Empirical Evidence-Based Semantic Models for Seismic Vulnerability Assessment of Masonry Historical Buildings:

Lessons from Mexican Experiences.

Rafael Eudave
Tiago Ferreira and Paulo Lourenço, supervisors
Fernando Peña (II-UNAM)

Motivation.

- In September 2017, two strong earthquakes hit the centre and south of Mexico. Although ca. 2340 historical monuments were affected (including 1,680 temples built before 1900) a still unknown number of "*minor*" historical buildings (namely vernacular houses) were damaged or lost.

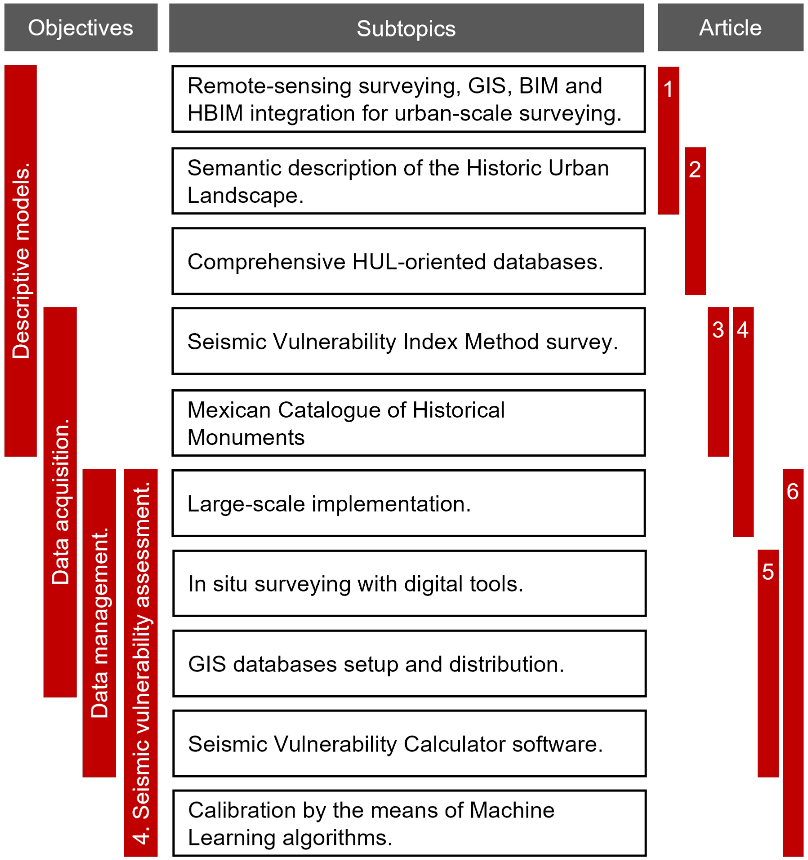
Research questions.

- How can we address the seismic vulnerability of large groups of historical constructions?
- Can we use generalised approaches (i.e., parametric models) for characterising the seismic vulnerability of masonry structures in Mexico?
- How can we manage urban-scale information in a reliable and flexible framework?
- How can we enhance the representativeness of simplified parametric models on the basis of empirical evidence?

Objectives.

- Definition of suitable descriptive models.
- Design of data acquisition techniques.
- Design of data management frameworks.
- Implementation, discussion and enhancement of seismic vulnerability assessments.

Structure of this research and subjacent papers.

