EUCENTRE
FOR YOUR SAFETY.

Built environment data for multi-hazard vulnerability models within EPOS

Gerard J. O'Reilly

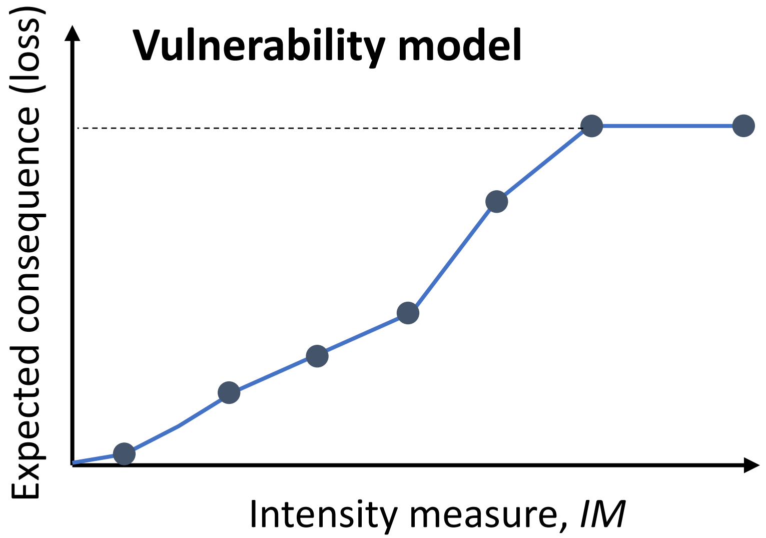
EUCENTRE Foundation
IUSS Pavia
Italy

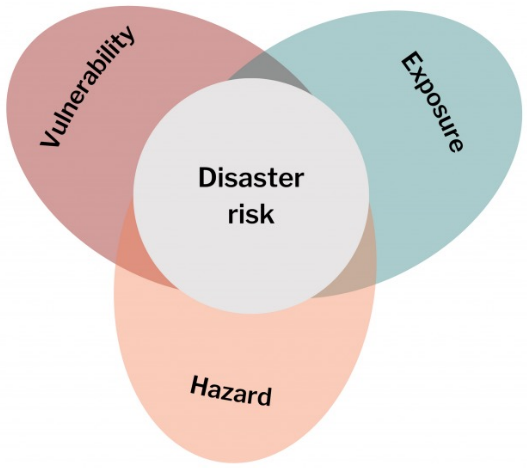
27-29 November 2024
EFEHR Scientific Session 2024
102nd Journées Luxembourgeoises de Géodynamique (JLG)

Overview

- When examining the impacts of natural hazards on the built environment, we use vulnerability models
- These are necessary for estimating risks and subsequent impacts
- The outputs of which can help stakeholders, policy and decision-makers

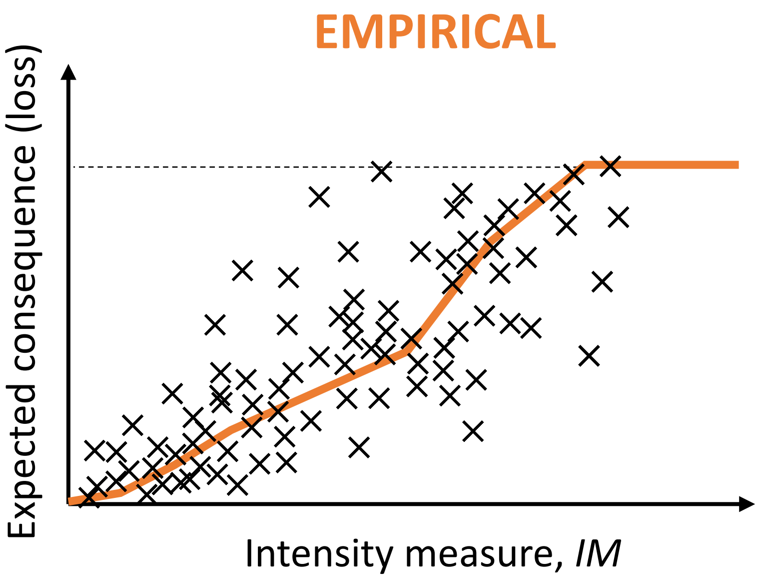
Türkiye, 2023

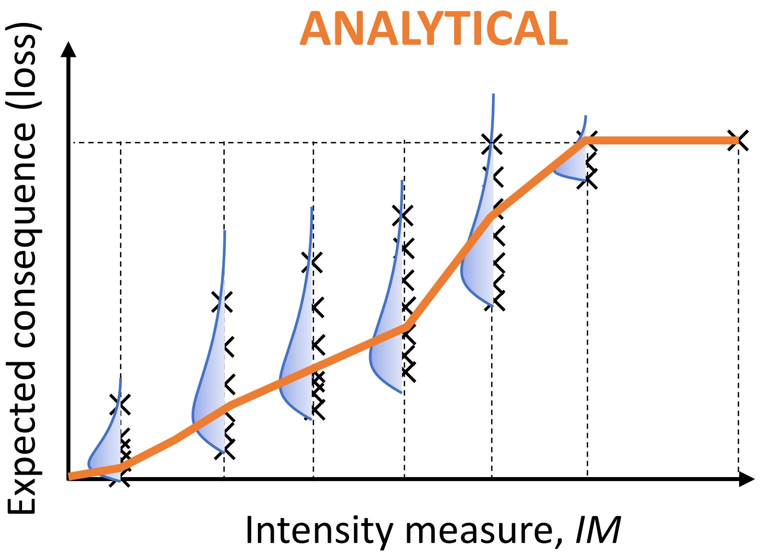




Vulnerability Modelling

- Given the key role of these vulnerability models in risk management and mitigation, it is critical to understand the various ways they can be developed
- Today, we discuss two methods:
  - **Empirical:** based on the statistical interpretation of past data
  - **Analytical:** based on simulations of numerical models
- Empirical model development requires **data** and statistics to decipher and harmonise models
- Analytical model development requires numerical **models** and computational tools





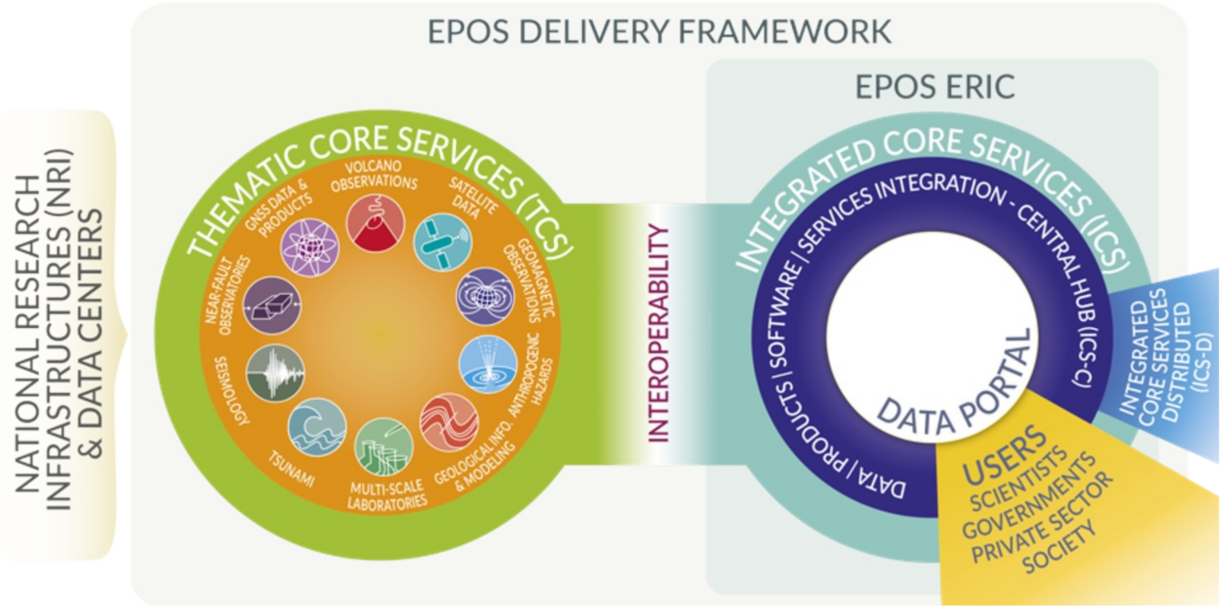
Built Environment Data

- The collection and archiving of data is key in this context
- At the Eucentre Foundation, we are leading an initiative termed Built Environment Data (BED)
- It aims to provide access to data and services related to the built environment
- A memorandum of understanding (MoU) exists with the European Plate Observing System (EPOS) to integrate BED as a Thematic Core Service (TCS)

