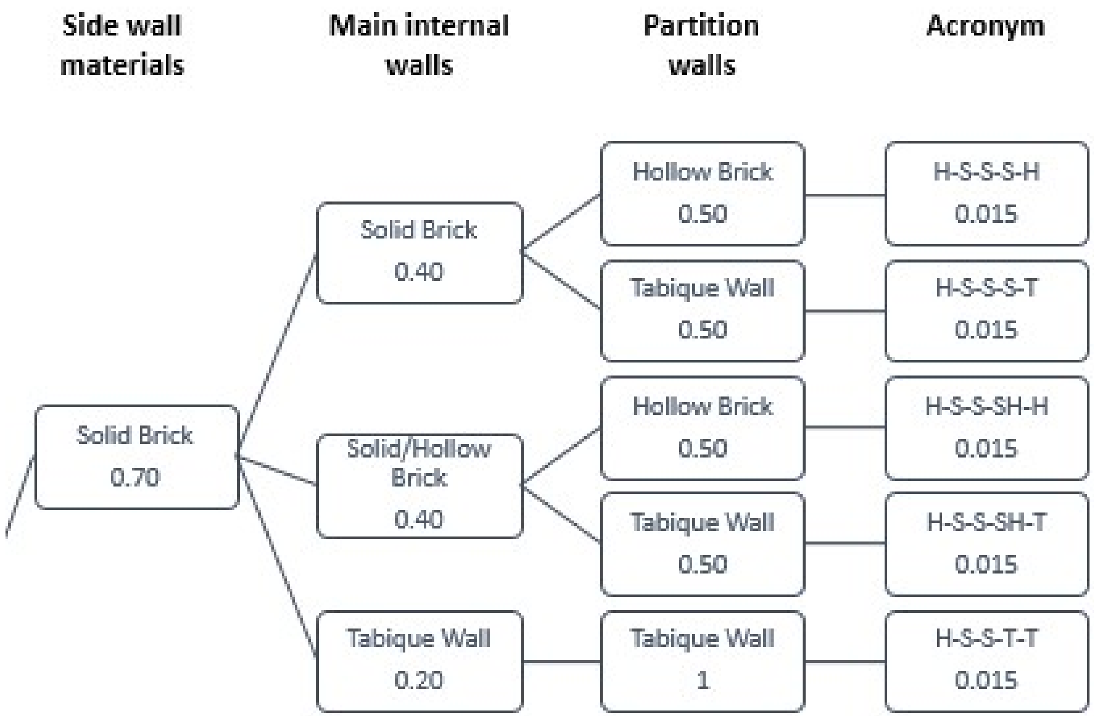




Analyse of uncertainties: epistemic



32 models



- Ground floor configuration: housing vs. shopping
- Constructive details: shared vs. independent side walls
- Side wall materials: solid brick vs. hollow brick masonry
- Main internal walls: solid brick vs. hollow brick vs. timber
- Partition walls: hollow brick vs. timber (“tabique”)

Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.

$$P(A \mid B) = \frac{P(A) \times P(B \mid A)}{P(B)}$$

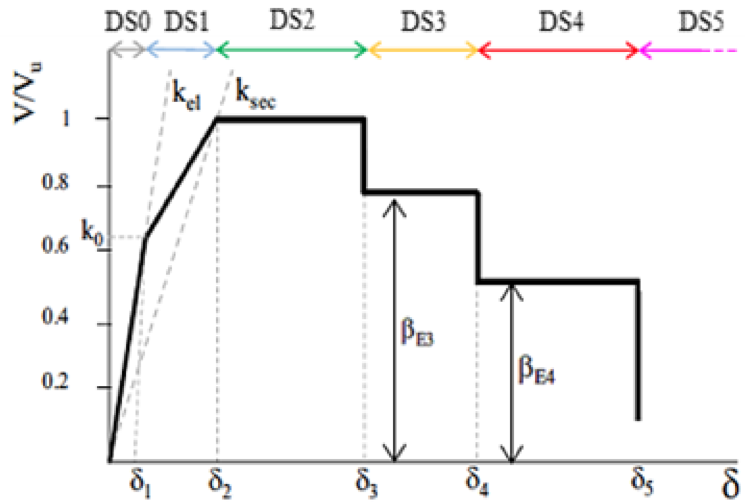
Material	Reference	f_c (MPa)	E (GPa)	τ_0 (MPa)
Rubble Stone	INTC (2009)	1.00 – 1.80	0.69 – 1.05	0.030 – 0.048
	Update	0.84 – 1.07	0.62 – 0.88	0.018 – 0.026
Solid Brick	INTC (2009)	2.40 – 4.00	1.20 – 1.80	0.060 – 0.092
	Update	0.95 – 1.19	0.72 – 0.99	0.060 – 0.092
Hollow Brick	INTC (2009)	2.40 – 4.00	1.20 – 1.80	0.060 – 0.092
	Updated	0.76 – 1.00	0.72 – 0.99	0.060 – 0.092

