EVALUATION AND REDUCTION OF THE VULNERABILITY OF "GAIOLEIRO" BUILDINGS

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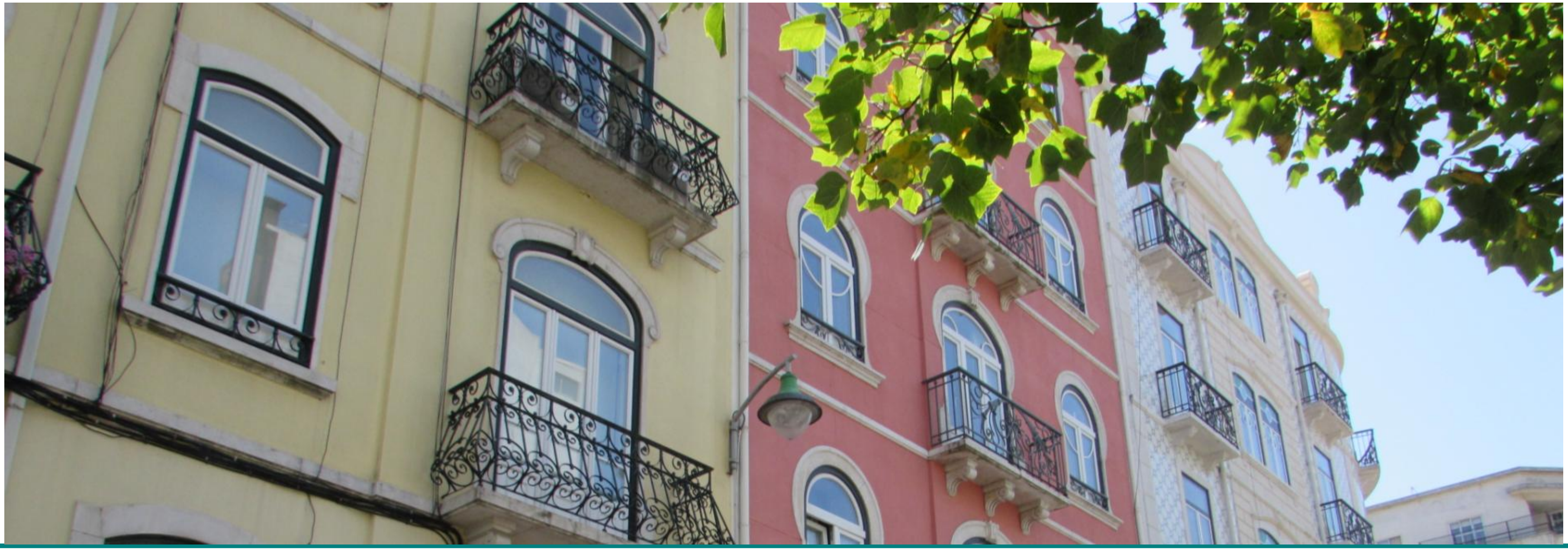


Motivation

Old Masonry Buildings

- Buildings before 1755 Earthquake
- “Pombalino” Buildings (after 1755)
- “Gaioleiro” Buildings (1880 - 1940)
- “Placa” Buildings (1940 - 1960)

Motivation

- Masonry buildings were built for many centuries based on the available materials and empirical provisions.
- “Gaioleiro” buildings are classified as the typology with the <u>highest structural weaknesses</u> of the building stock of Lisbon.
- These buildings were built in a period of fast development of the city and real estate speculation which ended up affecting the structural system regarding the materials and constructive details used.

Outline

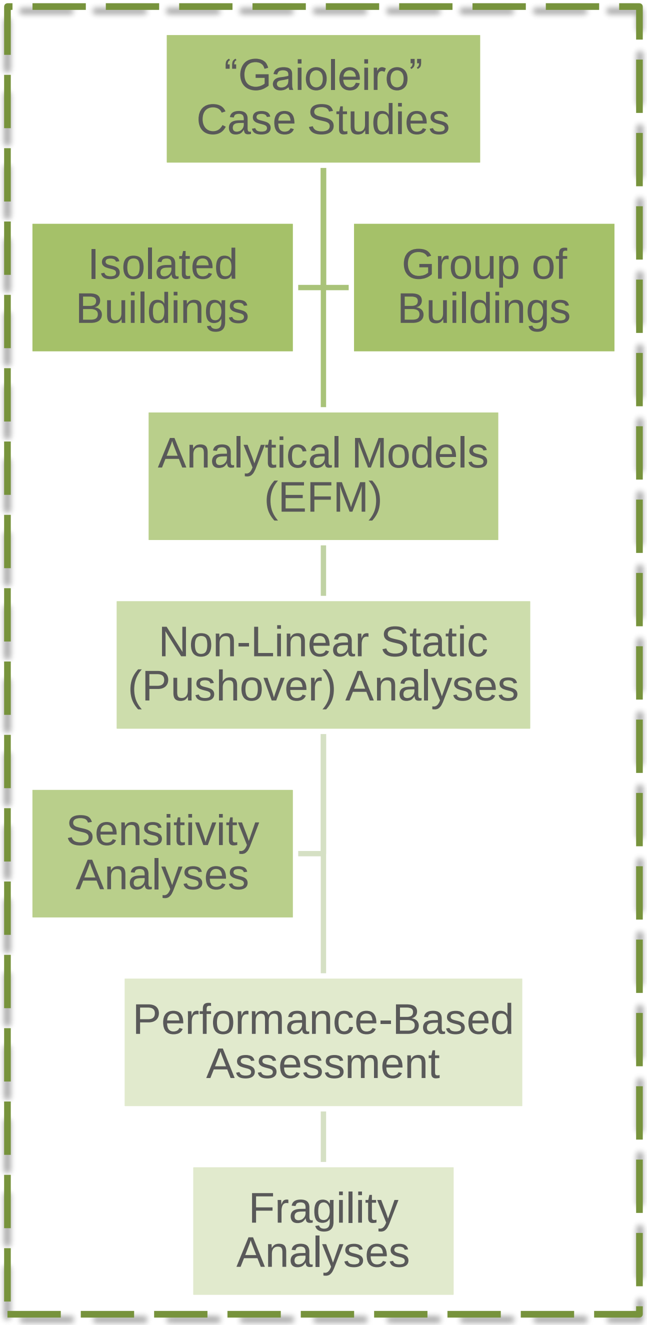
- Introduction
- The “Gaioleiro” Buildings
- Detailed Seismic Assessment
- Simplified Assessment of the Aggregate
- Conclusions