Built Environment Data

www.builtenvdata.eu

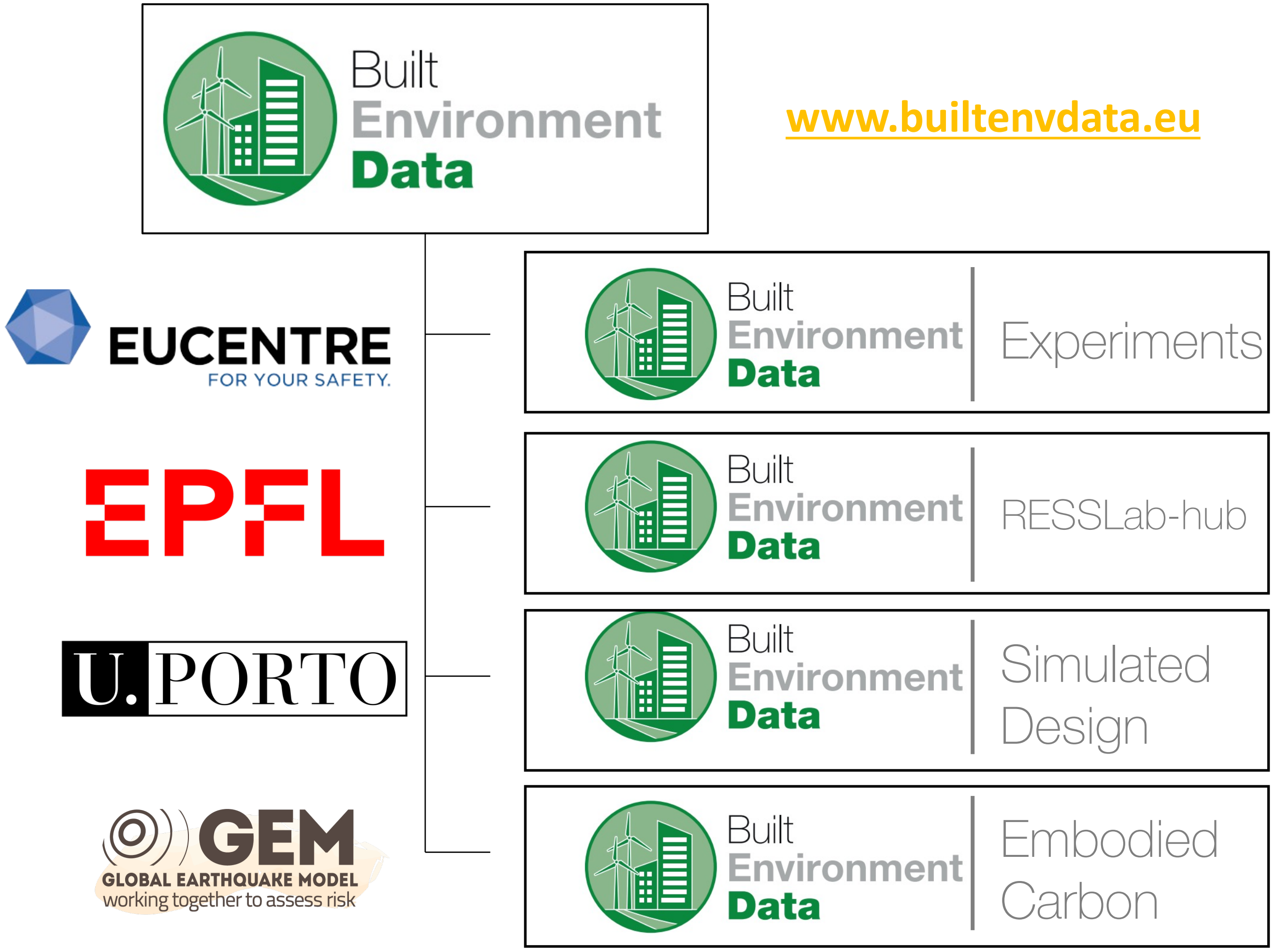
EUROPEANPLATEOBSERVINGSYSTEM



Built Environment Data

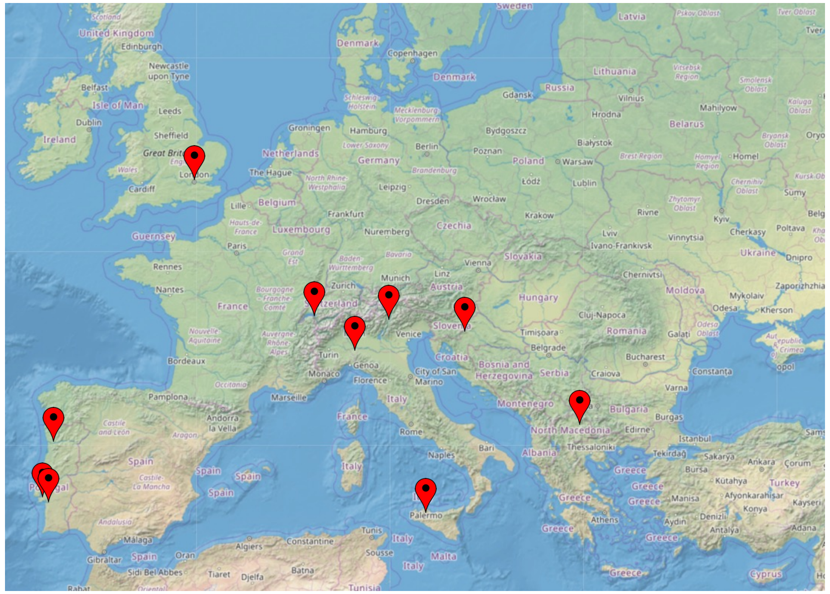
- BED hosts both data and services needed to enhance risk assessment and ensure the safety and resilience of the built environment
- Currently, there are four services within BED led by different institutions around Europe:
    - Experiments (EUCENTRE)
    - RESSLab-Hub (EPFL)
    - Simulated Design (UPORTO)
    - Embodied Carbon (GEM)
- The scope is to extend and grow these services in the context of risk assessment of the built environment

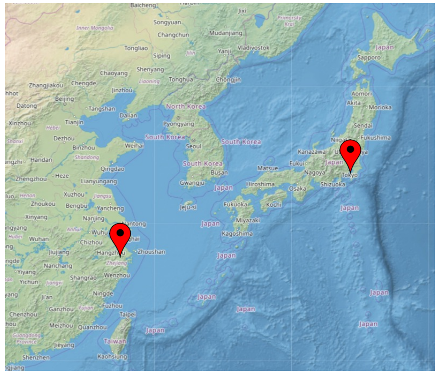
www.builtenvdata.eu



BED: Experiments

- One service that is growing quickly relates to experimental test data
- While not directly related to vulnerability modelling, it is fundamental to understand structural behaviour and calibrate numerical models
- Currently contributions from laboratories across Europe and around the world, with more tests added each week





Query the datasets

Built Environment Data | Experiments

experiments.builtenvdata.eu/explore?tax=FSA%2FMUR

Built Environment Data | Experiments — Explore Datasets · Web Services · About Us · Taxonomy · Publish Datasets

Explore Published Datasets

Taxonomy String: FSA+MUR+

Number of Available Datasets / Total Number of Datasets Available: 5 / 20

explore-results/FSA/MUR

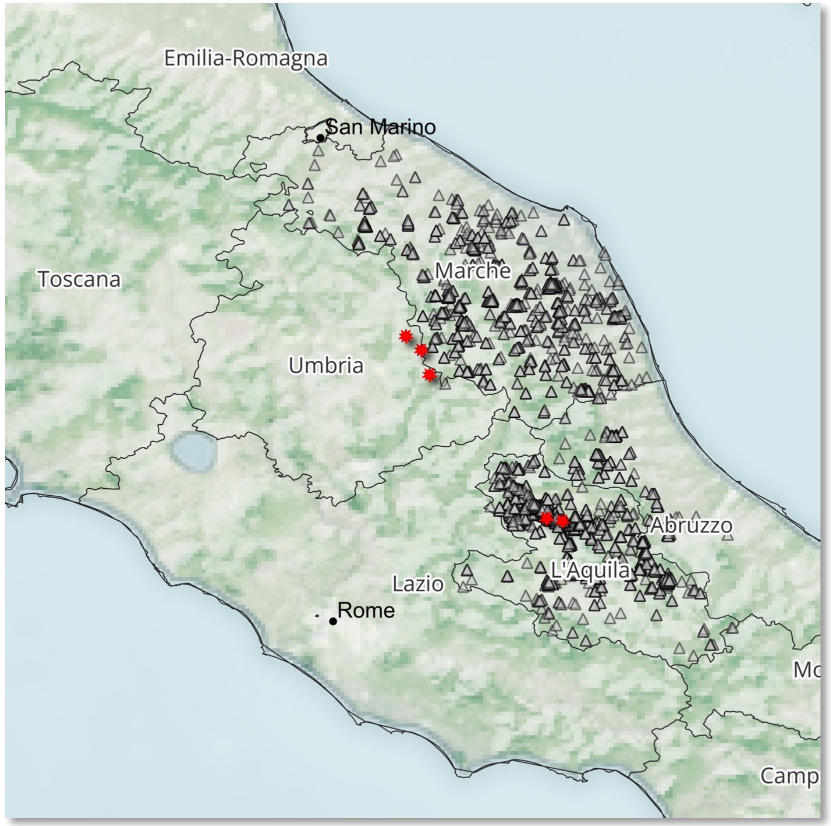
Show 10

Dataset Title	Dataset PI(s)	Dataset Facility	Year of Experiment
Shake-table testing of two full-scale URM cavity-wall buildings: effect of an innovative timber retrofit (EUC-BUILD-6 & -7)	F. Graziotti	EUCENTRE, Pavia	2019
Shake-table testing of three identical clay-URM buildings under multi-directional seismic input motions (EUC-BUILD-8.1, -8.2 & -8.3)	F. Graziotti	EUCENTRE, Pavia	2019
Shake-table testing of a full-scale clay-URM building with chimneys to near-collapse conditions (LNEC-BUILD-3)	F. Graziotti	LNEC, Lisbon	2018

Documentation of web services available at https://experiments.builtenvdata.eu/web-services

BED: Damage data?