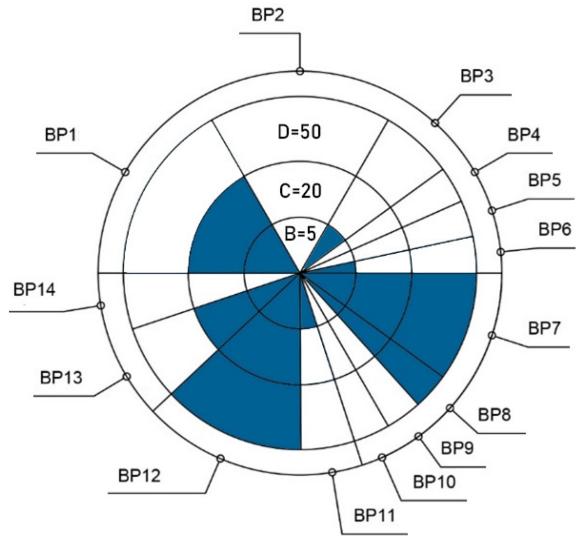


- [1] R. Ramírez Eudave and T. M. Ferreira (2021) **On the suitability of a unified GIS-BIM-HBIM framework for cataloguing and assessing vulnerability in Historic Urban Landscapes: a critical review**, International Journal of Geographical Information Science, 35 (10), 2047-2077.
- [2] R. Ramírez Eudave and T. M. Ferreira (2021) **Characterisation of the Historic Urban Landscape through the Aristotelian Four Causes: Towards Comprehensive GIS Databases**, Remote Sensing, 13 (10), 1879.
- [3] R. Ramírez Eudave and T. M. Ferreira (2021**) On the potential of using the Mexican National Catalogue of Historical Monuments for assessing the seismic vulnerability of existing buildings: a proof-of-concept study**, Bulletin of Earthquake Engineering 19 (12) 4945–4978.
- [4] R. Ramírez Eudave, T. M. Ferreira and Romeu Vicente (2022) **Parameter-based seismic vulnerability assessment of Mexican historical buildings: Insights, suitability, and uncertainty treatment**, International Journal of Disaster Risk Reduction, 74, 102909.
- [5] R. Ramírez Eudave, D. Rodrigues, T. M. Ferreira and R. Vicente (2023) **Implementing Open-Source Information Systems for Assessing and Managing the Seismic Vulnerability of Historical Constructions**, Buildings 12 (2) 540.
- [6] R. Ramírez Eudave, T. M. Ferreira, R. Vicente, P. B. Lourenço and F. Peña (2023) **Parametric and Machine Learning-Based Analysis of the Seismic Vulnerability of Adobe Historical Buildings Damaged After the September 2017 Mexico Earthquakes**, International Journal of Architectural Heritage.

Composition of the Vulnerability Index.

Parametric model based on the GNDT-II model. There is affinity between the descriptors and Mexican National Catalogue of Historical Monuments model (with more than 100k records). Each parameter receives a C_{vi} class from A to D.

Parameters	Weight (p_i)
BP1. Type of resisting system	2.50
BP2. Quality of the resisting system	2.50
BP3. Conventional strength	1.00
BP4. Maximum distance between walls	0.50
BP5. Number of floors	0.50
BP6. Location and soil conditions	0.50
BP7. Aggregate position and interaction	1.50
BP8. Plan configuration	0.50
BP9. Height regularity	0.50
BP10. Wall façade openings and alignment	0.50
BP11. Horizontal diaphragms	0.75
BP12. Roofing system	2.00
BP13. Fragilities and conservation status	1.00
BP14. Non-structural elements	0.75



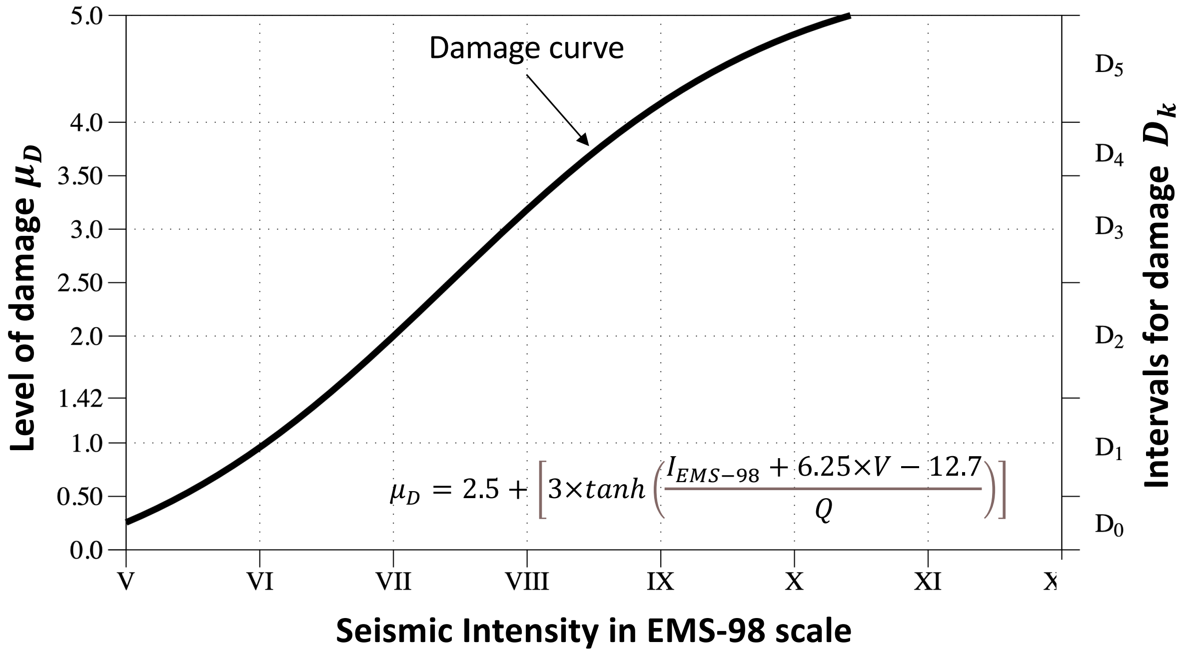
$$I_{vf}^{*} = \sum_{i=1}^{14} C_{vi} \times p_i$$