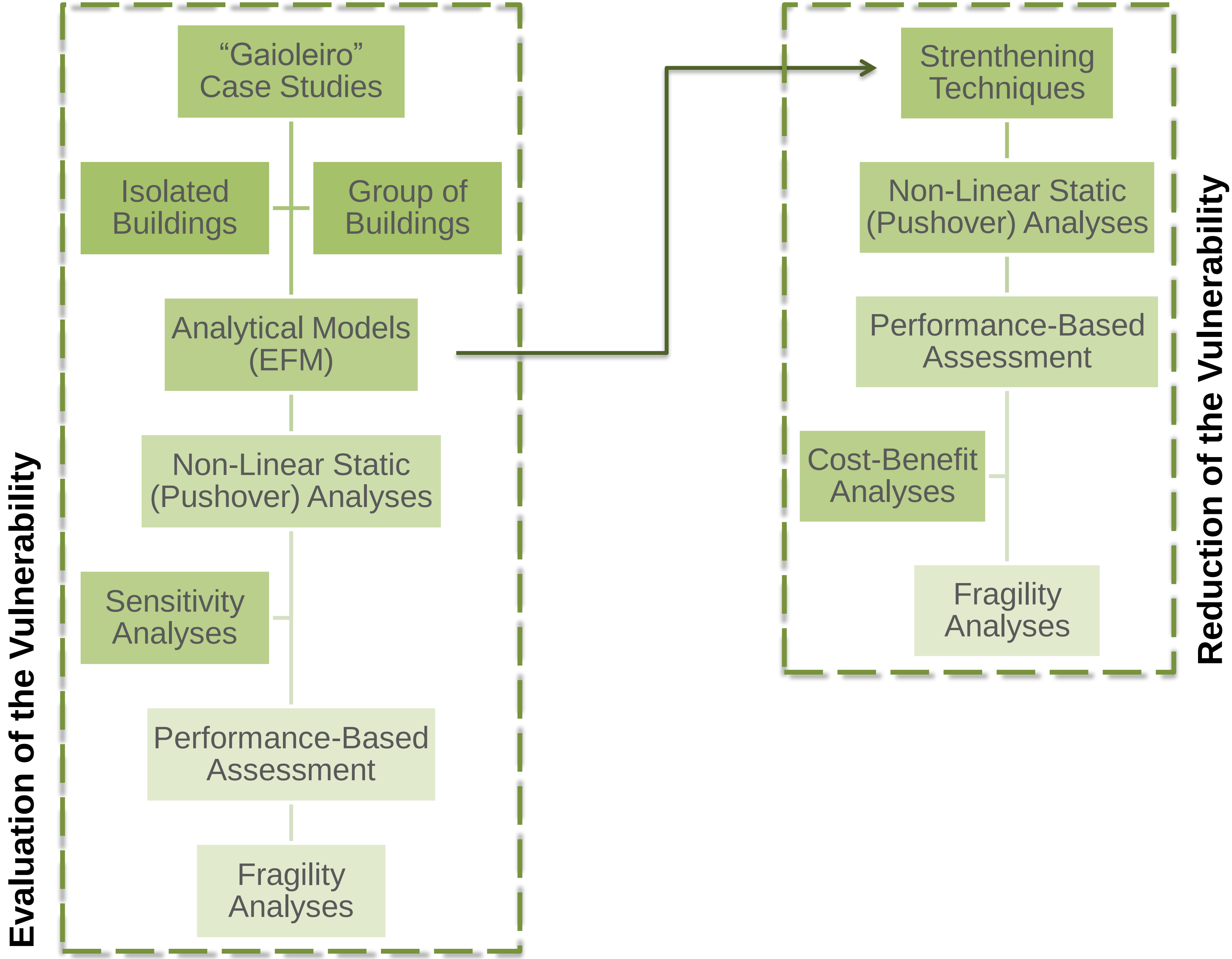
Introduction

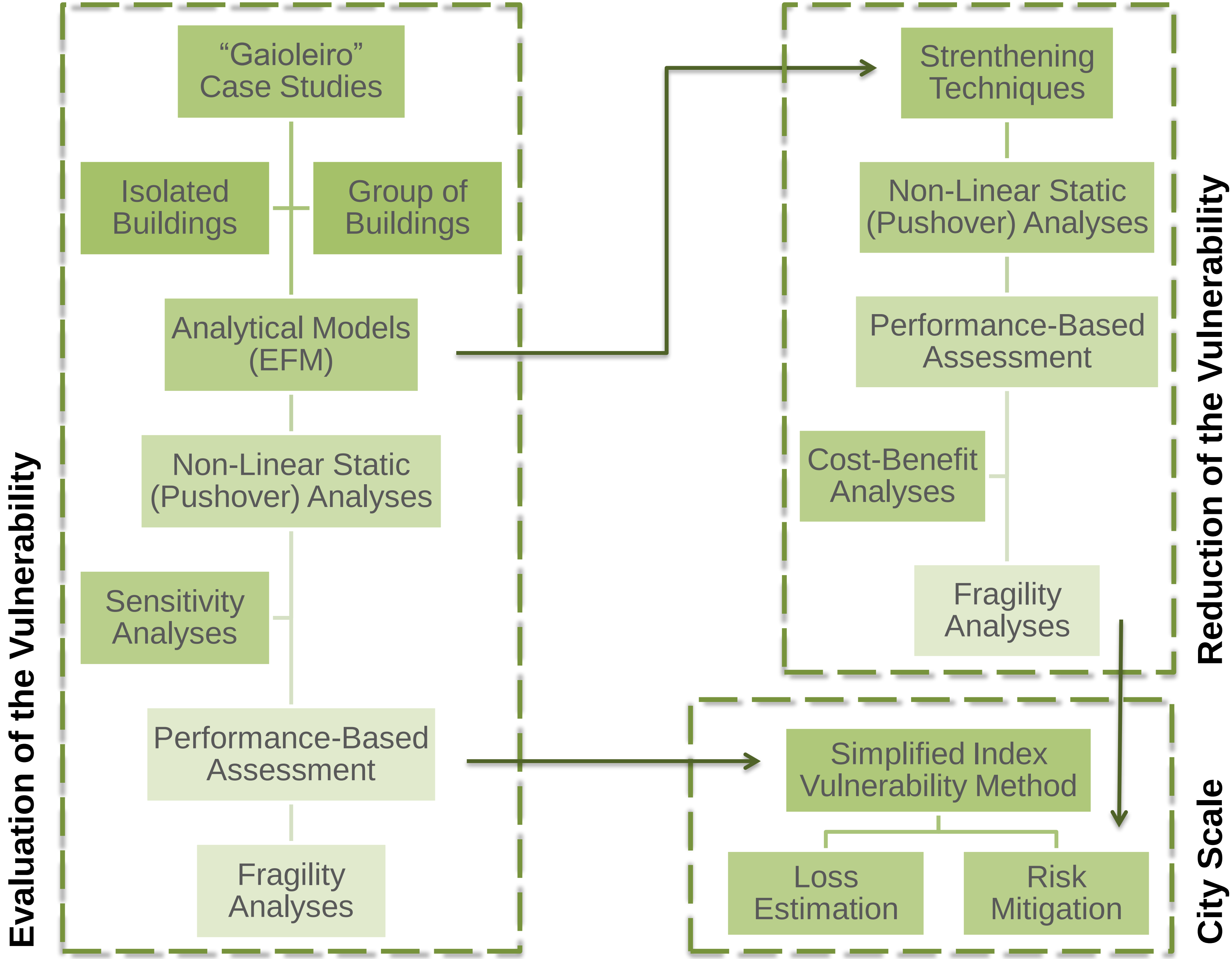
Main goals of the PhD research work:

- Evaluation of the seismic vulnerability of “Gaioleiro” buildings based on 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;
- Development of a method for the seismic risk assessment of “Gaioleiro” buildings at the city scale using a Geographic Information System (GIS) mapping tool.

Evaluation of the Vulnerability




Evaluation of the Vulnerability
"Gaioleiro" Case Studies
Isolated Buildings
Group of Buildings
Analytical Models (EFM)
Non-Linear Static (Pushover) Analyses
Sensitivity Analyses
Performance-Based Assessment
Fragility Analyses
Reduction of the Vulnerability
Strenthening Techniques
Non-Linear Static (Pushover) Analyses
Performance-Based Assessment
Cost-Benefit Analyses
Fragility Analyses



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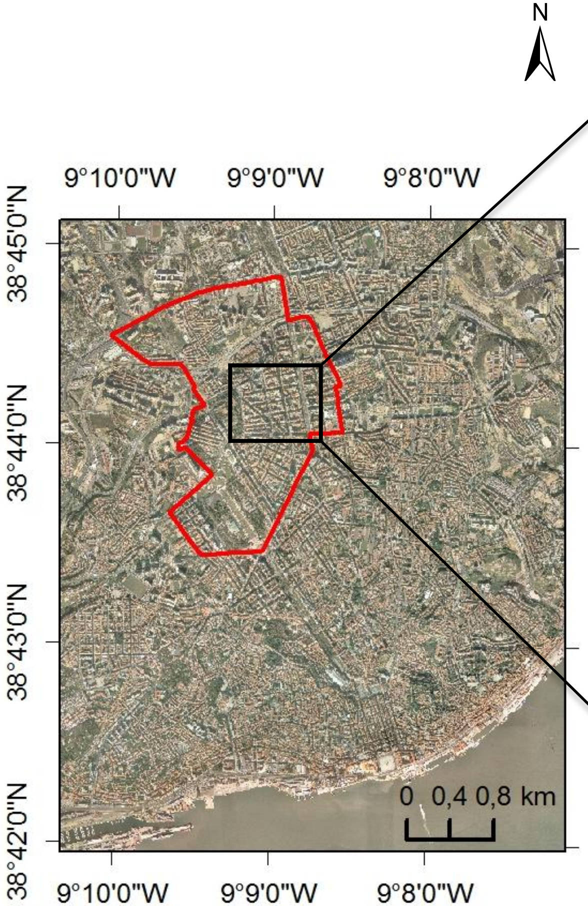
City Scale
Simplified Index Vulnerability Method
Loss Estimation
Risk Mitigation

The “Gaioleiro” Buildings



“Avenidas Novas” district

Aggregates of buildings

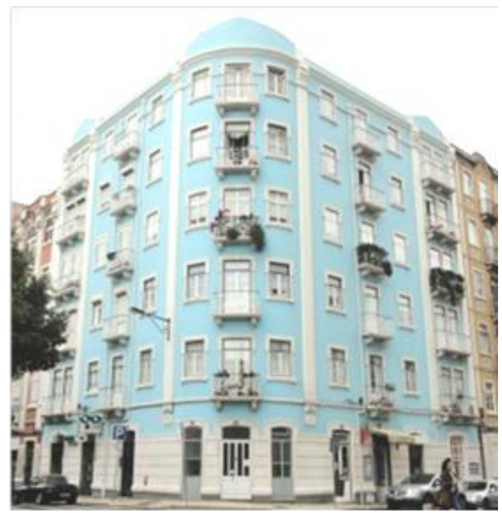
The “Gaioleiro” Buildings

- 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

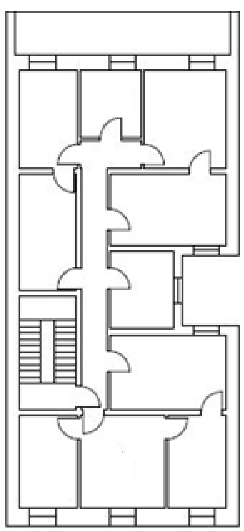
Type III



Type IV

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



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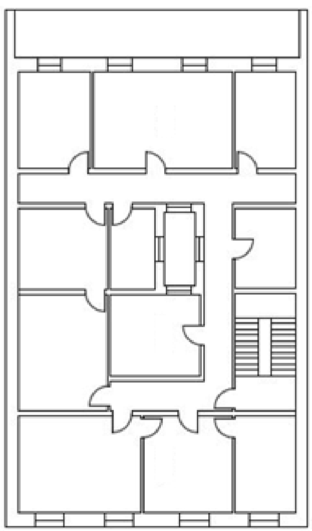
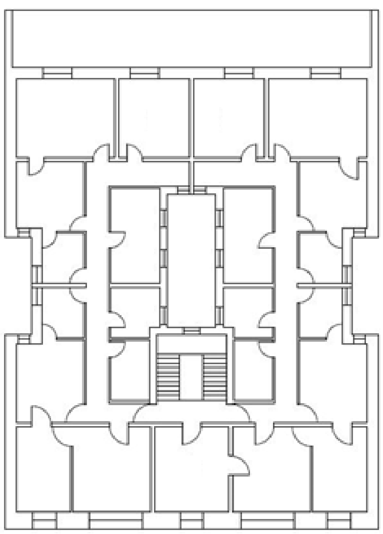
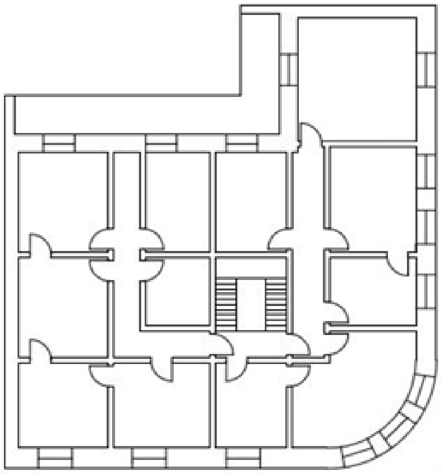