- It is envisaged that a service related to empirical damage data following earthquakes can be implemented in such a manner and added to BED
- This would be useful within the EPOS geo-referenced platform, as the spatial distribution of data can be browsed and examined with respect to other hazards and measured data
- The archiving and geo-referencing of this data will be key for empirical vulnerability model development



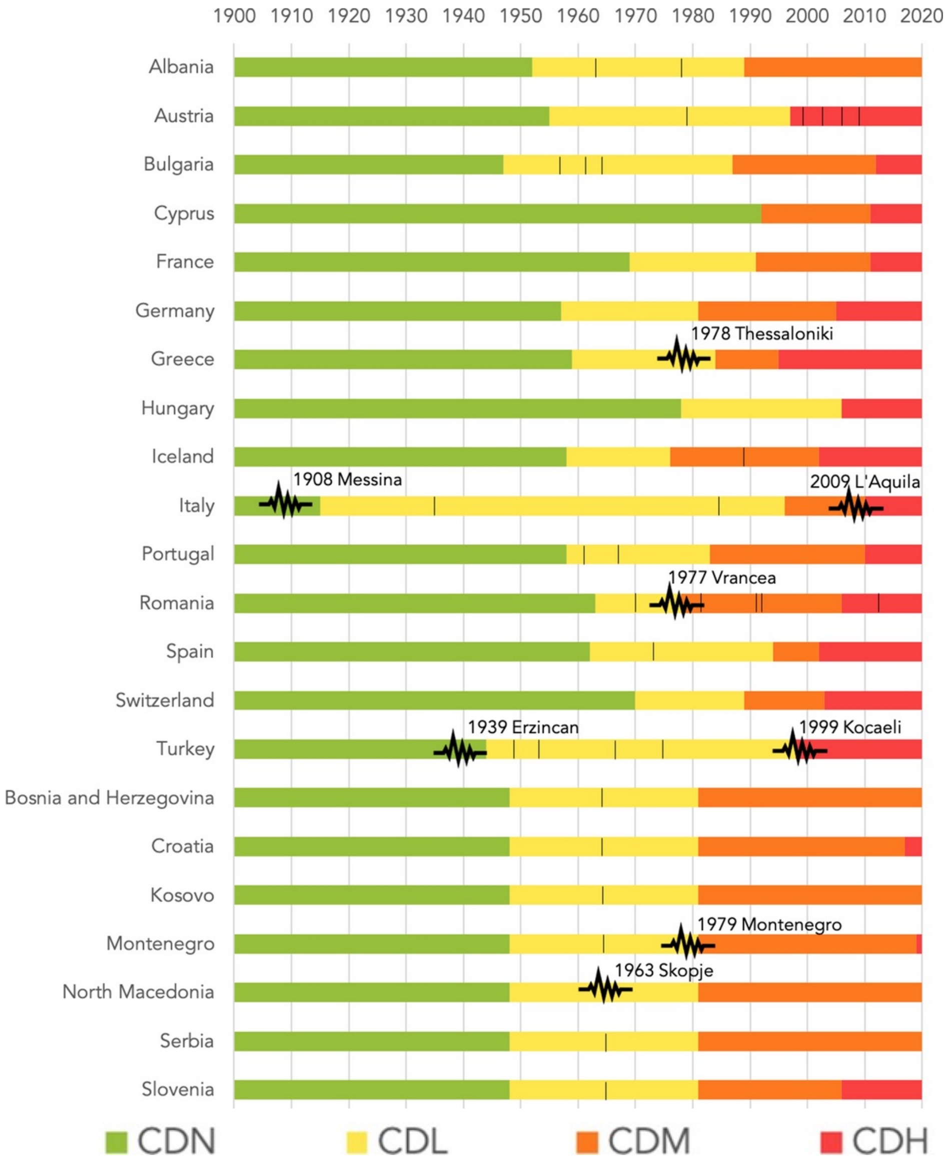
- Friuli 1976
- Irpinia 1980
- Abruzzo 1984
- Umbria-Marche 1997
- Pollino 1998
- Molise-Puglia 2002
- Emilia 2003
- L'Aquila 2009
- Emilia 2012
- Garfagnana-Lunigiana 2013
- Central Italy 2016 - 2017
- Mugello 2019

DaDO: Database of Observed Damage

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

BED: Simulated Design

- BED: Simulated Design is an initiative aimed at automating the creation of numerical models
- They are regionally specific and capture the temporal evolution of construction practices across Europe
- The typical choices of engineers at various points in time have been collected and documented
- This allows building designs to be simulated and be representative of what was done at different locations and at different times in the past
- The principal outputs are designs and numerical models for feasible designs
- The analysis of these is key to vulnerability model development



Crowley et al. (2021)