Flat-jack tests

Simões, A.; Bento, R.; Gago, A; Lopes, M (2015). Mechanical characterization of masonry walls with flat-jack tests. Experimental Techniques. Doi: 10.111/ext.12133.

Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.
- Modelling of masonry elements: multilinear constitutive law (K, δ and β).

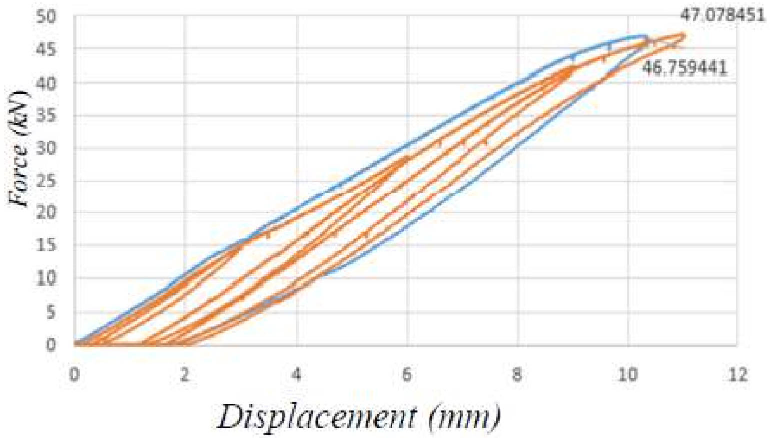


Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.
- Modelling of masonry elements: multilinear constitutive law (K, δ and β).
- Modelling of spandrels with brick arch on the façade walls.

Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.
- Modelling of masonry elements: multilinear constitutive law (K, δ and β).
- Modelling of spandrels with brick arch on the façade walls.
- Timber ("tabique") wall properties from experimental results.



Rebelo, A.; Guedes, J. M.; Quelhas, B.; Ilharco, T. (2015) Assessment of the mechanical behaviour of tabique walls through experimental tests. Proceedings of the 2nd International Conference on Historic Earthquake-Resistant Timber Frames in the Mediterranean Region – H.E.a.R.T 2015. LNEC.

Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.
- Modelling of masonry elements: multilinear constitutive law (K, δ and β).
- Modelling of spandrels with brick arch on the façade walls.
- Timber (“tabique”) wall properties from experimental results.
- Stiffness of timber floors (G) – NZSEE code.

Direction of loading	Joist continuity	Condition rating	Shear stiffness†, G_d (kN/m)
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

Note:
† 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

Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.
- Modelling of masonry elements: multilinear constitutive law (K, δ and β).
- Modelling of spandrels with brick arch on the façade walls.
- Timber ("tabique") wall properties from experimental results.
- Stiffness of timber floors (G) – NZSEE code.
- Connections between walls (A and I of link beams).

Analyse of uncertainties: aleatory

- Masonry properties (E, G, f_c, τ_0) determined with the Bayes Theorem.
- Modelling of masonry elements: multilinear constitutive law (K, δ and β).
- Modelling of spandrels with brick arch on the façade walls.
- Timber ("tabique") wall properties from experimental results.
- Stiffness of timber floors (G) – NZSEE code.
- Connections between walls (A and I of link beams).