$$I_v = \frac{I_v^{*} \times 100}{750}$$

$$V = 0.592 + 0.0057 \times I_v$$

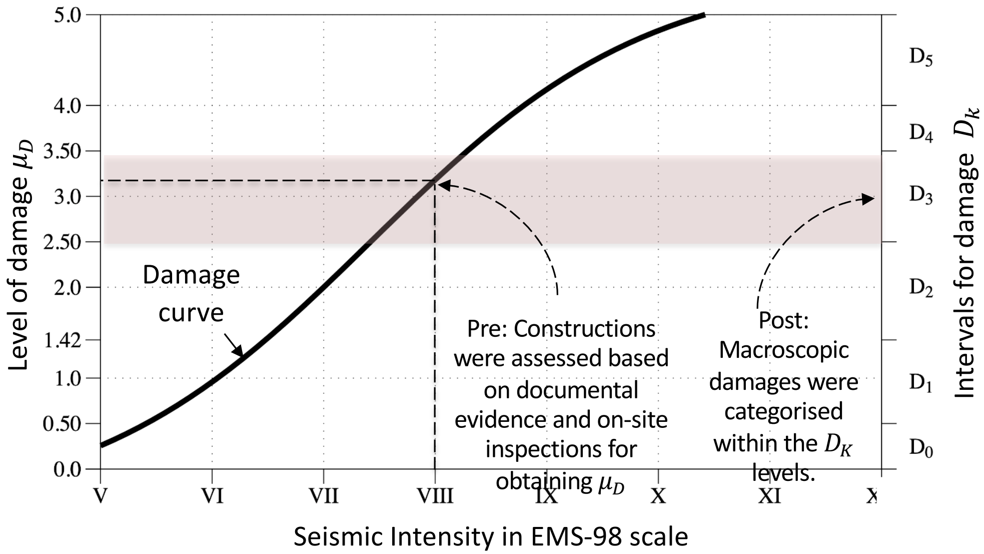
From the Vulnerability Index to damage curves.

- The typification of damage is based in the European Macroseismic Scale EMS-98 and permits the correlation between a quantitative continuous damage value (μ_D) and discrete levels of damage (D_K). The mathematic expression for building this curve is based on analytic calibrations (regressive analysis) when new evidence is available.



2017 Post-seismic evidence for assessing the quality of the VIM

- **Pre**: Constructions were assessed based on documental evidence and on-site inspections for obtaining μ_D.
- **Post**: Discrete damages were categorised within the D_K levels.
- μ_D and D_K were compared in order to assess the representativeness of the parametric model prediction.



Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage).

Hair-line cracks in very few walls.
Fall of small pieces of plaster only.
Fall of loose stones from upper parts of buildings in few cases.

Grade 2: Moderate damage (slight structural damage, moderate non-structural damage).

Cracks in many walls.
Fall of fairly large pieces of plaster.
Partial collapse of chimneys.

Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage).

Large and extensive cracks in most walls.
Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).

Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage).

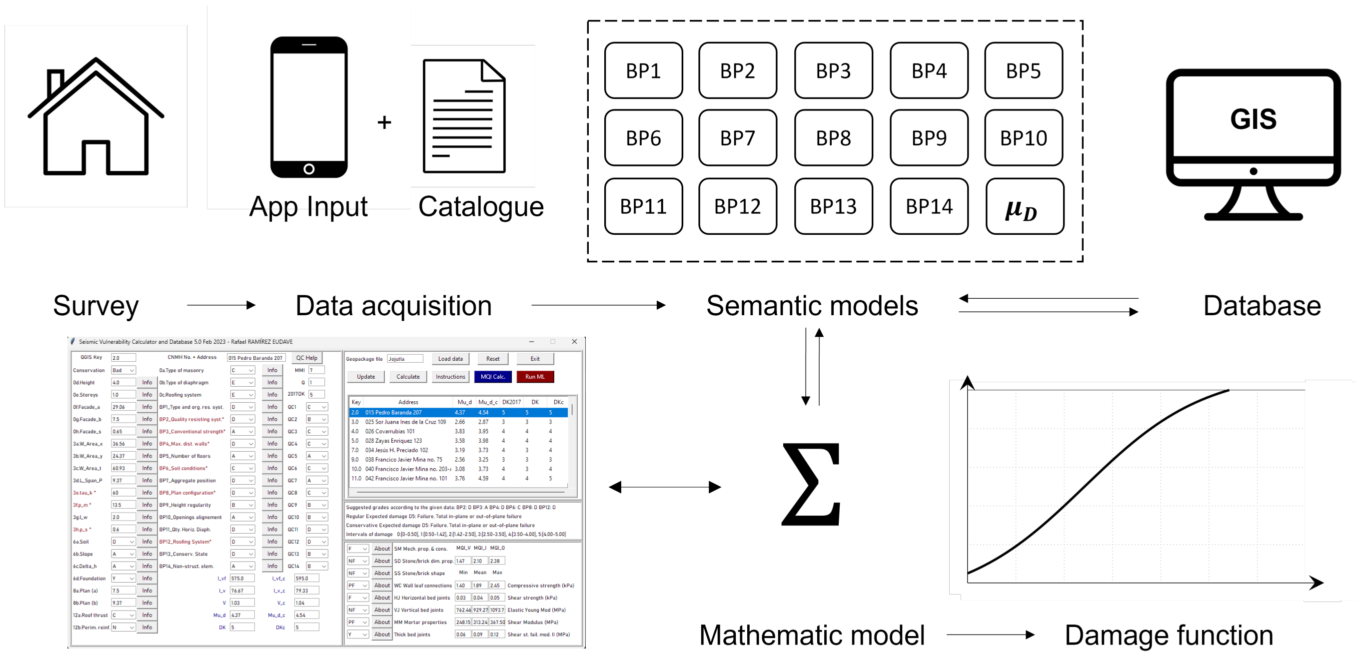
Serious failure of walls; partial structural failure of roofs/floors.