Workflow

Built Environment Data

Design Engine

User Inputs

- Typology
- Taxonomy — { Year, Region }
- # Storeys
- β Coefficient

Workflow

Typology → RC-MRF | RC-Wall | Steel-MRF

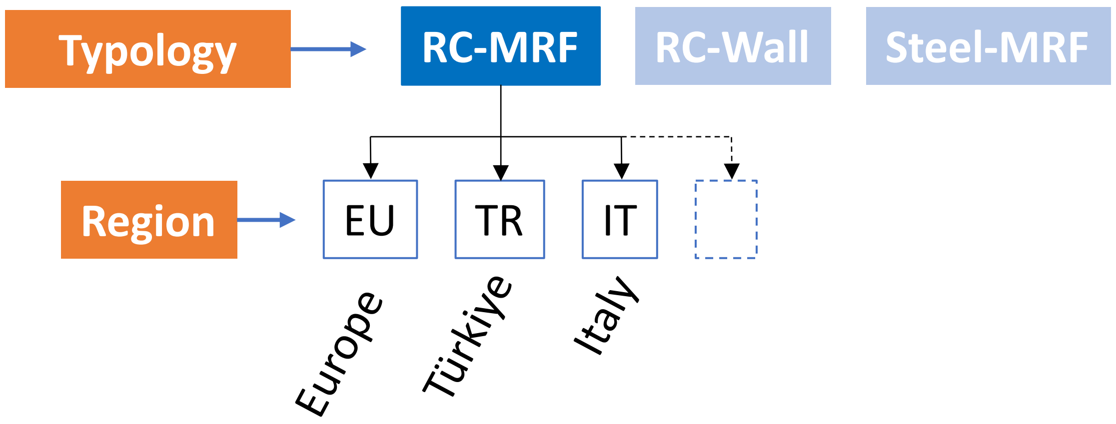
Built Environment Data

Design Engine

User Inputs

Typology
Taxonomy { Year, Region }
Storeys
β Coefficient

Workflow



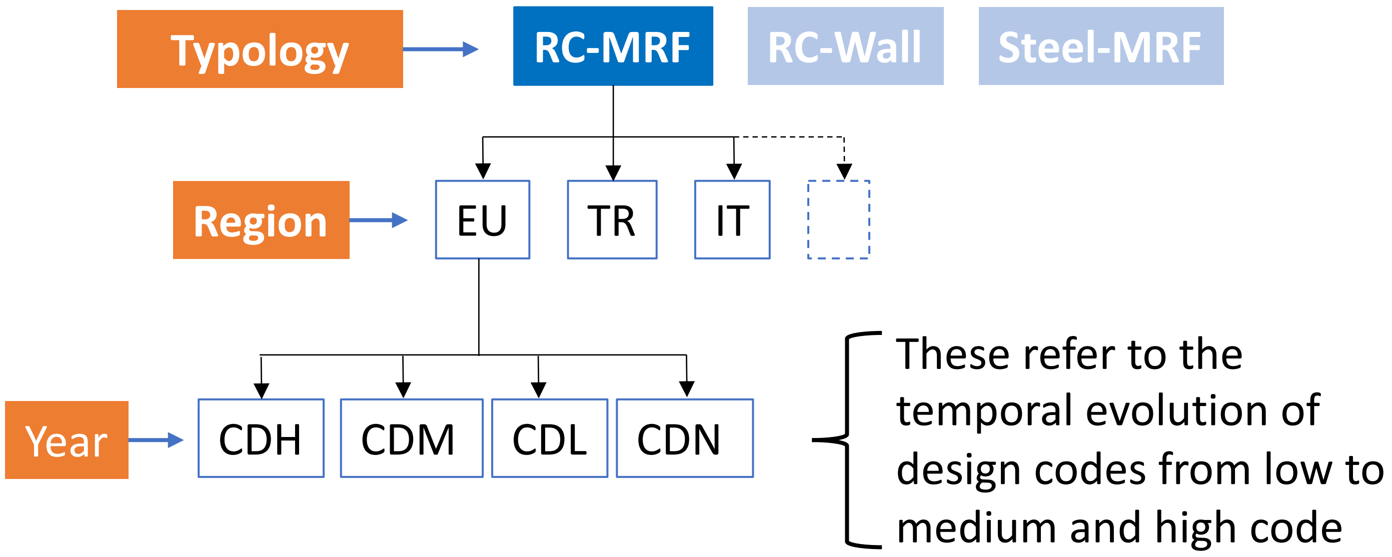
Built Environment Data

Design Engine

User Inputs

Typology
Taxonomy — Year, Region
Storeys
β Coefficient

Workflow



Built Environment Data

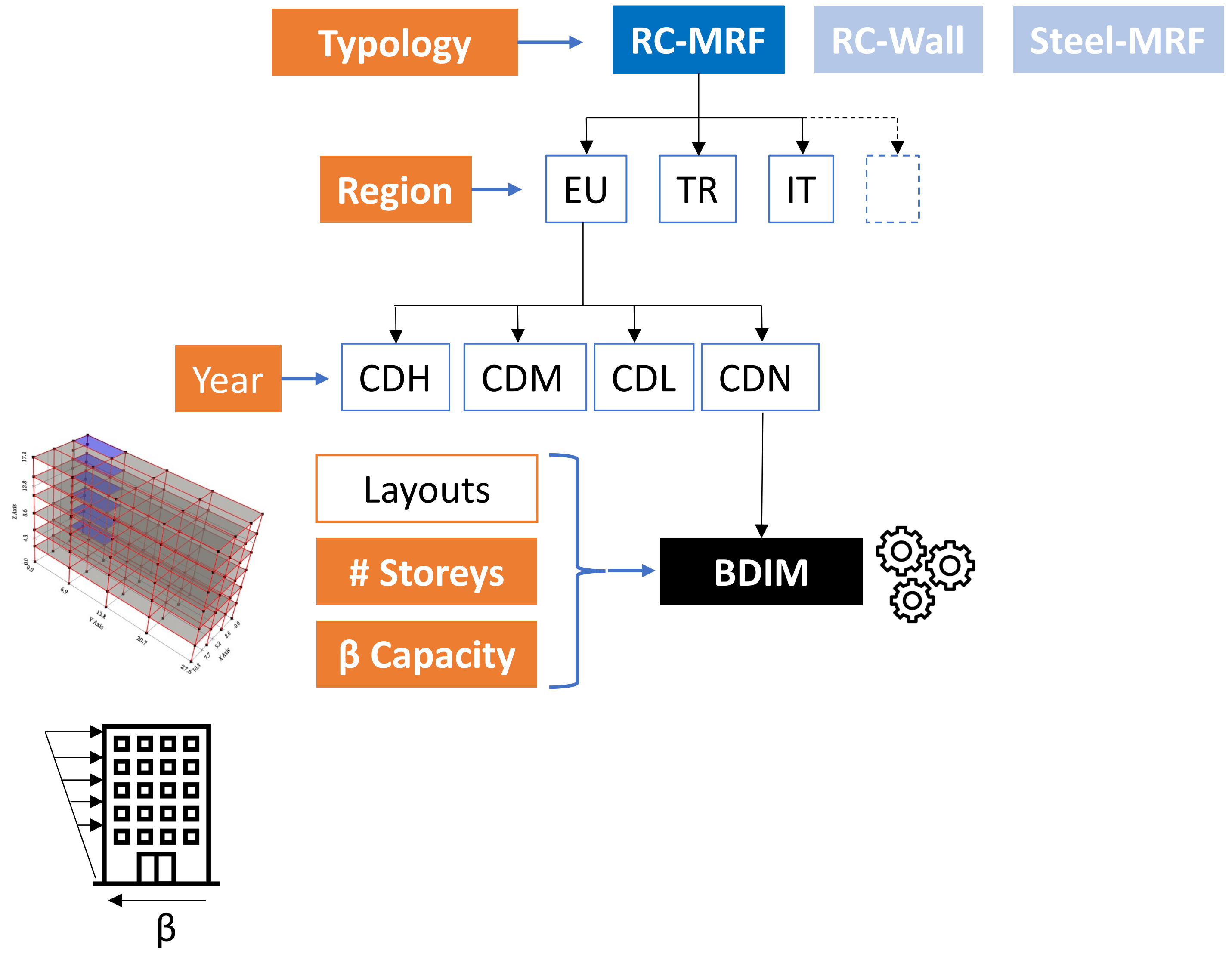
Design Engine

User Inputs

Typology
Taxonomy
Storeys
β Coefficient

Year
Region

Workflow



Built Environment Data

Design Engine

User Inputs

Typology
Taxonomy { Year, Region }
Storeys
β Coefficient

Workflow

Typology → RC-MRF | RC-Wall | Steel-MRF