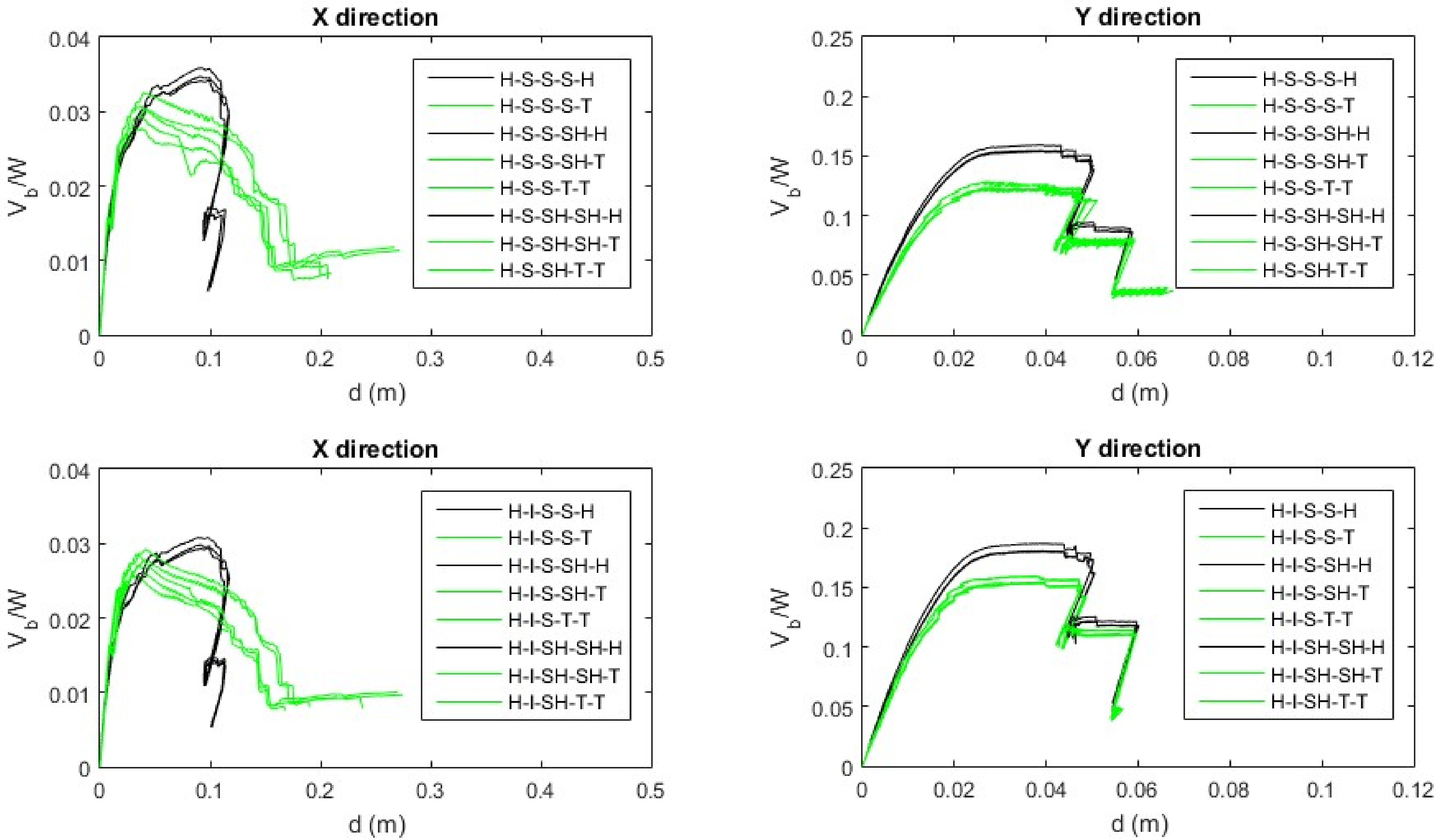
Type	Group	Random Variable	Units	Median	Standard Deviation
Rubble Stone Masonry	1	E	MPa	491.0	0.180
		G	MPa	163.7	0.180
		f_c	MPa	0.95	0.120
	2	τ_0	MPa	0.022	0.184
Solid Brick Masonry	3	E	MPa	560.4	0.160
		G	MPa	186.8	0.160
		f_c	MPa	1.07	0.113
	4	τ_0	MPa	0.074	0.214
	5	μ_{loc}	-	0.529	0.280
Hollow Brick Masonry	6	E	MPa	560.4	0.160
		G	MPa	186.8	0.160
		f_c	MPa	0.87	0.135
	7	τ_0	MPa	0.074	0.214
	8	μ_{loc}	-	0.529	0.280