Grade 5: Destruction (very heavy structural damage)

Total or near total collapse.

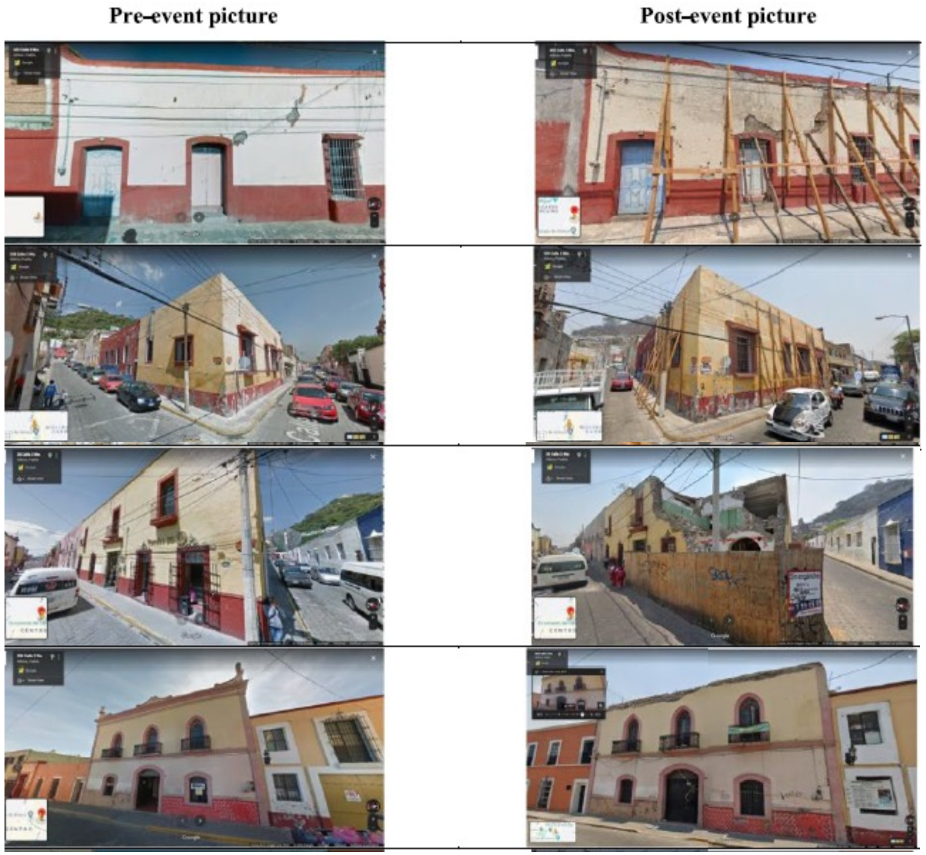
Data acquisition and management.

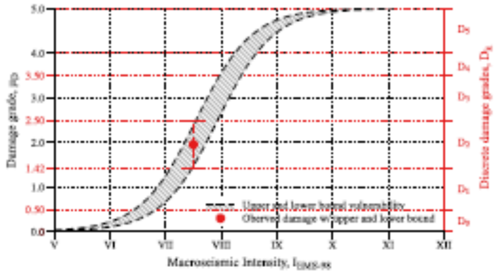
- The data acquisition was based on existing documents and on-site surveys. A Python-based package was developed to calculate the vulnerability index and the level of damage (given a certain seismic intensity), and to manage the database without the need to operate the GIS environment.



Case study 1. Atlixco-I.