Type II



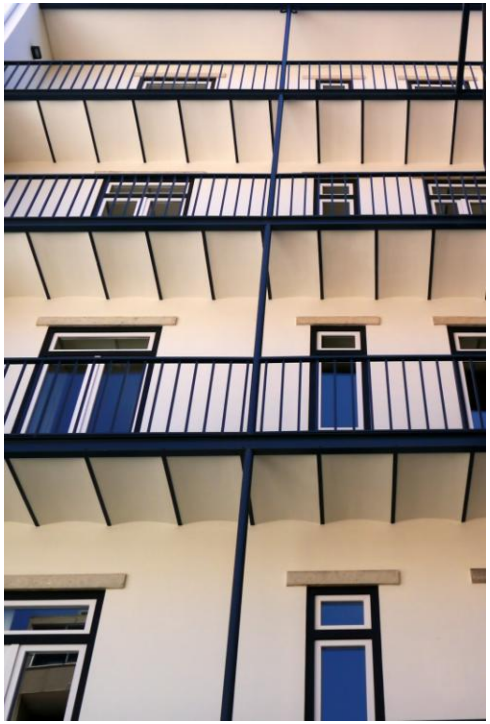
Type III



Type IV

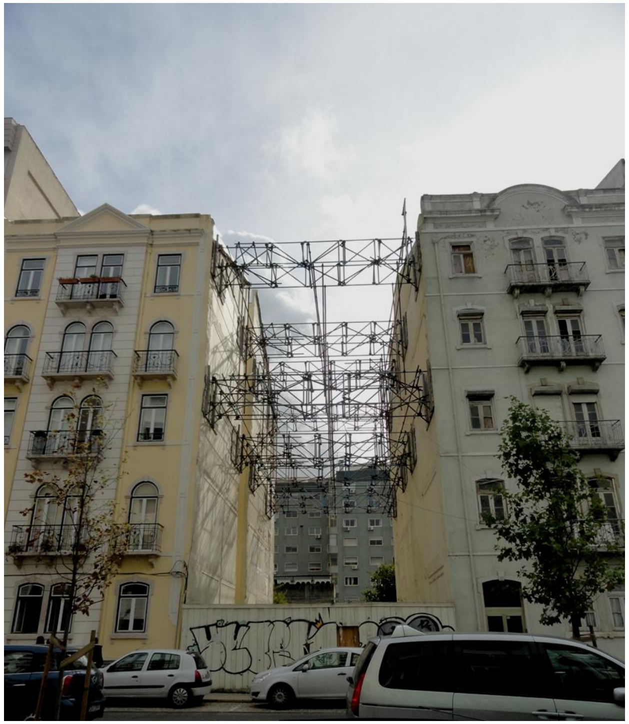
The “Gaioleiro” Buildings

- Steel-masonry balconies on the back façade wall



The “Gaioleiro” Buildings

- Current aggregates of buildings – “Avenidas Novas”



The "Gaioleiro" Buildings

The “Gaioleiro” Buildings

- **Geometry of the buildings**

Type	N.º Buildings	Façade Wall (m)	Side Wall (m)	N.º Floors	Interstorey Height (m)
I	6	7.0 - 9.2	16.9 - 19.0	4 - 5	2.7 - 4.0
II	4	10.0 - 15.8	18.0 - 29.6	4 - 6	3.0 - 3.5
III	6	14.0 - 15.7	16.0 - 26.4	4 - 7	2.7 - 3.6
IV	3	12.3 - 25.0		4 - 5	3.2 - 4.5

- **Thickness of the walls**

Thickness (m)	Front Façade	Back Façade	Side Wall	Shaft Wall	Internal Wall
Foundation	0.70 - 1.50	0.70 - 1.10	0.30 - 0.80	0.50 - 1.00	0.40 - 0.60
Ground Wall	0.60 - 0.90	0.60 - 0.85	0.20 - 0.50	0.28 - 0.50	0.15 - 0.25
Top Wall	0.20 - 0.80	0.25 - 0.70	0.20 - 0.50	0.28 - 0.50	0.15 - 0.25

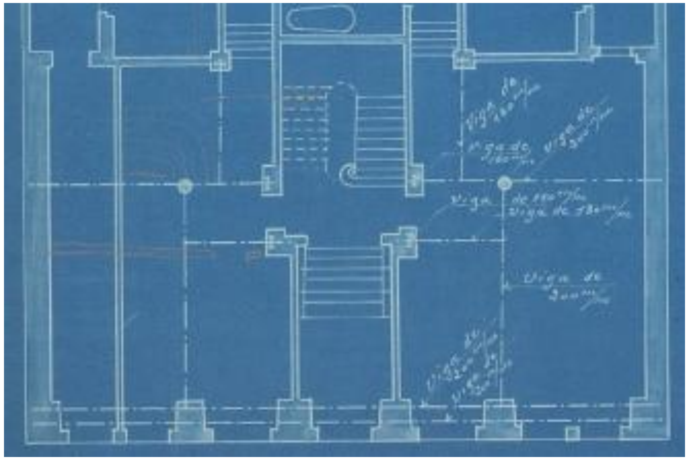
External wall

Internal wall

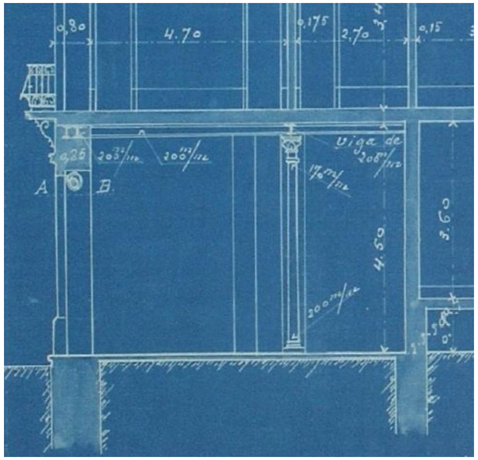
Partition wall

The “Gaioleiro” Buildings

- **Elimination of Internal Walls (10/19)**

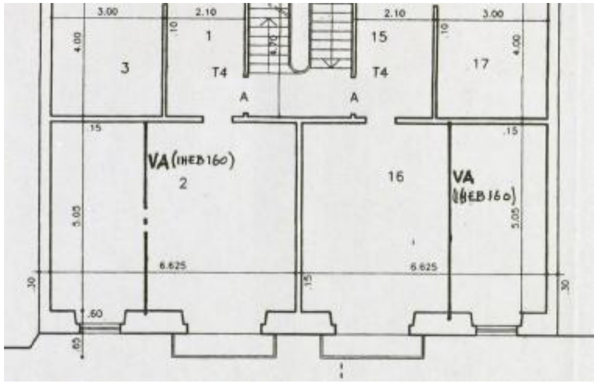


Ground floor plan

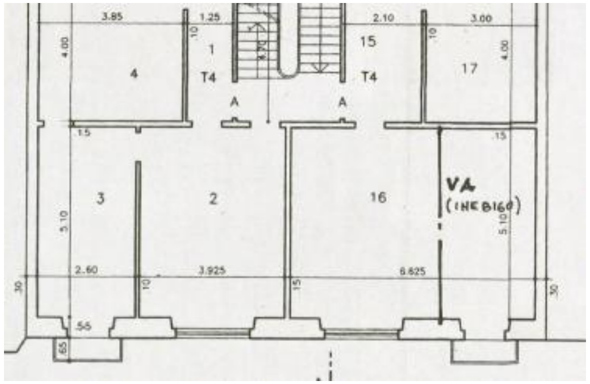


Section cut

- 8 internal walls
- I steel sections and circular columns
- Beams supported on perpendicular beams



First floor



Second floor

- 2 floors
- HEB 160 steel section
- Limited support of the façade wall

The “Gaioleiro” Buildings

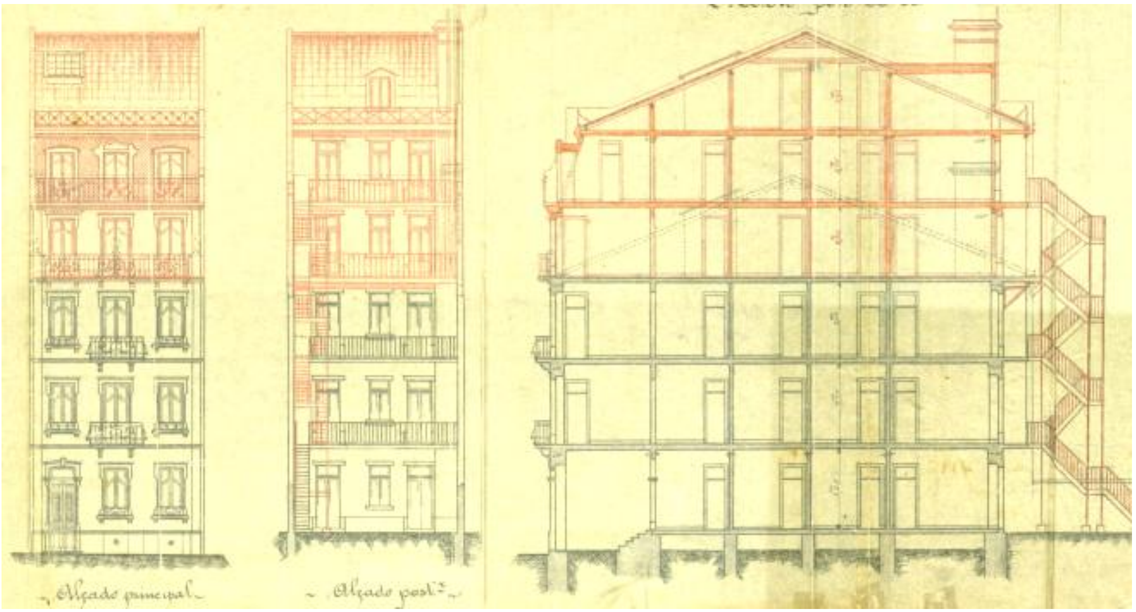
- **Cut of elements on the façade wall (3/19)**

- Reduction of the shear strength capacity in the base of the building.