Region → EU | TR | IT

Year → CDH | CDM | CDL | CDN

Layouts

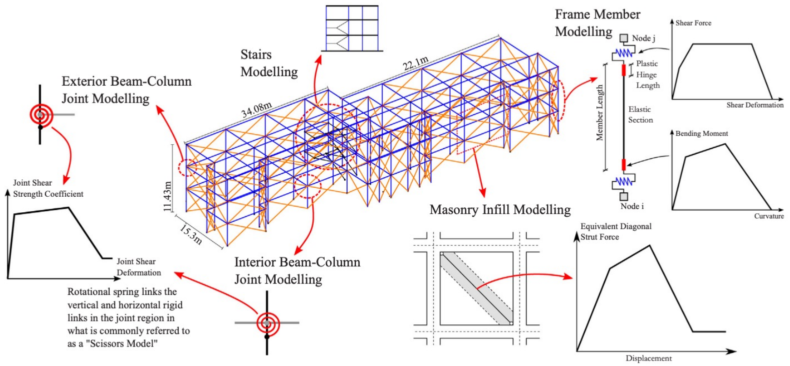
Storeys

β Capacity

→ BDIM

OpenSees

BED Design Outputs



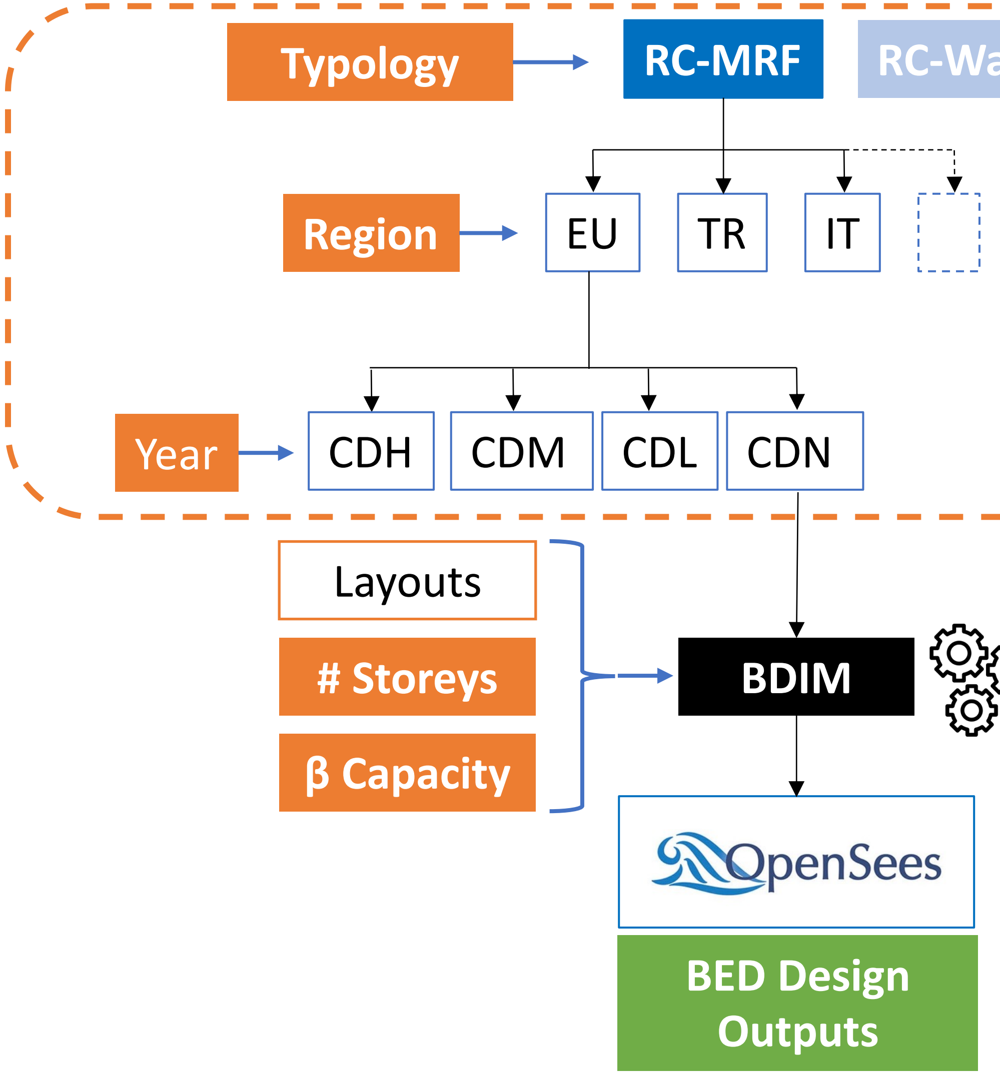
Built Environment Data

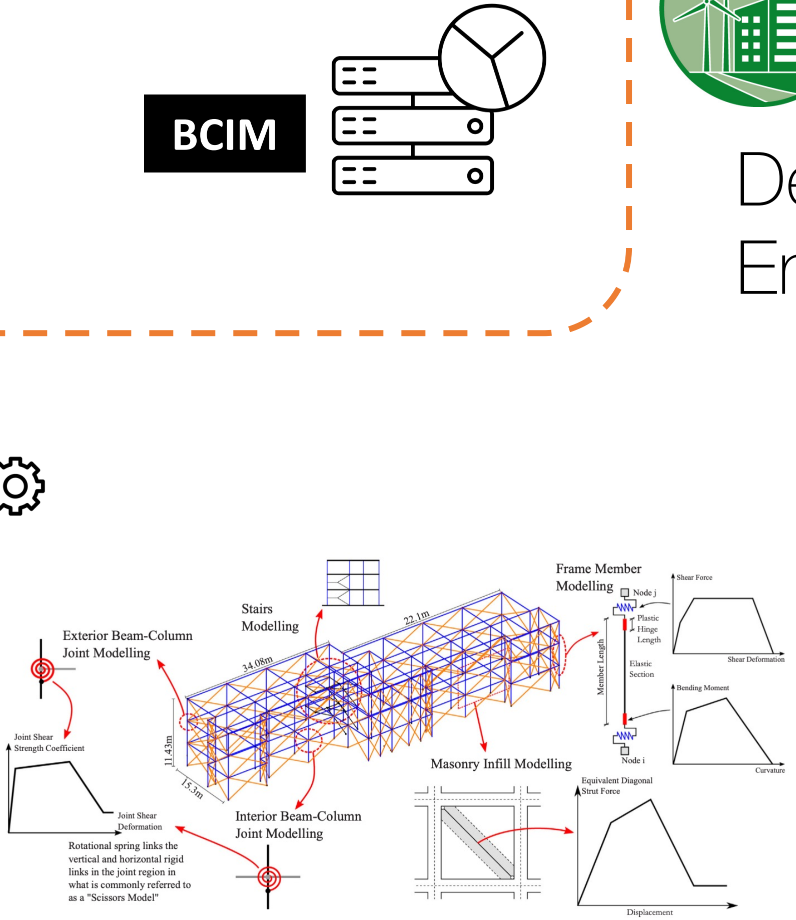
Design Engine

User Inputs

Typology
Taxonomy { Year, Region }
Storeys
β Coefficient

Workflow





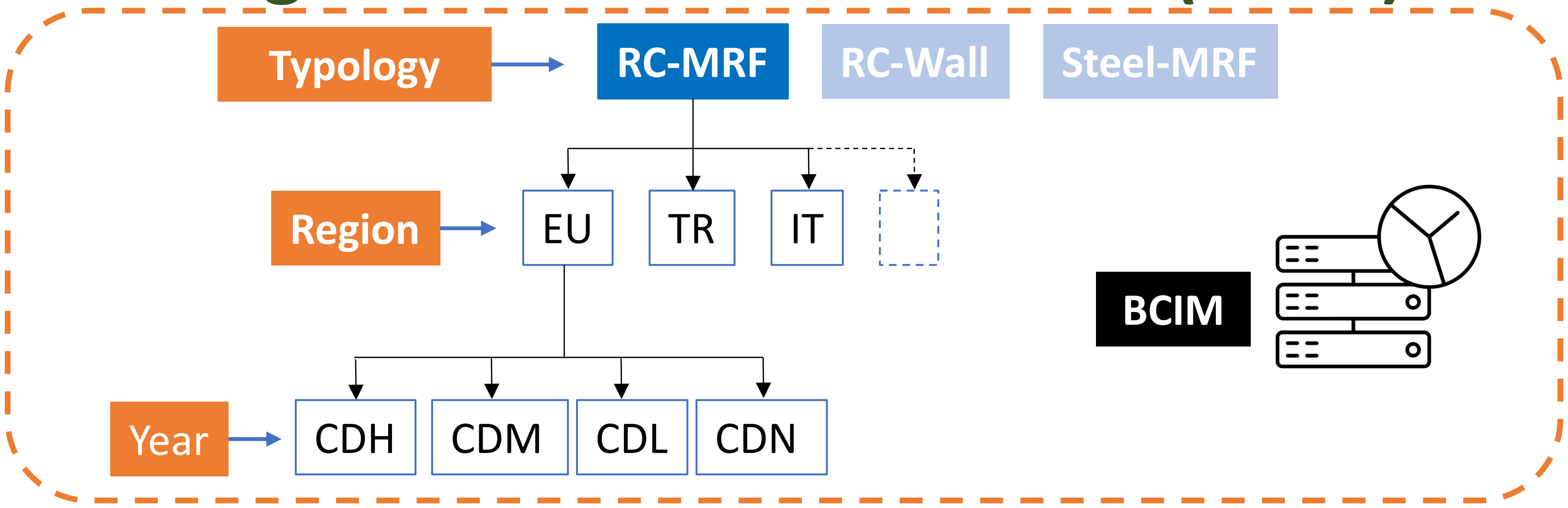
Built Environment Data

Design Engine

User Inputs

Typology
Taxonomy { Year, Region }
Storeys
β Coefficient

Building Class Information Model (BCIM)



Building Class Information Model (BCIM)

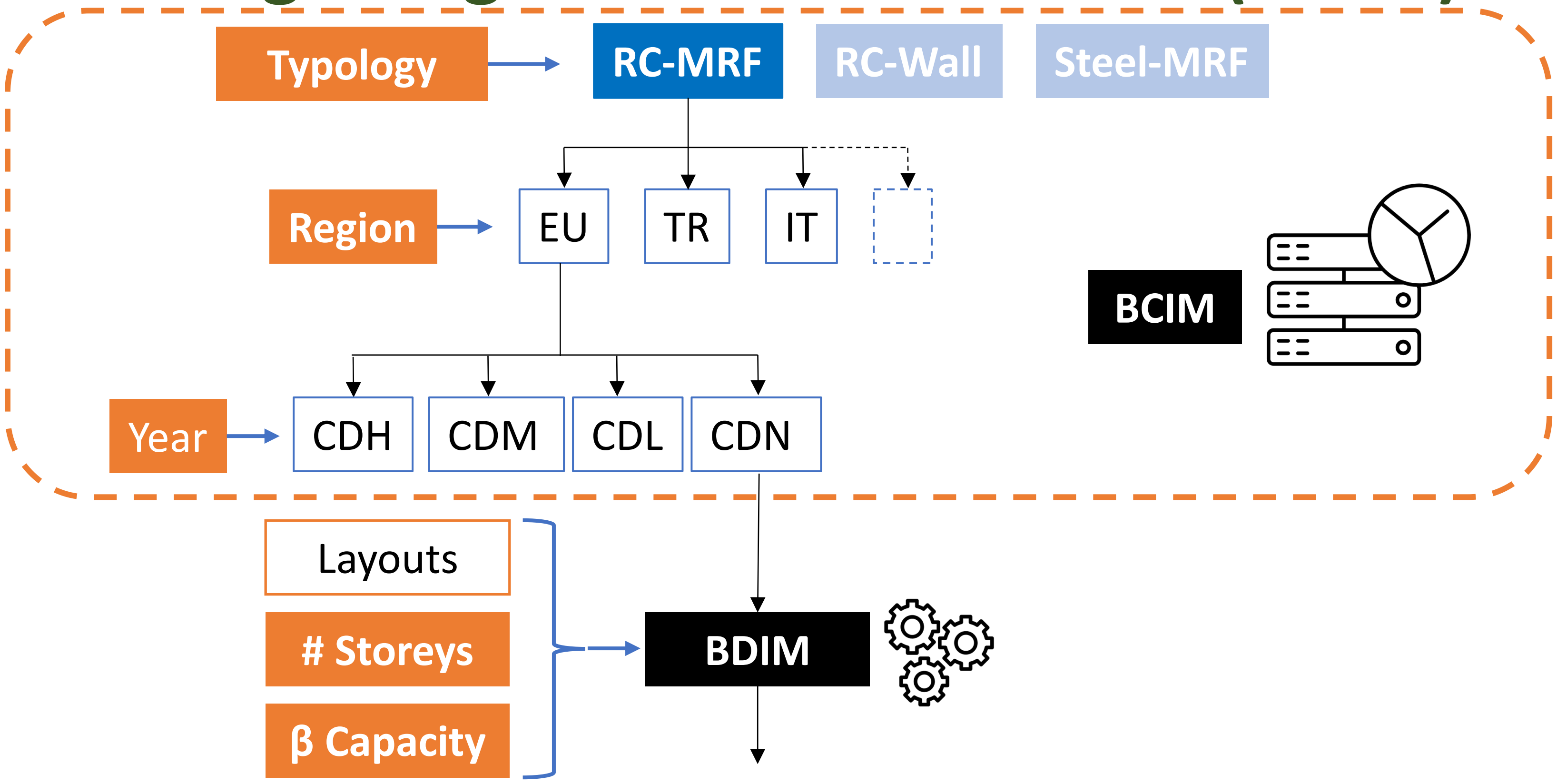
- The **building class information model** (BCIM) contains statistical information about a country's construction and evolution over time
- It answers the question:

  "What kind of buildings were constructed in this region?"

- It is obtained from case studies, census data, practitioner interviews, etc.
- It is stored in JSON file format also and is developed in specific studies:
  - `typical_storey_height`
  - `staircase_bay_width`
  - `standard_bay_width`
  - `steel`
  - `concrete`
  - `ground_storey_height`
  - `construction_quality`
  - `slab_properties`
  - `square_column_ratio`


```
"steel":
  {
    "grade": ["S400", "S500"],
    "probability": [0.10, 0.90]
  },
"concrete":
  {
    "grade": ["C20", "C25", "C30", "C35"],
    "probability": [0.30, 0.45, 0.20, 0.05]
  },
"ground_storey_height":
  {
    "maximum": 4.20,
    "factor": [1.0, 1.1, 1.2, 1.3, 1.4],
    "probability": [0.55, 0.10, 0.20, 0.10, 0.05]
  },
"construction_quality":
  {
    "probability": [0.6, 0.3, 0.1]
  },
"slab_properties":
  {
    "one_to_one_and_comp_ratio": 0.50,
    "two_to_two_and_comp_ratio": 0.65,
    "max_solid_length": 6.0,
    "max_thickness": 0.85,
    "staircase_slab_depth": 0.15
```

Building Design Information Model (BDIM)

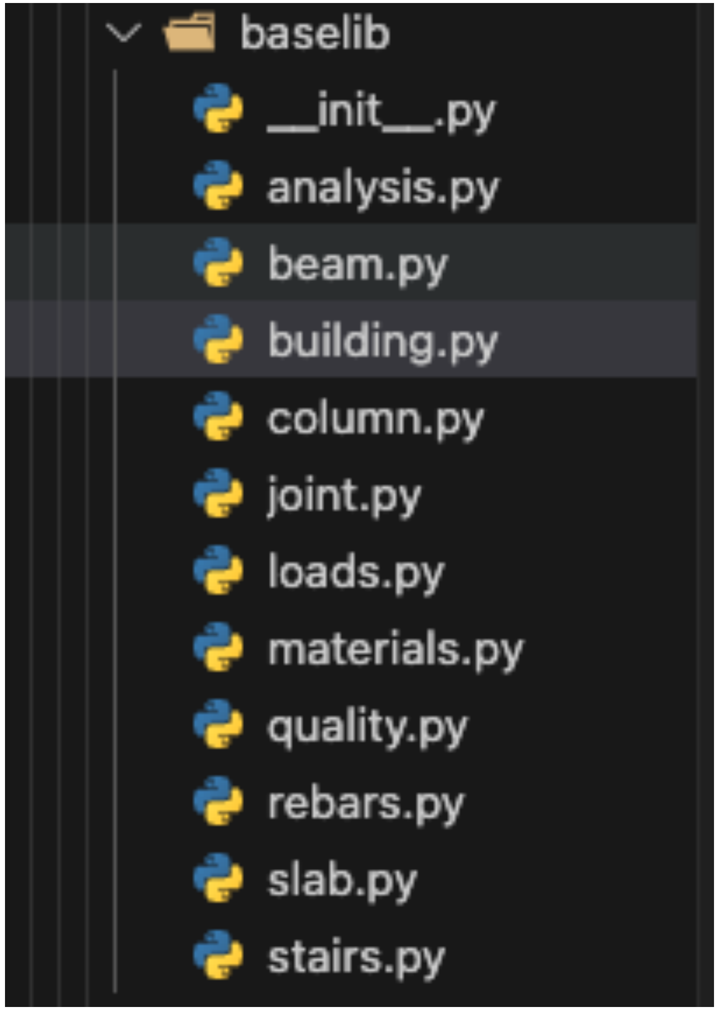


Building Design Information Model (BDIM)

- This **building design information model** (BDIM) defines the way in which engineers designed these buildings
- It answers the question:

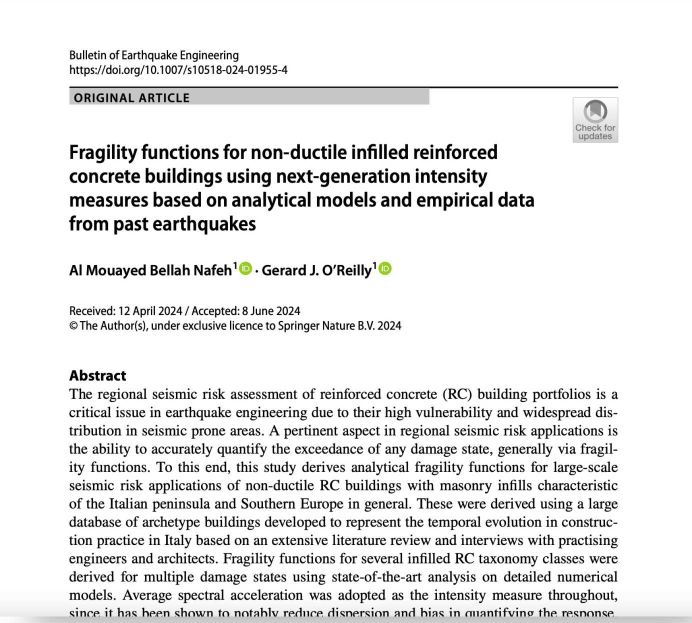
  "For these kinds of buildings that were constructed in this region, how did the engineers typically design them during that period?"

- It is obtained from past design manuals, reference textbooks, case studies, practitioner interviews, etc.
- It is implemented as several classes and methods in what is termed the base library
- The BDIM for specific regions, periods and typologies can be modified and extended



Simulated designs in vulnerability modelling

- BED: Simulated Design offers a new service to allow analysts to create the models often needed in vulnerability modelling
- With such data and services, we can begin to explore new possibilities in vulnerability modelling
- A recent example of this was in Nafeh and O'Reilly (2024), which developed fragility functions for non-ductile RC frames with infills
- It followed two approaches:
  - **Empirical data** available following the 2009 L'Aquila and 1997 Umbria-Marche earthquakes in Italy
  - **Analytical models** developed following a Simulated Design approach
- The scope of the research:
  - Compare the fragility functions obtained via empirical data and analytical models
  - Illustrate how recent research developments can be introduced for more accurate fragility and vulnerability models


Bulletin of Earthquake Engineering
https://doi.org/10.1007/s10518-024-01955-4

ORIGINAL ARTICLE

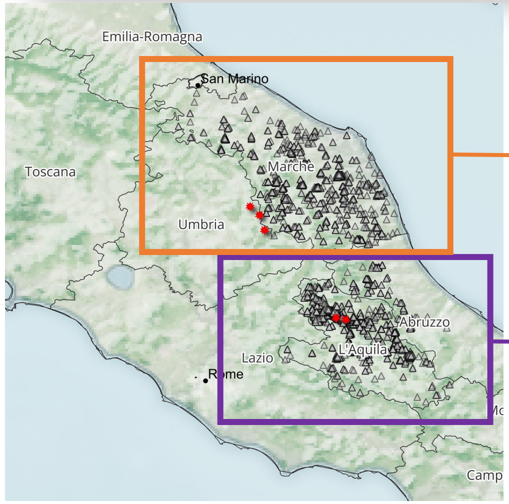
Check for updates

Fragility functions for non-ductile infilled reinforced concrete buildings using next-generation intensity measures based on analytical models and empirical data from past earthquakes