Due to the limitations imposed by the COVID-19 lockdowns, the National Catalogue of Historical Monuments was used as a secondary source of information, together with public street-view repositories, newspapers and social media photographs.





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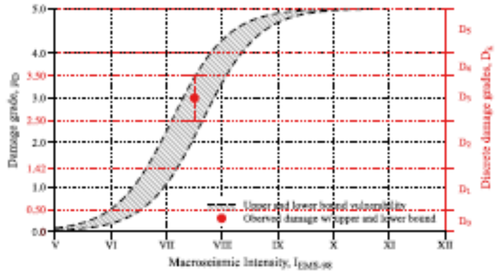

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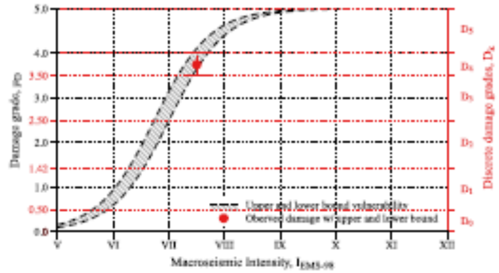

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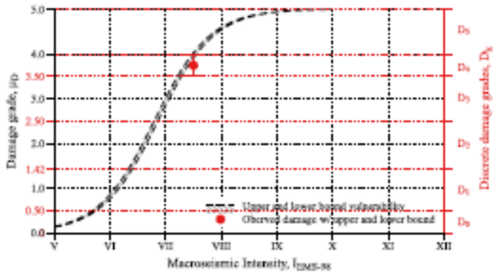

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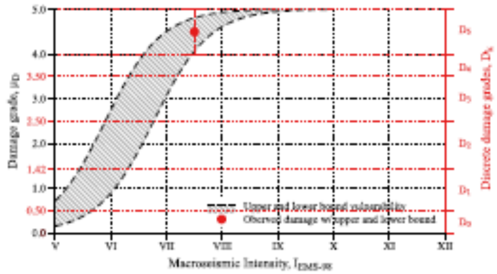

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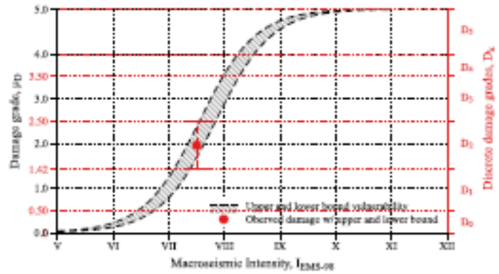

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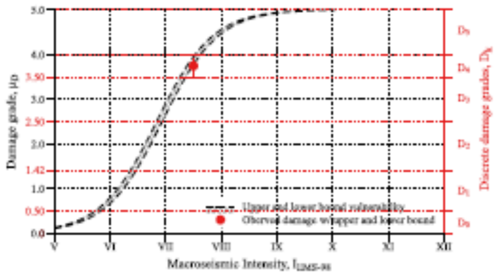
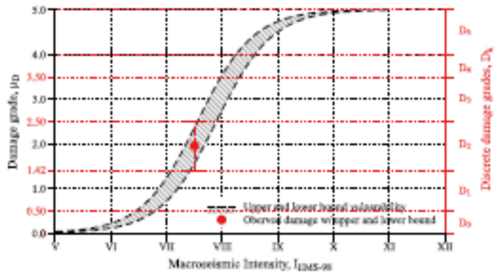
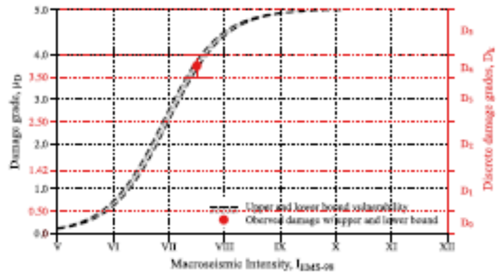
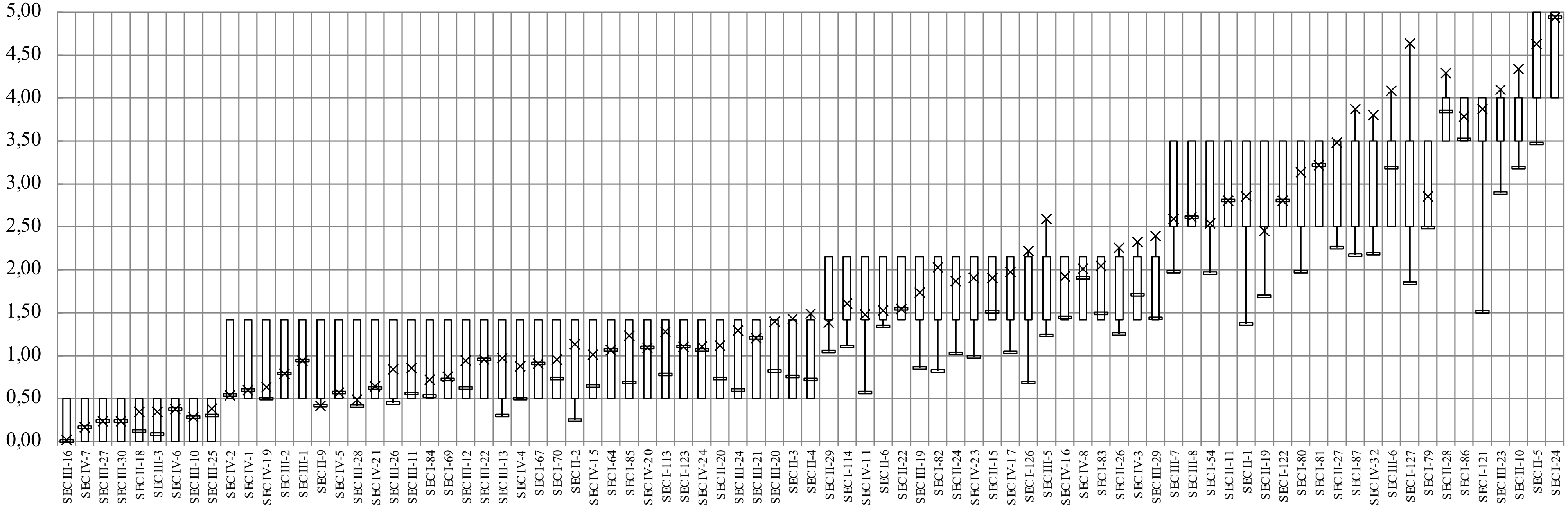