- Generation of artificial soft-stories which result on the support of a rigid element (upper floors) over weaker and flexible elements.

The “Gaioleiro” Buildings

- **Addition of new floors (6/19)**

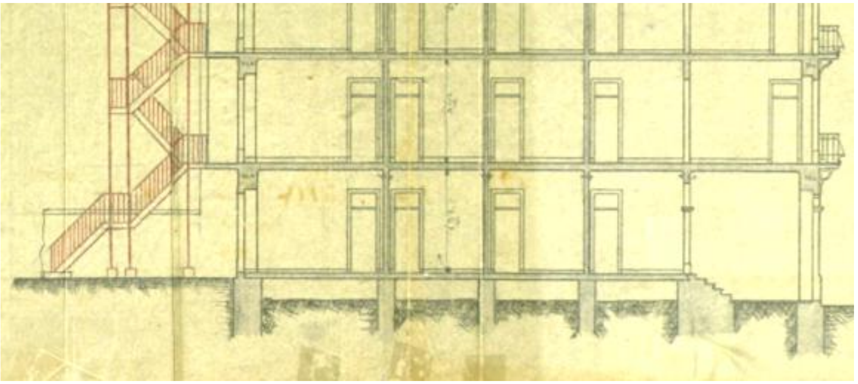


- Increment of the weight of the resulting on the increasing inertia horizontal forces and displacements during the seismic action.

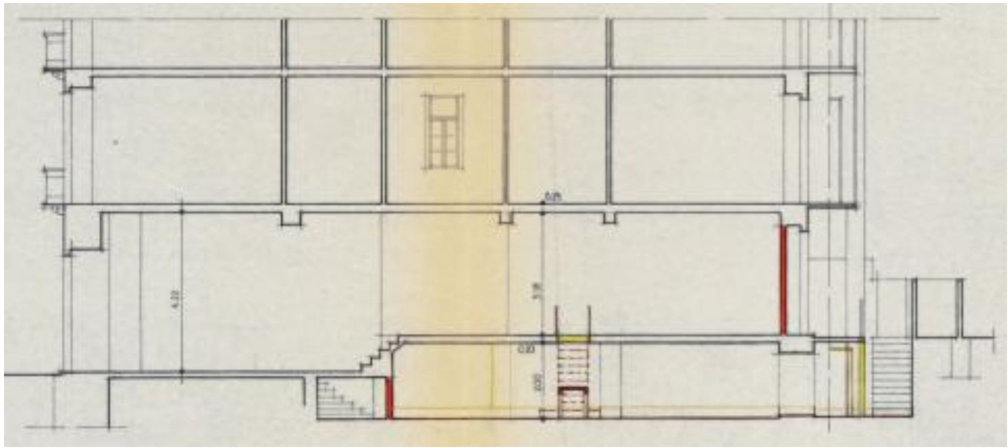
- External walls may not have been properly supported by internal perpendicular walls.

The “Gaioleiro” Buildings

- **Opening of semi-basements (6/19)**



  - Impact on the foundation system and on the stability of the building.



The “Gaioleiro” Buildings

- **State of conservation**

Supported façade wall

Major intervention (3/19)

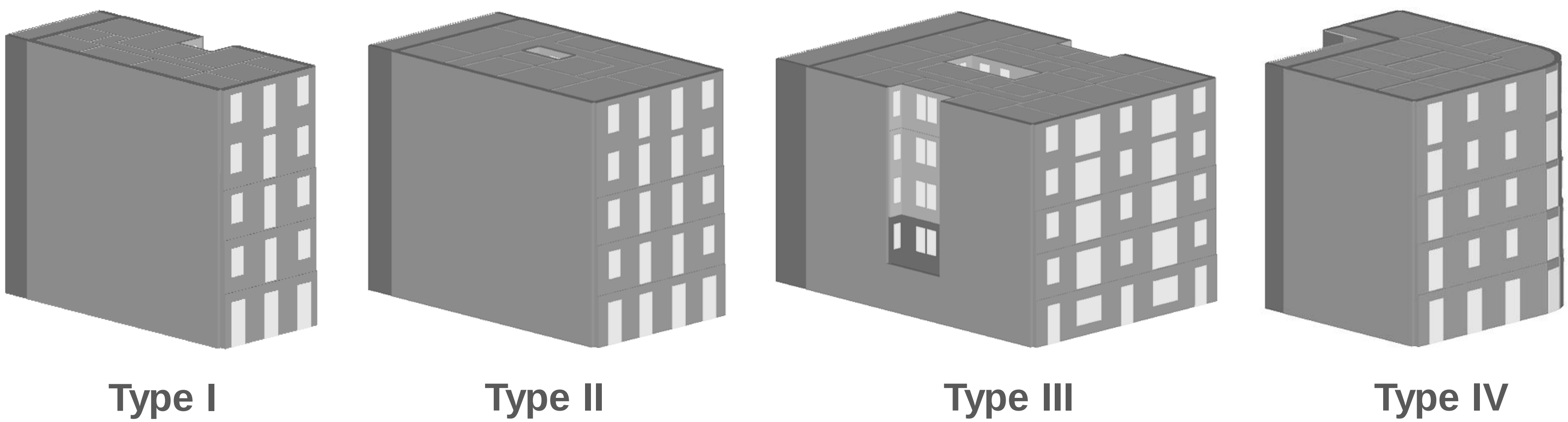
Medium to small (4/19)

Recent intervention (12/19)

Detailed Seismic Assessment – Four types of buildings

- Assessment of the global seismic response of the four types of “Gaioleiro” buildings and comparison of the structural performance.

- The buildings were modelled based on the non-linear equivalent frame model approach (Tremuri Program) on the assumption that proper connections prevented the activation of local failure modes mainly associated with the out-of-plane response of the walls.

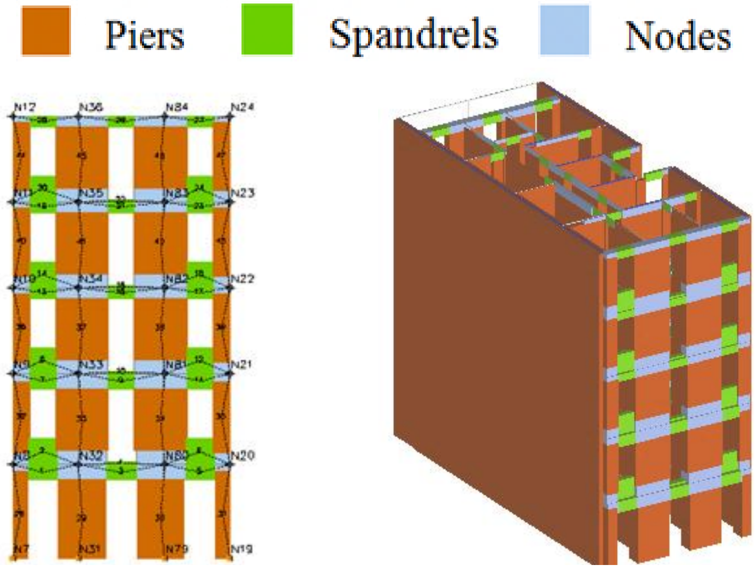


Detailed Seismic Assessment – Four types of buildings

• Masonry walls were discretized by a set of panels in which the non-linear response is concentrated – **piers and spandrels** – connected by a rigid area – **nodes** – where no damage occurs.

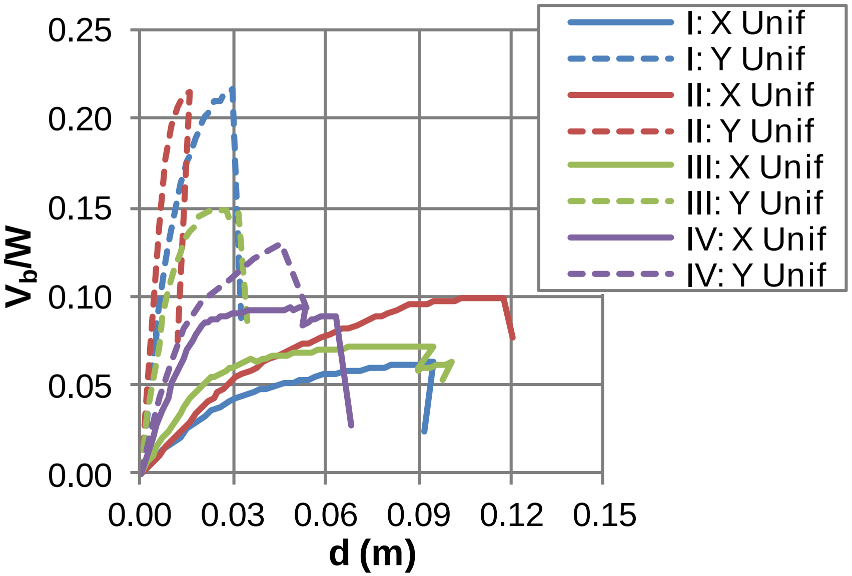
• The in-plane behaviour of the panels was modelled by non-linear beams, being the strength criteria defined according to the recommendations on the Eurocode 8 and the Italian Structural Code.

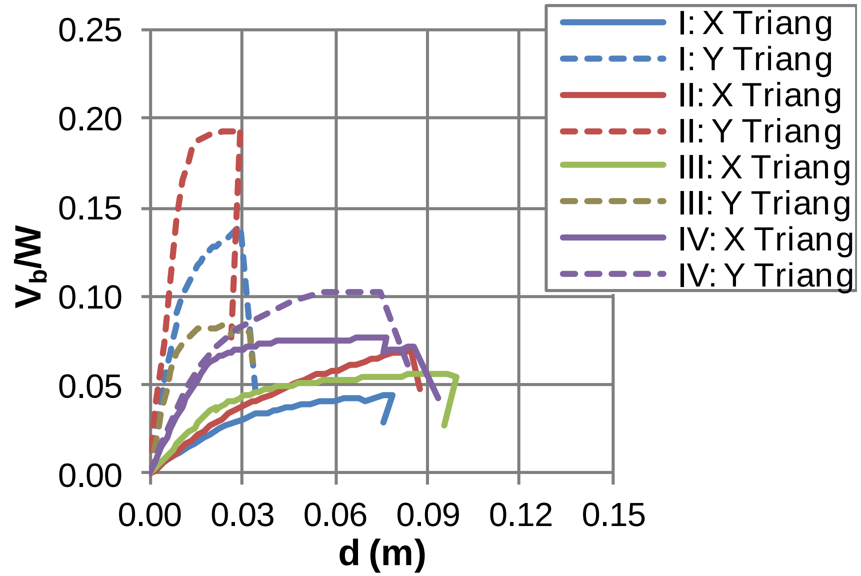
• Floors were modelled as anisotropic membrane finite elements.