Al Mouayed Bellah Nafeh[1] · Gerard J. O'Reilly[1]

Received: 12 April 2024 / Accepted: 8 June 2024
© The Author(s), under exclusive licence to Springer Nature B.V. 2024

Abstract
The regional seismic risk assessment of reinforced concrete (RC) building portfolios is a critical issue in earthquake engineering due to their high vulnerability and widespread distribution in seismic prone areas. A pertinent aspect in regional seismic risk applications is the ability to accurately quantify the exceedance of any damage state, generally via fragility functions. To this end, this study derives analytical fragility functions for large-scale seismic risk applications of non-ductile RC buildings with masonry infills characteristic of the Italian peninsula and Southern Europe in general. These were derived using a large database of archetype buildings developed to represent the temporal evolution in construction practice in Italy based on an extensive literature review and interviews with practising engineers and architects. Fragility functions for several infilled RC taxonomy classes were derived for multiple damage states using state-of-the-art analysis on detailed numerical models. Average spectral acceleration was adopted as the intensity measure throughout, since it has been shown to notably reduce dispersion and bias in quantifying the response



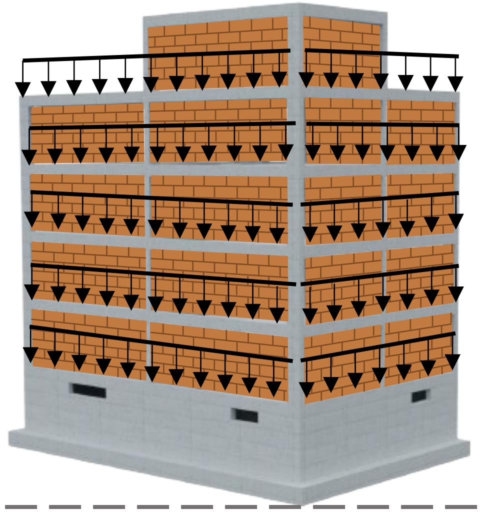
1997 Umbria-Marche

2009 L'Aquila

Database of Archetype Numerical Models

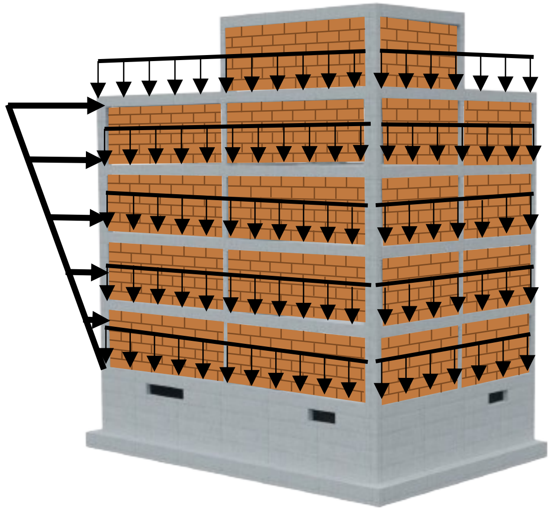
- Design space considerations through identification of the geographic construction practice

Pre-1970s
(GLD)



- Gravity loads only
- Allowable stress method (RD 2229/39)
- Smooth rebars with a low yield strength (≈ 325 MPa)
- Concrete with low compressive strength (≈ 25 MPa)
- Low shear reinforcement ratios
- Inadequate detailing of beam-column joints
- Frames spanning in one direction

- ELF method (Seismic coefficient 5-10%)
- Allowable stress method
- Deformed rebars with typical yield strength (≈ 430 MPa)
- Concrete with moderate compressive strength (≈ 28 MPa)
- Low shear reinforcement ratios
- Frames spanning in one (or both) direction

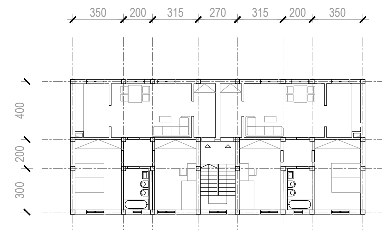


1970s-1980s
(SSD)

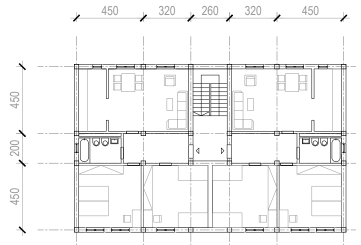
EUCENTRE
FOR YOUR SAFETY.