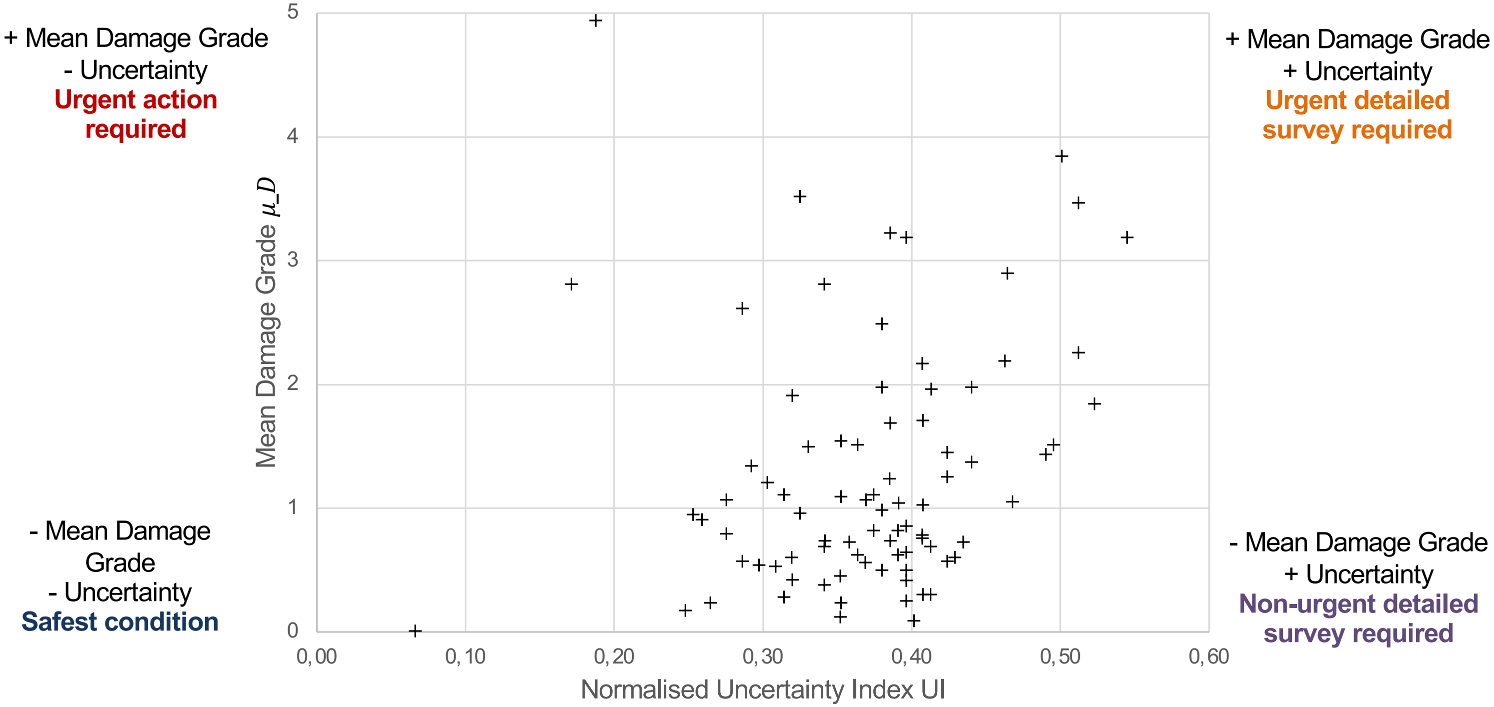
Case study 2. Atlixco-II.