Detailed Seismic Assessment – Four types of buildings

- The in-plane capacity curves of the buildings were obtained by **non-linear static (pushover) analysis** considering the uniform and the pseudo-triangular load patterns.

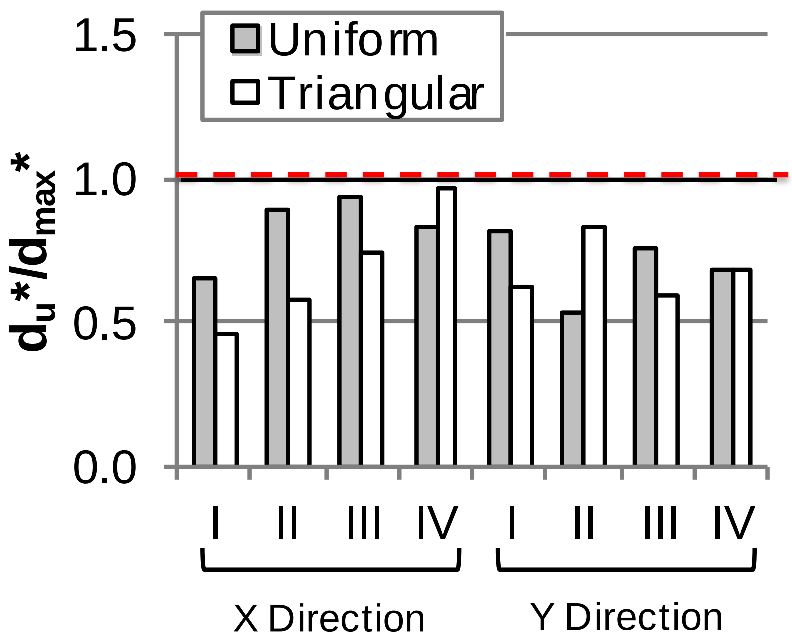




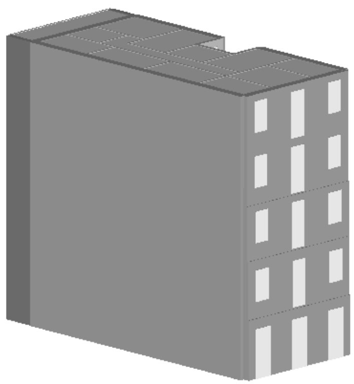
- The two load distributions define an envelope of the expected behaviour of the buildings. In general, lower stiffness and strength are determined with the pseudo-triangular load.

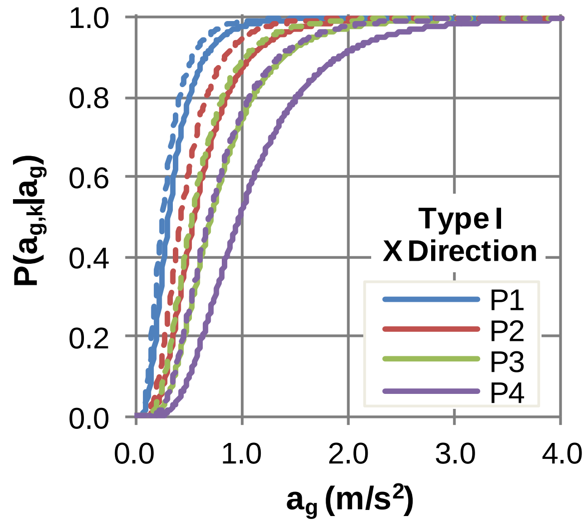
Detailed Seismic Assessment – Four types of buildings

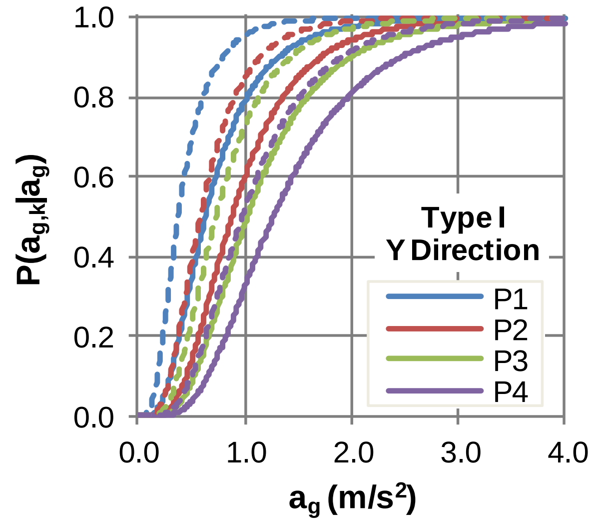
- The **seismic performance-based assessment** comprehends the determination of the <u>performance point</u> or <u>target displacement</u> of a structure from the intersection between the **capacity curve** and the **response spectrum** that represents the seismic action.
- **Structural safety is verified when $d_u^*/d_{max}^* > 1$**



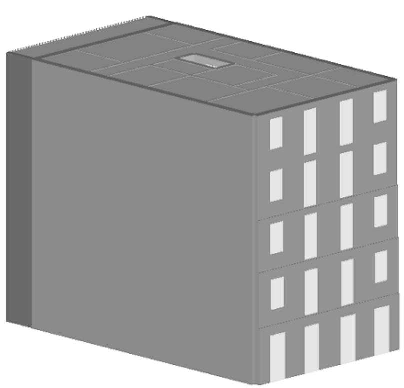
Detailed Seismic Assessment – Four types of buildings

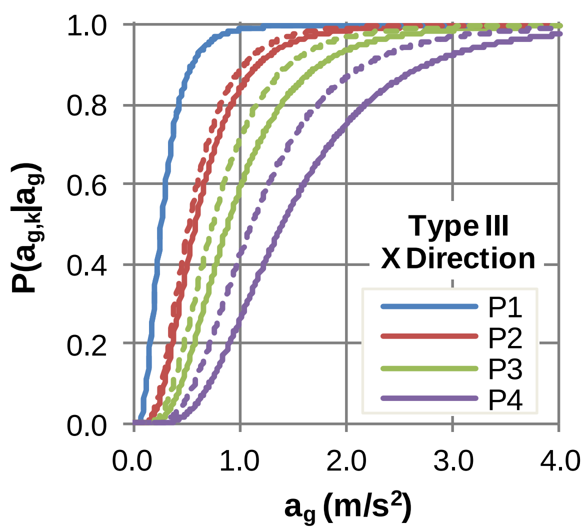


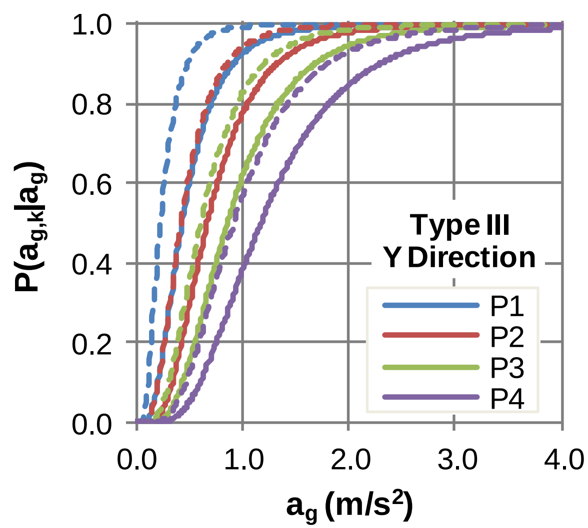




Type I



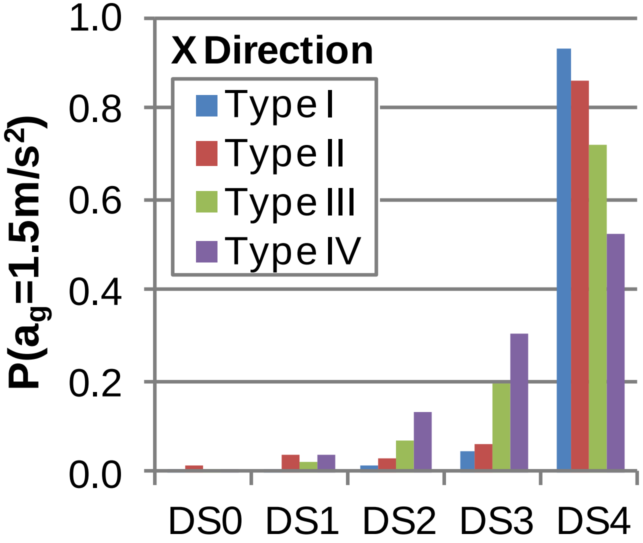


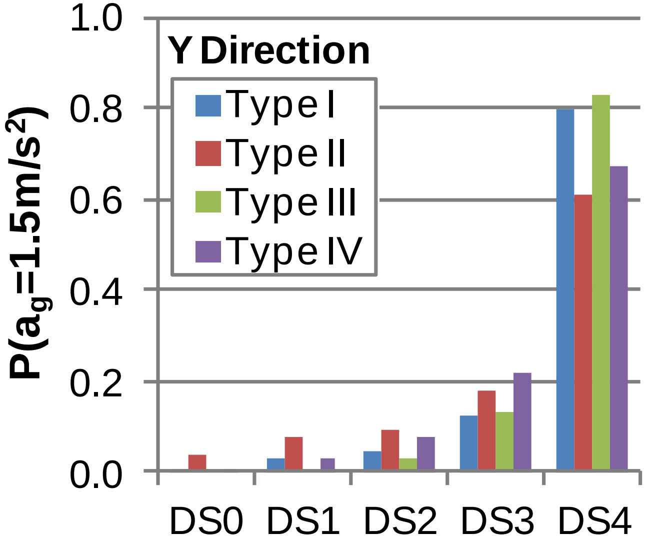


Type III

Detailed Seismic Assessment – Four types of buildings

- Probability of damage associated with the different limit states in case of the seismic action type 1.3 (a_g=1.5 m/s^2). Results for the pseudo-triangular load.