17 groups and 50 random variables

Lognormal and Beta distributions

1000 Monte Carlo simulations

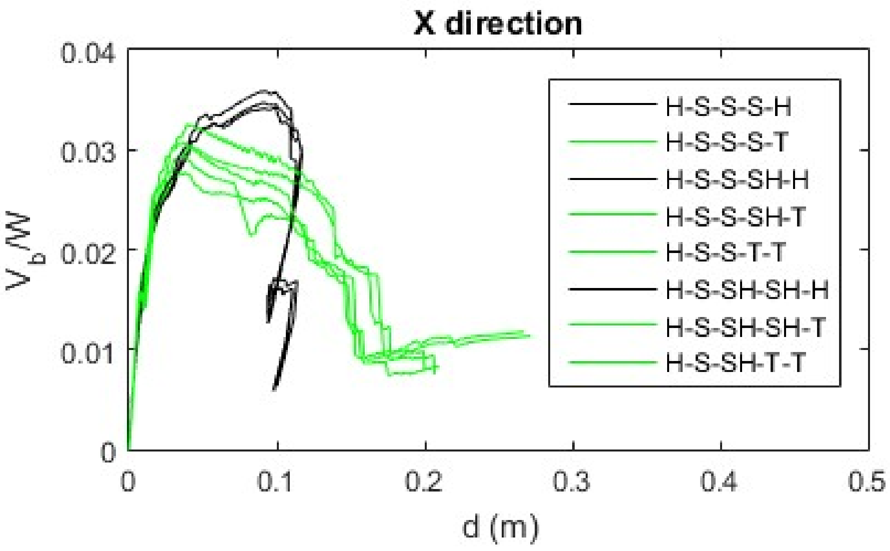
Sensitivity analysis

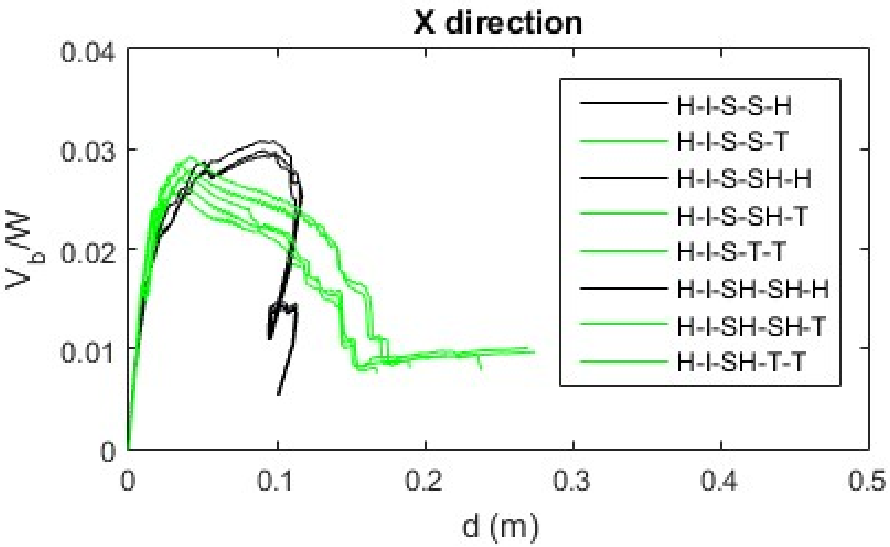


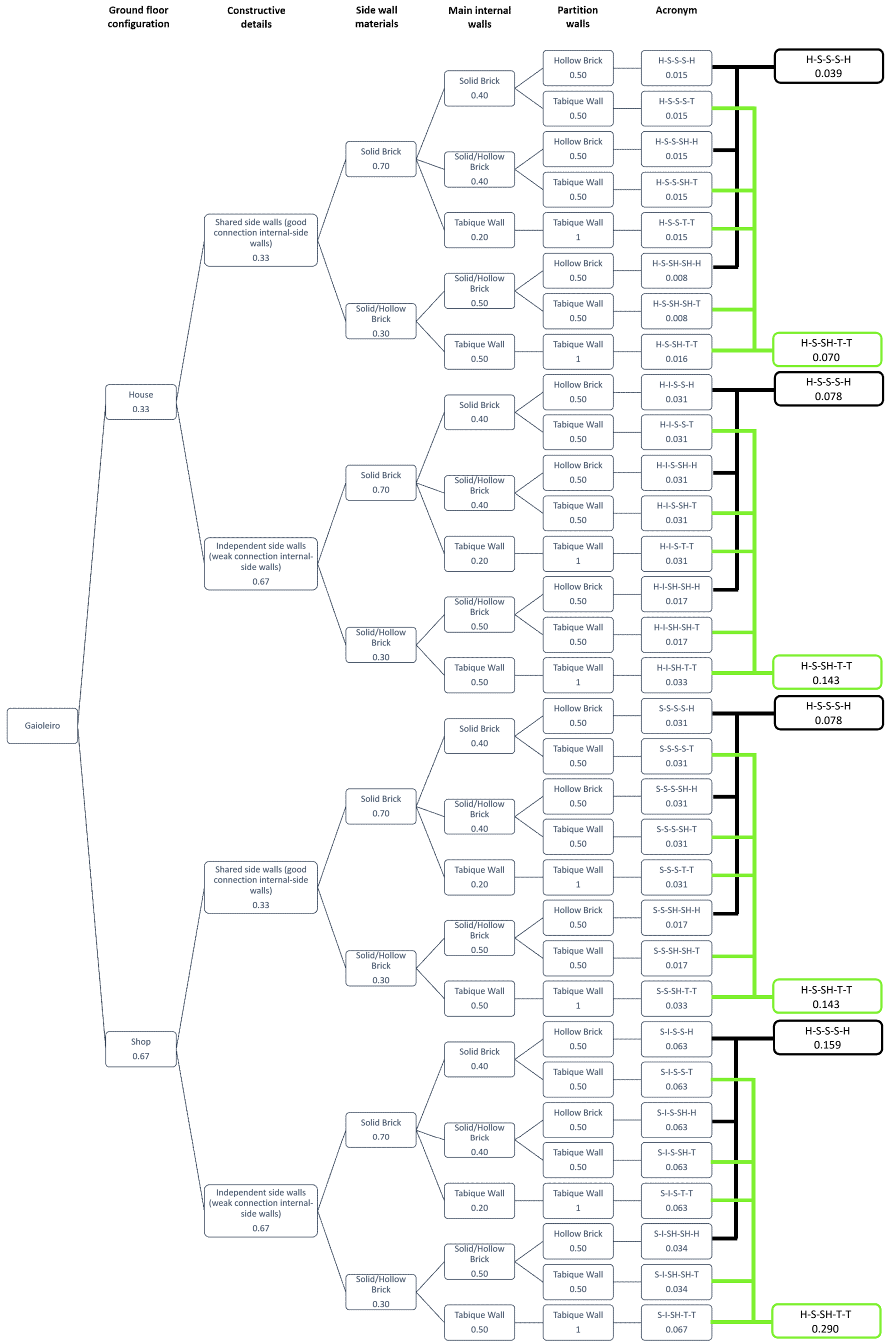
Pushover curves of the 32 models

(median values of the 50 random variables)

Sensitivity analysis







32 models ⟶ 8 models

Final comments

- 8 models x 1000 MC simulations.
- Pushover analysis: 2 load pattern (U/T) x 2 directions (X/Y) x 2 ways (+/-).
- **8 thousand analyses!**
- PGA compatible with different limit states.
- Definition of numerical fragility curves for this class of buildings.

Future work

- Analysis of the local behaviour: out-of-plane mechanisms.
- Modelling of strengthening techniques to reduce the seismic vulnerability.
- Derivation of the corresponding fragility curves.

Thank you!