- 84 constructions were used in this second case study. This was possible thanks to a series of surveys carried out by a group of MSc students before the event and the possibility of performing on-site data acquisition. Nevertheless, the challenges for assessing specific aspects in some constructions lead to the formulation of a coefficient to quantify the reliability of the vulnerability class assigned to each parameter. Such coefficient permitted to stablish a range-based assessment, able to be refined after more detailed data acquisition campaigns.



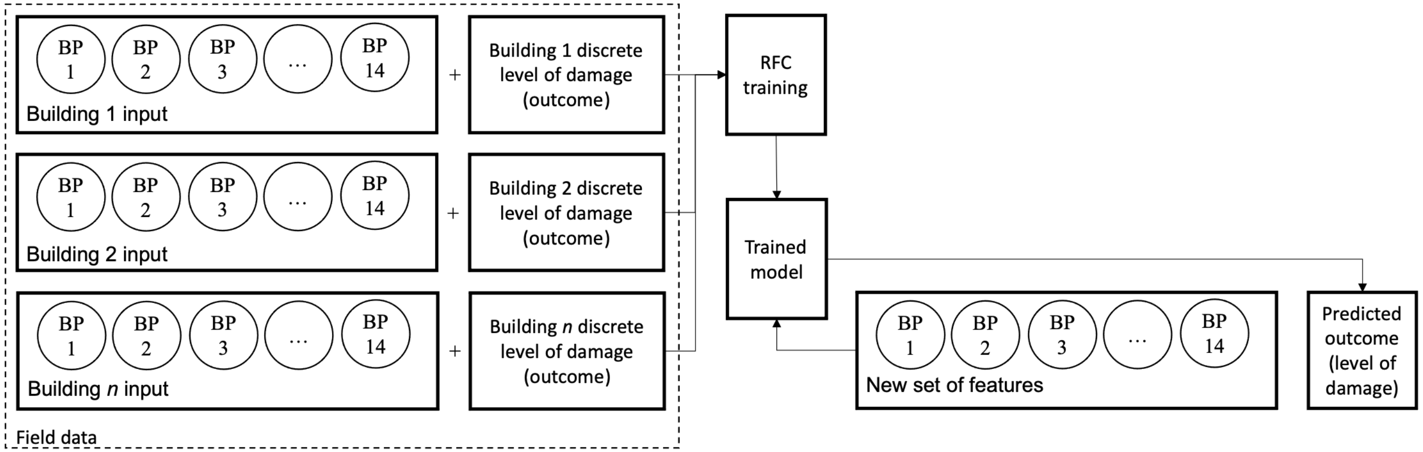
Case study 2. Atlixco-II.

- The adoption of this coefficient allowed to create some interesting outcomes, such as a cartesian representation of the combined assessment of uncertainty and level of damage.



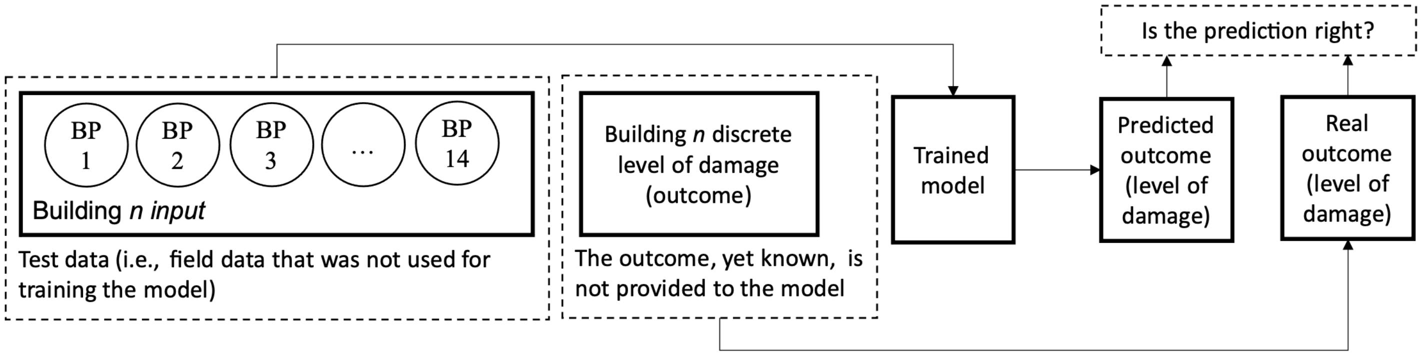
Case study 3. Morelos.