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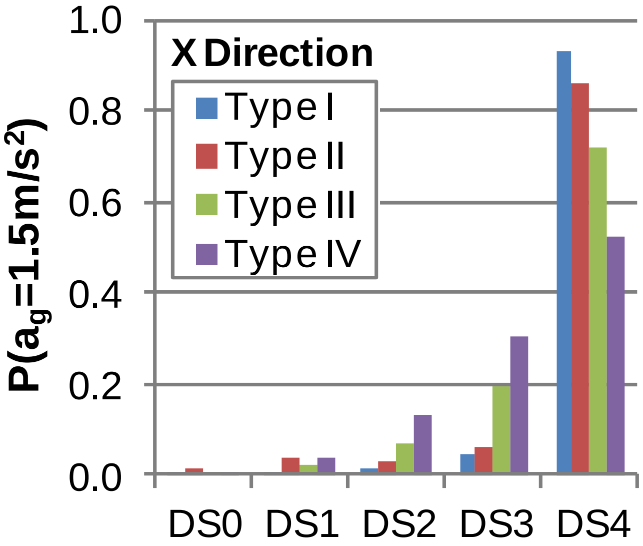
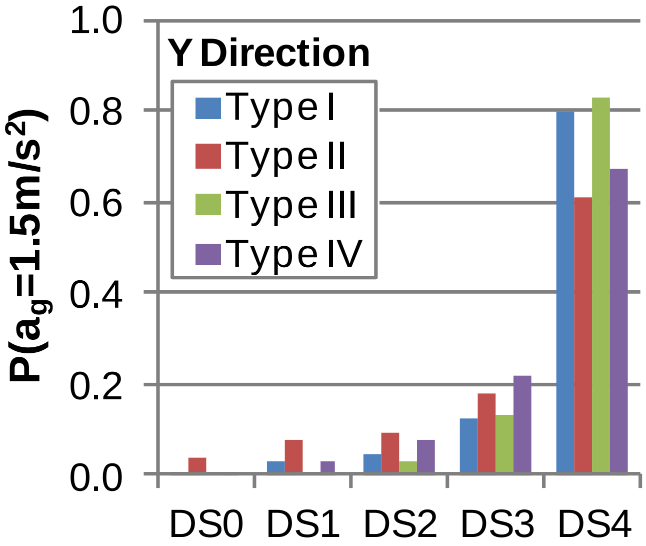




- From the cases studies herein considered, it can be concluded that **“Gaioleiro” buildings have a very high seismic vulnerability**, putting in evidence the need of defining appropriated strengthening solutions to increase their seismic capacity.

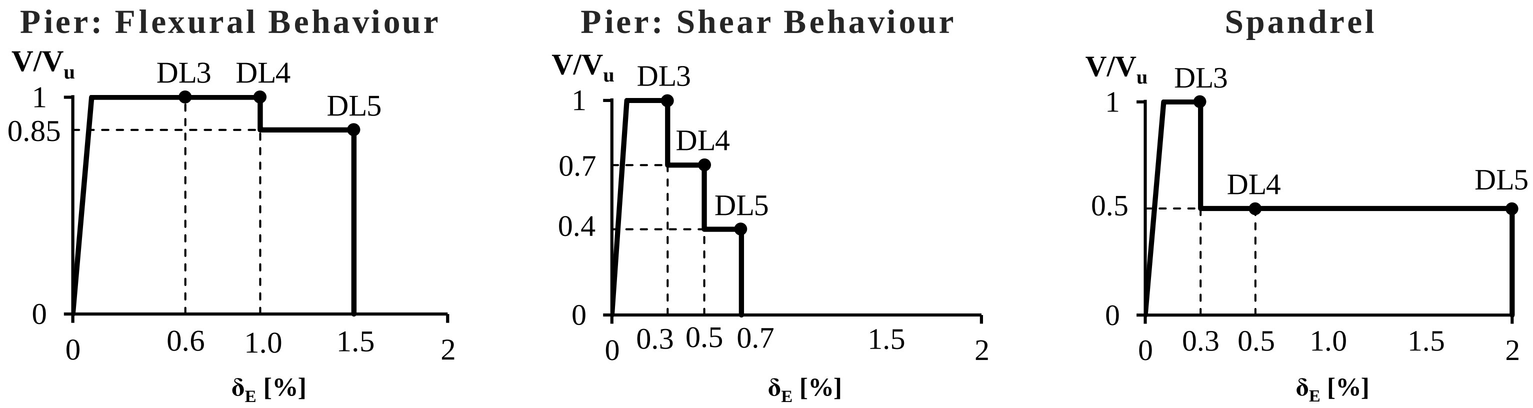
Detailed Seismic Assessment – Building type I

- Assessment of the **global response** and the possible occurrence of **local out-of-plane mechanisms** by neglecting their interaction.

Detailed Seismic Assessment – Building type I

- Assessment of the **global response** and the possible occurrence of **local out-of-plane mechanisms** by neglecting their interaction.

- The response of the masonry panels was modelled by non-linear beams with multilinear constitutive law which aims to describe the non-linear response of masonry panels until very severe damage levels.



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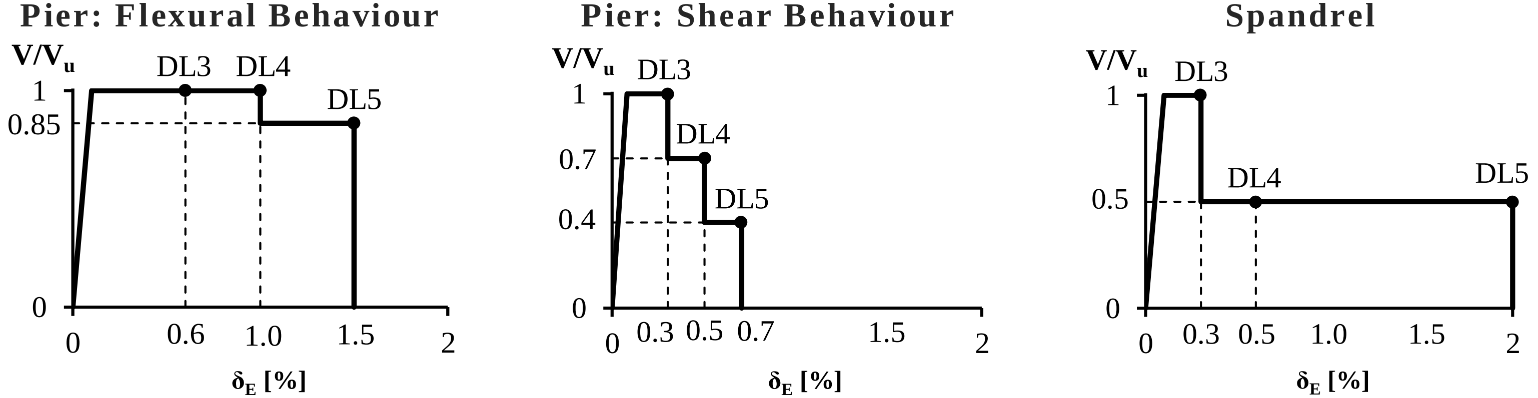


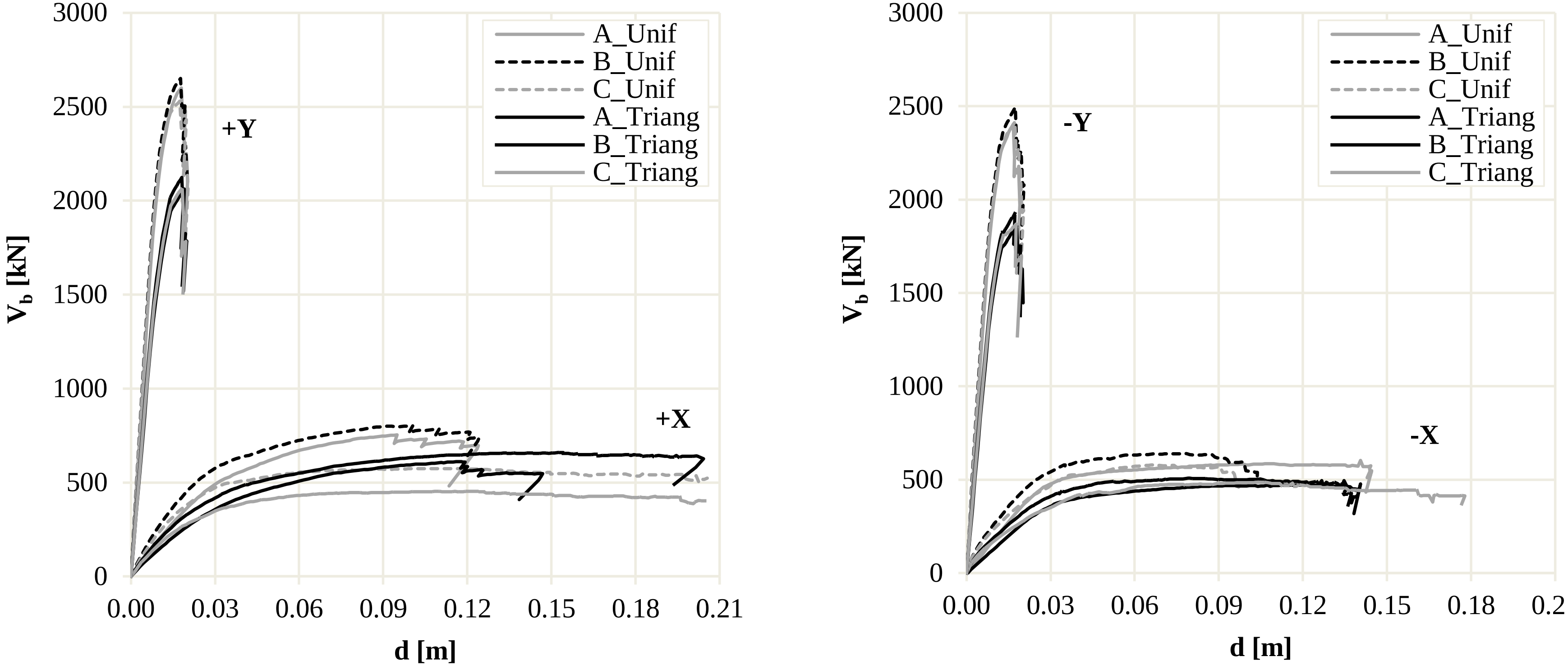
- **Parametrical analyses** were carried out taking into account:
    1) the strength capacity of spandrel beams;
    2) the influence of the degree of connection between walls.