- A larger data acquisition campaign favoured to perform more experimental data treatments. Given the number of samples, the possibility of training a Machine Learning algorithm for redefining the relative weight of each parameter was considered. The subjacent logic is, in fact, very similar to the empirical approach that permitted the design of the parameter-based method in its origin: to recognise hidden patterns among a series of incomes and some specific outcomes.



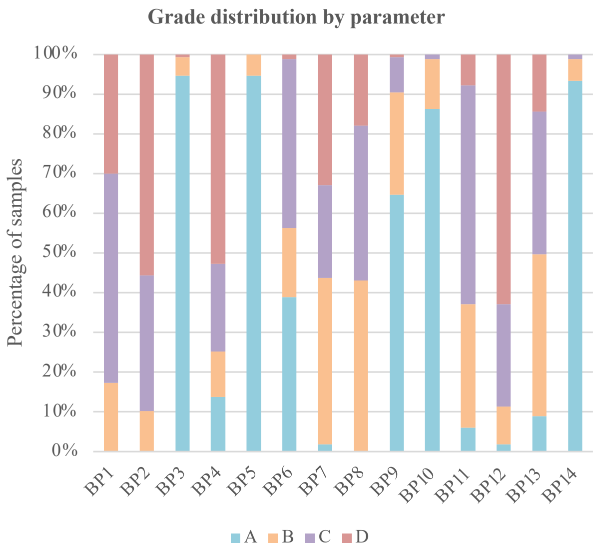
Case study 3. Morelos.

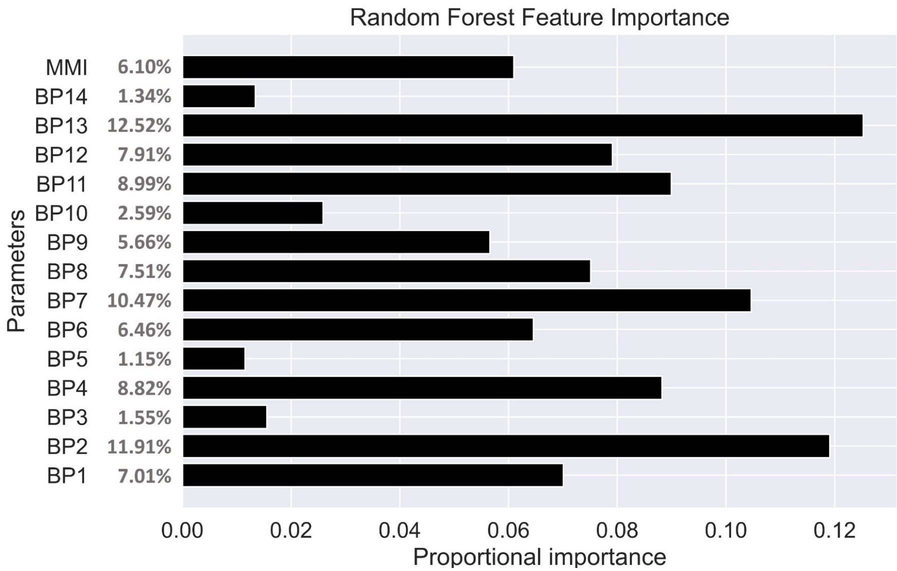
- A supervised classification algorithm was selected. Given the nature of the phenomenon, the Random Forest Classifier (RFC) seemed to be the most suitable approach. The classification is intended to link a series of descriptors (the parameters) with one of the five discrete levels of damage identified during the field campaign.



Case study 3. Morelos.

- The trained model had a very adequate representation of the phenomenon when assessed by the means of a reserved portion of the dataset. The new proportional importance of each parameter is influenced by the variability of classes within the parameter, which demonstrates the capacity of calibrating the semantic model for better fitting a certain typology or type of constructions.





Final Remarks.

- The compatibility between the method's parameters and the National Catalogue of Historical Monuments supports the implementation of this strategy.
- GIS databases are suitable environments for implementing the survey, perform data-acquisition and management.
- The experiences performed in Atlixco demonstrated an adequate representativeness of the model when comparing the damages predicted by the analytical model against those in the aftermath of the 2017 Puebla-Morelos Earthquake.
- The quantification and systematisation of the uncertainties on the parameter's class permitted to stablish ranges for predicted damage that can be reduced when the level of knowledge is improved.
- Even if a documental-based assessment can result into large ranges, it represent a first step for identifying critical assets and planning more strategic survey campaigns.
- These experiments permitted to demonstrate the ability of training Machine Learning algorithms for better fitting the parameter's weight distribution and reaching more representative models for certain typologies or environments.