Detailed Seismic Assessment – Building type I

Model A: spandrels with no tensile strength & walls with good connection;

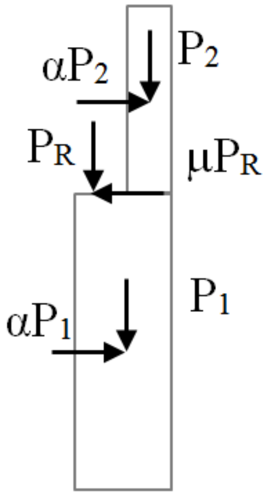
Model B: spandrels with equivalent tensile strength & walls with good connection;

Model C: spandrels with equivalent tensile strength & walls with weak connection.

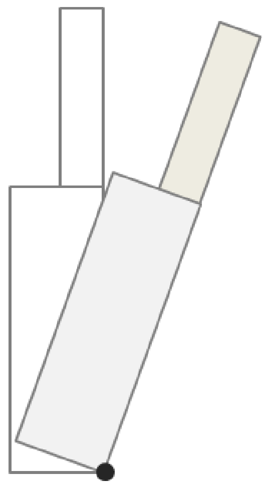


Detailed Seismic Assessment – Building type I

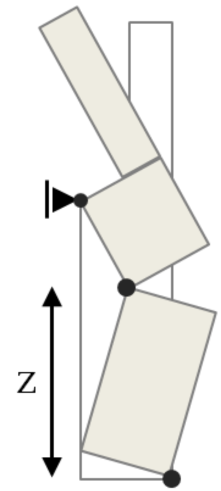
• The **local response** of the façade wall was analysed by adopting a macro-block approach. The wall out-of-plane capacity curves were determined through **limit non-linear kinematic analysis** (MB Perpetuate Program) after considering a set of possible collapse mechanisms.



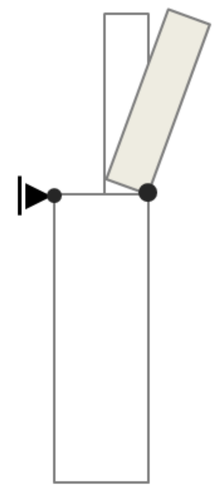
Actions on the element



Mech-1 Overturning



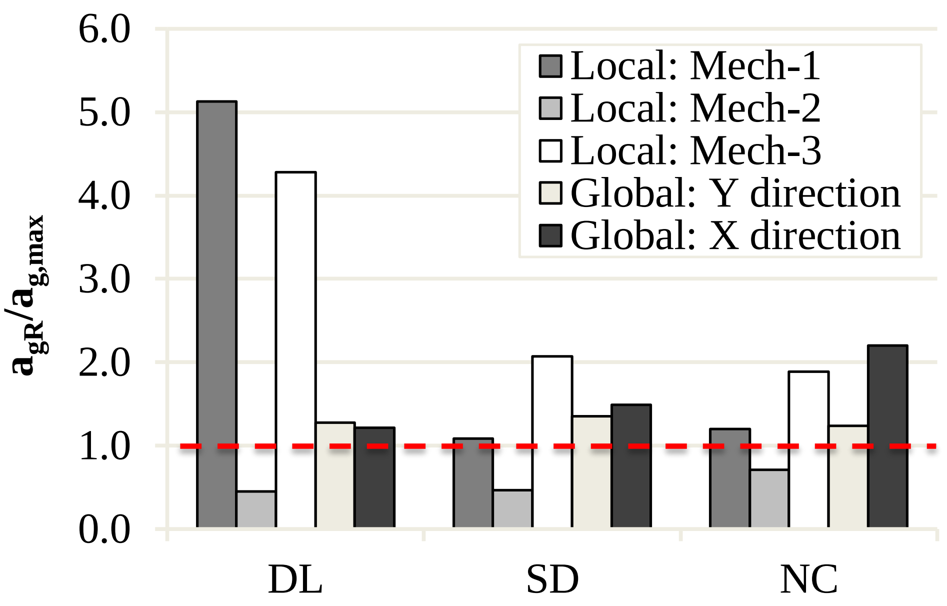
Mech-2 Flexural Mechanism



Mech-3 Overturning

Detailed Seismic Assessment – Building type I

• Seismic performance-based assessment of all mechanisms based on ratio between the ground acceleration associated with the expected hazard level and the maximum acceleration on the structure ($a_{gR}/a_{g,max}$) considering seismic action type 1.3.



Simplified Assessment of the Aggregate

Simplified Assessment of the Aggregate

- Application of the vulnerability index method proposed by Vicente et al. (2011) to the old city centre of Coimbra, Portugal.

- The method was defined starting from the procedure proposed by the GNDT (*Gruppo Nazionale per la Difesa dai Terremoti*) for the seismic vulnerability assessment of residential masonry buildings – GNDT II level approach – based on post-earthquake damage observations in Italy.

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• Calculation of a vulnerability index (I_V) as the weighed sum of 14 parameters which evaluate different aspects affecting the seismic performance of the building.

• Definition of <u>vulnerability and fragility curves</u> and estimation the expected damage on the buildings for different intensities of the seismic action.

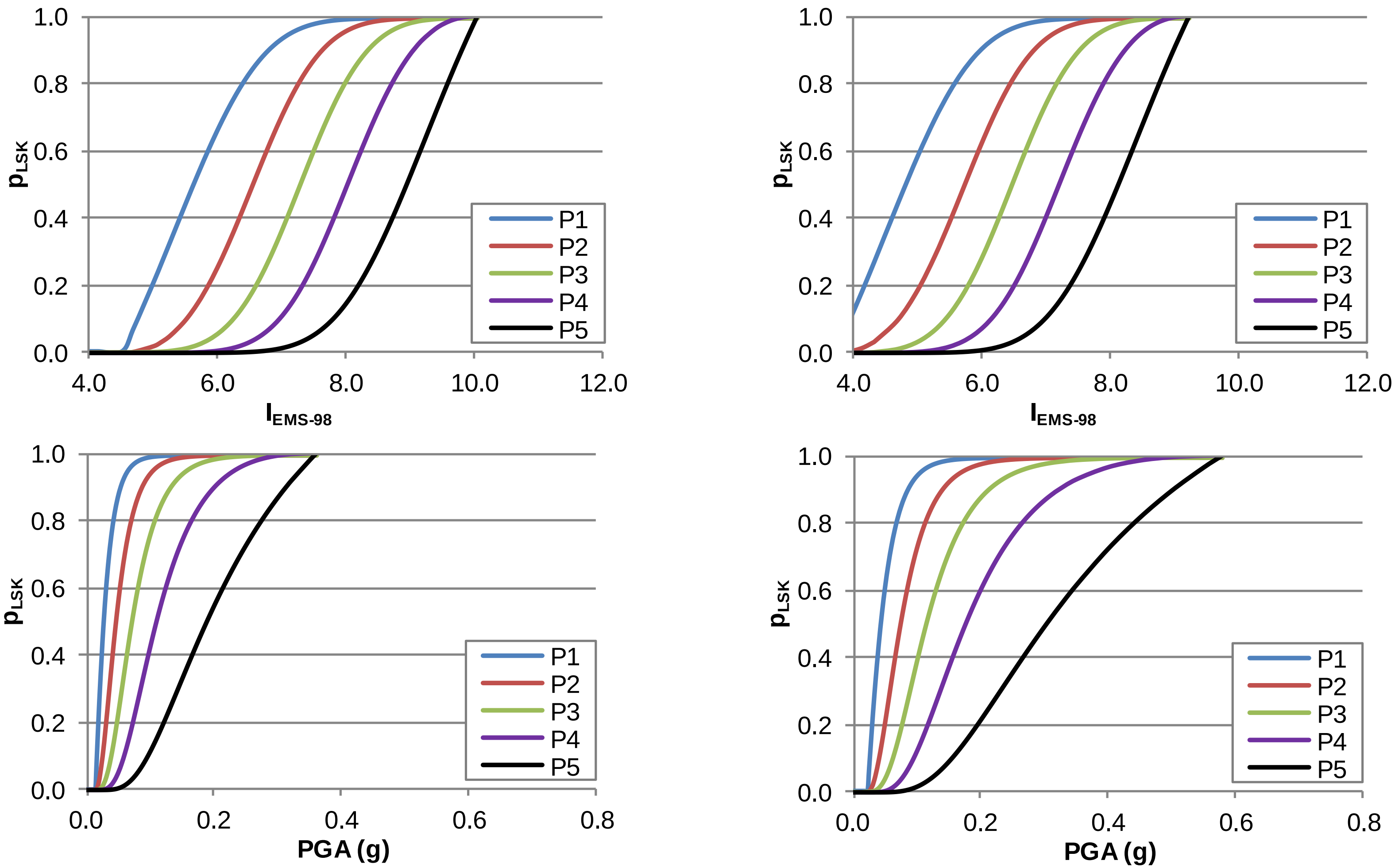
Simplified Assessment of the Aggregate

Simplified Assessment of the Aggregate

- Mean damage distribution for the seismic action type 1.3 (PGA=0.15)

Simplified Assessment of the Aggregate

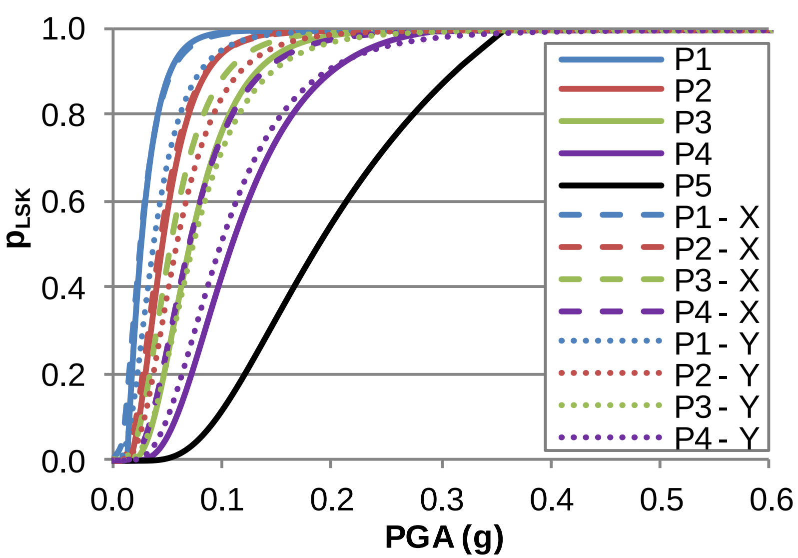
- Fragility curves for the different vulnerability values: average (V=0.87) and maximum (V=1.00) vulnerability

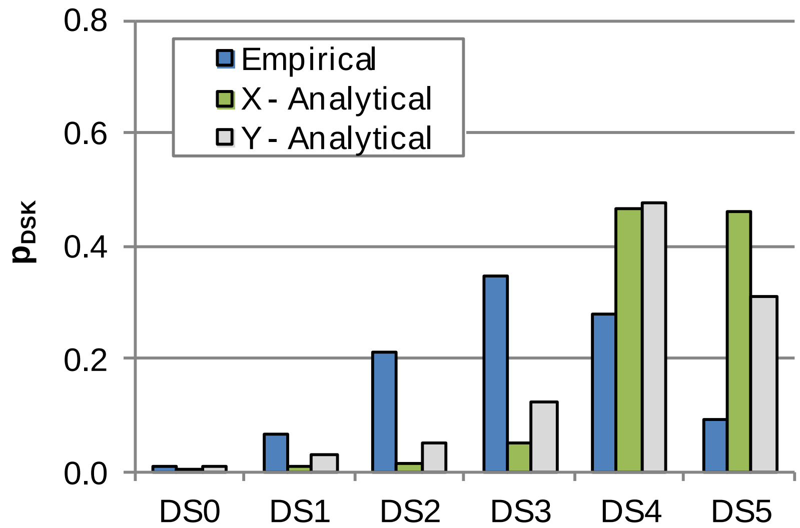


Simplified Assessment of the Aggregate

- Comparison between the analytical curves (dotted lines) obtained for the building type I on the X and Y direction with the empirical curves (gross lines) determined for a building type I with average vulnerability (V=0.87).

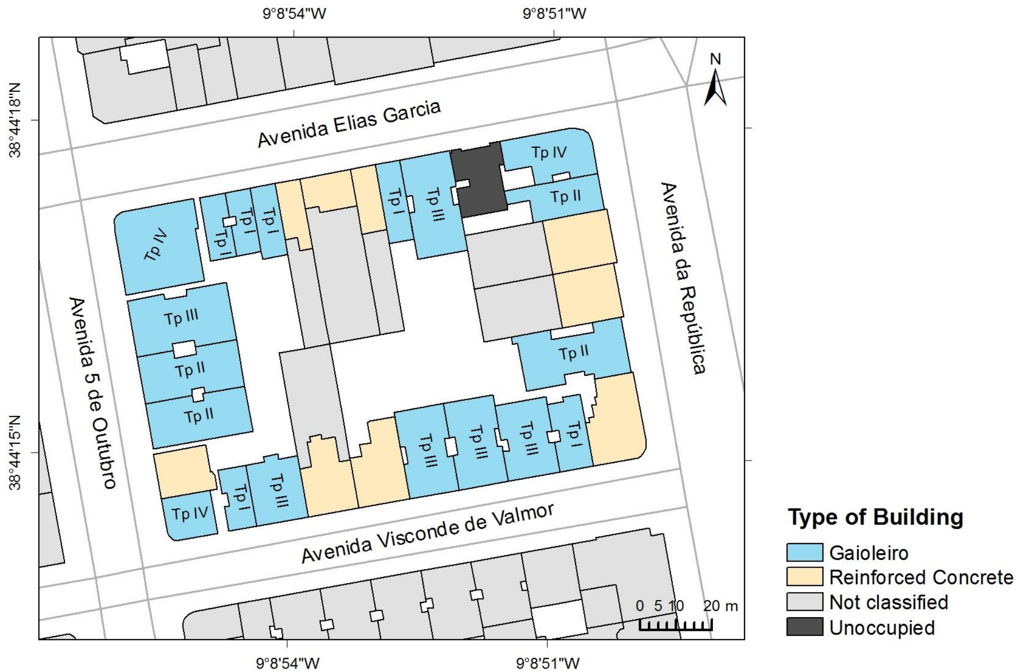
- Damage distribution for the seismic action type 1.3 (PGA=0.15)

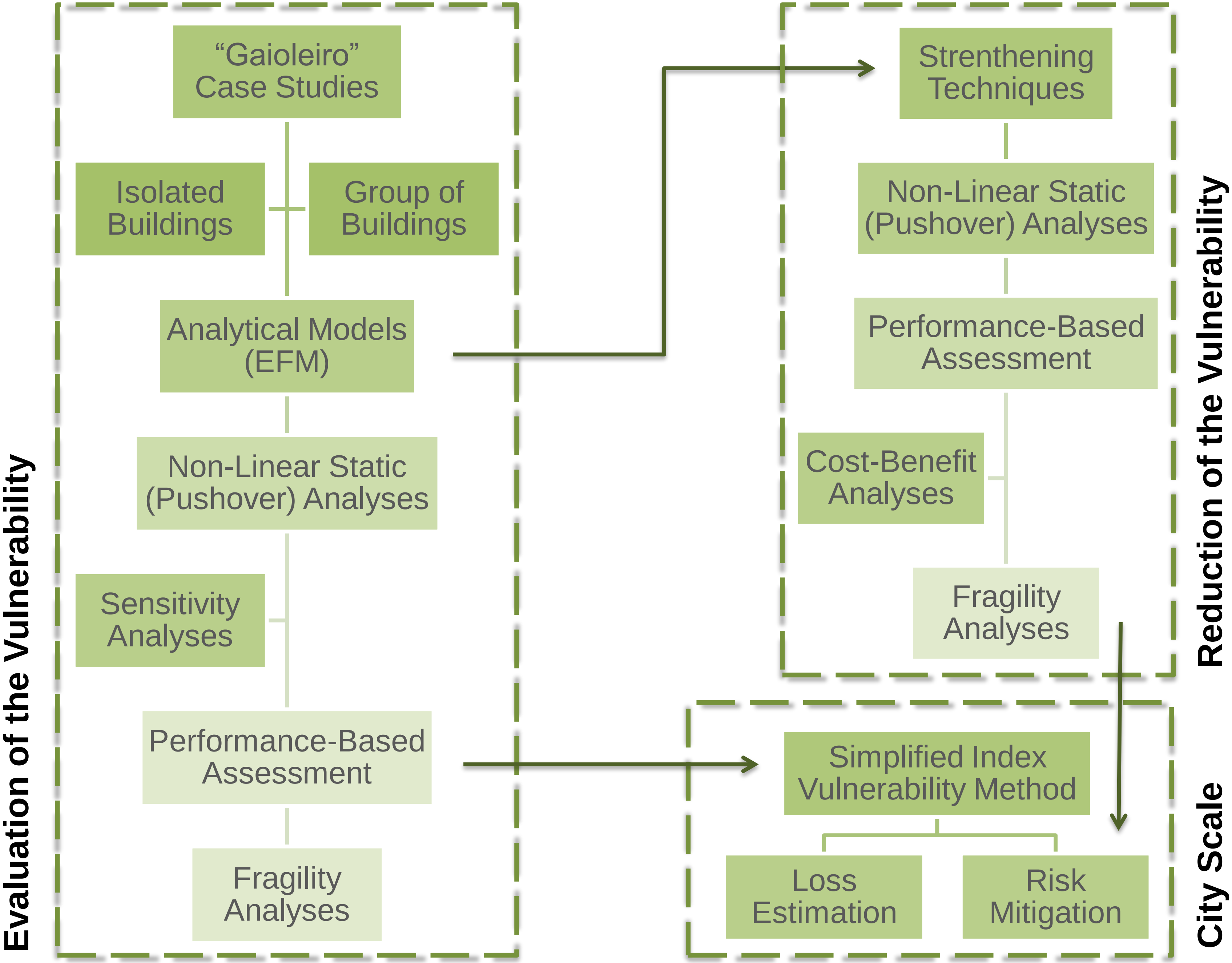




Conclusions

- The work developed until this moment provided a general overview about the procedures for the seismic assessment of existing masonry buildings. It was also possible to cover the main steps until the definition of the fragility curves for the original non-strengthened buildings.
- The next steps of the work will be focused on the study of the **aggregate of "Gaioleiro" buildings**.

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Reduction of the Vulnerability
Strenthening Techniques
Non-Linear Static (Pushover) Analyses
Performance-Based Assessment
Cost-Benefit Analyses
Fragility Analyses
City Scale
Simplified Index Vulnerability Method
Loss Estimation
Risk Mitigation