Database of Archetype Numerical Models

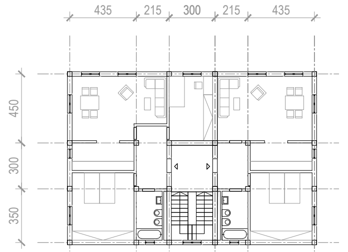
Architectural Layouts



Archetype A

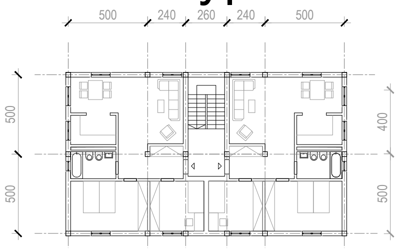


Archetype B

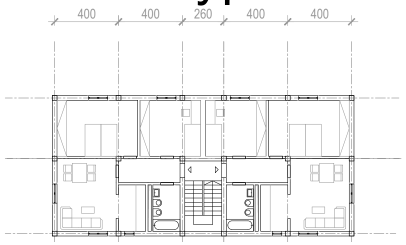


Archetype C

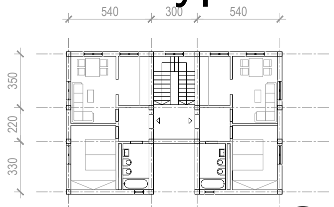
Archetype D



Archetype E

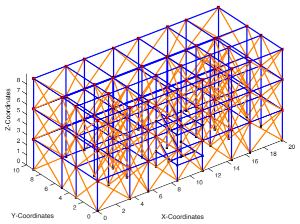


Archetype F

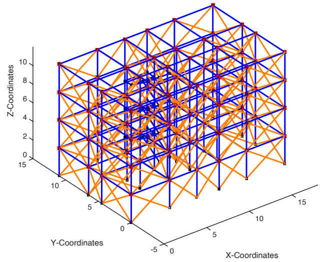


Archetype G

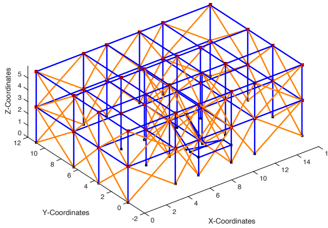
Numerical Models



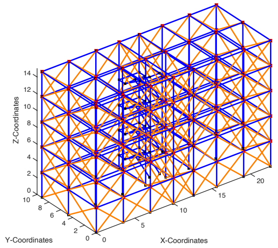
Archetype A



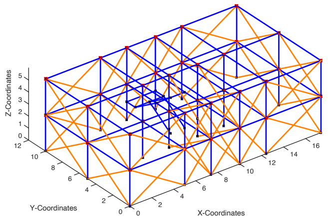
Archetype B



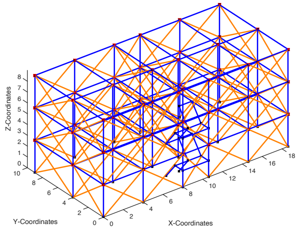
Archetype C



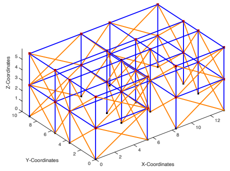
Archetype D



Archetype E



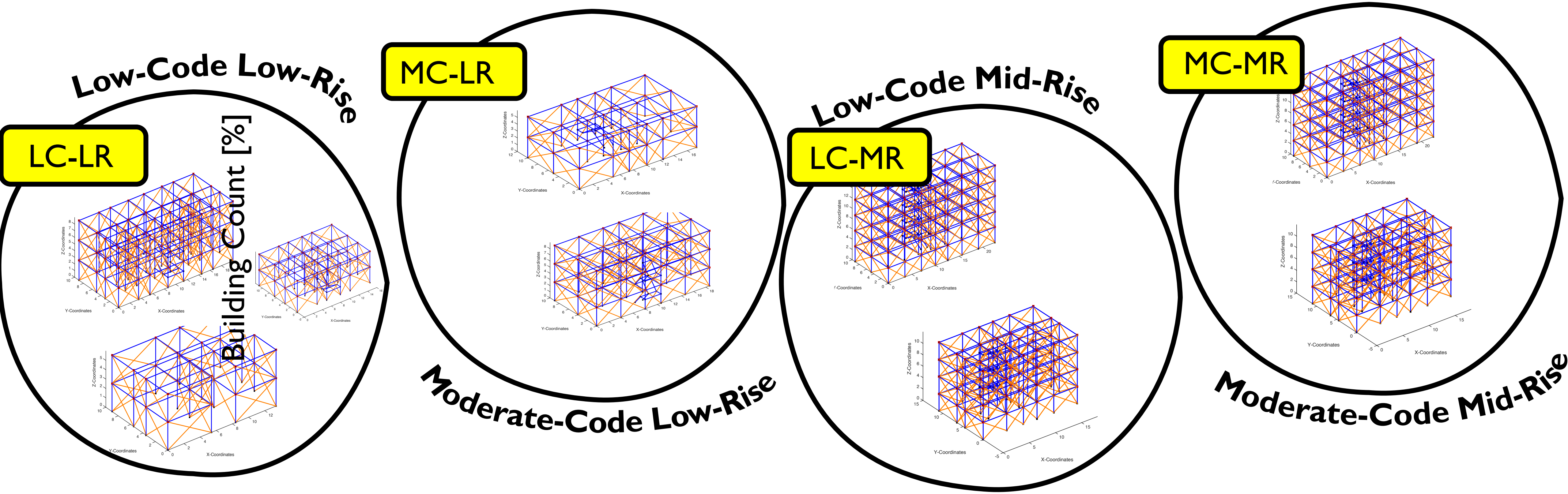
Archetype F



Archetype G

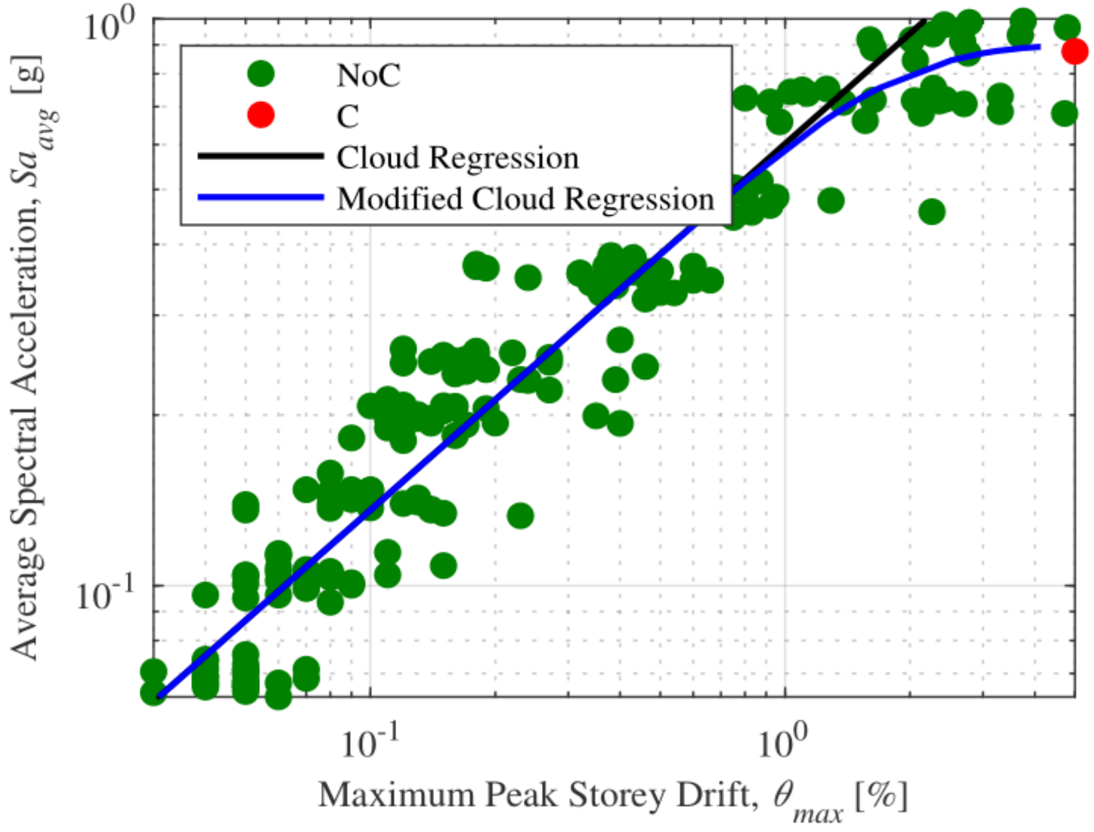
Definition of Building Classes

- The definition of a building class is a key step towards assessing seismic risk.
- Building classes must be defined using building attributes relevant to seismic vulnerability



Seismic Performance Assessment

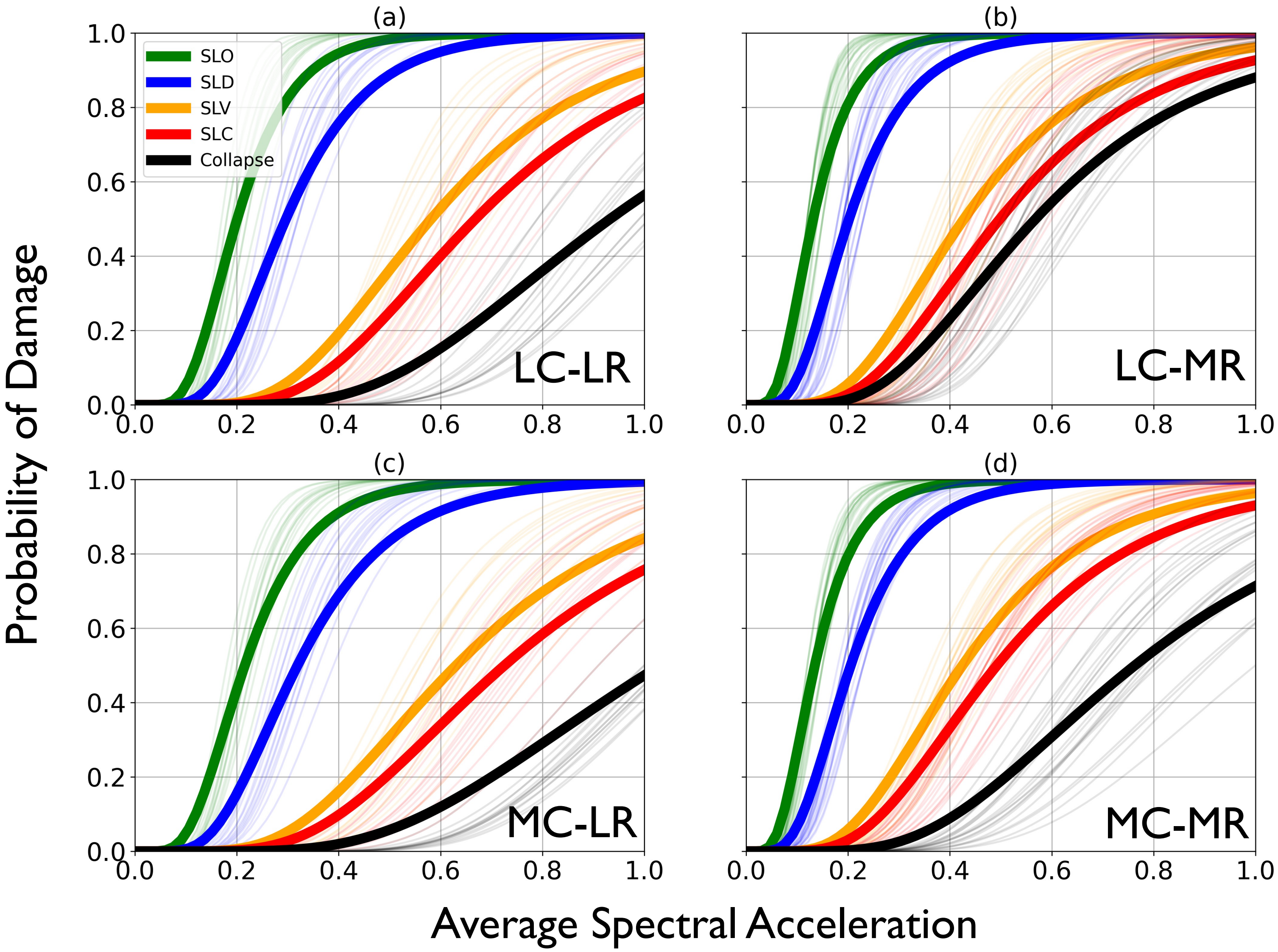
- The seismic performance was assessed using non-linear response history analysis
- Nine intensity measure levels corresponding to return periods of 22-4975 years
- Next-generation intensity measure of average spectral acceleration $Sa_{avg}(T^*)$ was used
- Structural response was characterised in terms of the maximum peak storey drift (ϑ_{max})



Numerical analysis results of

a case study building

Analytical Fragility Functions

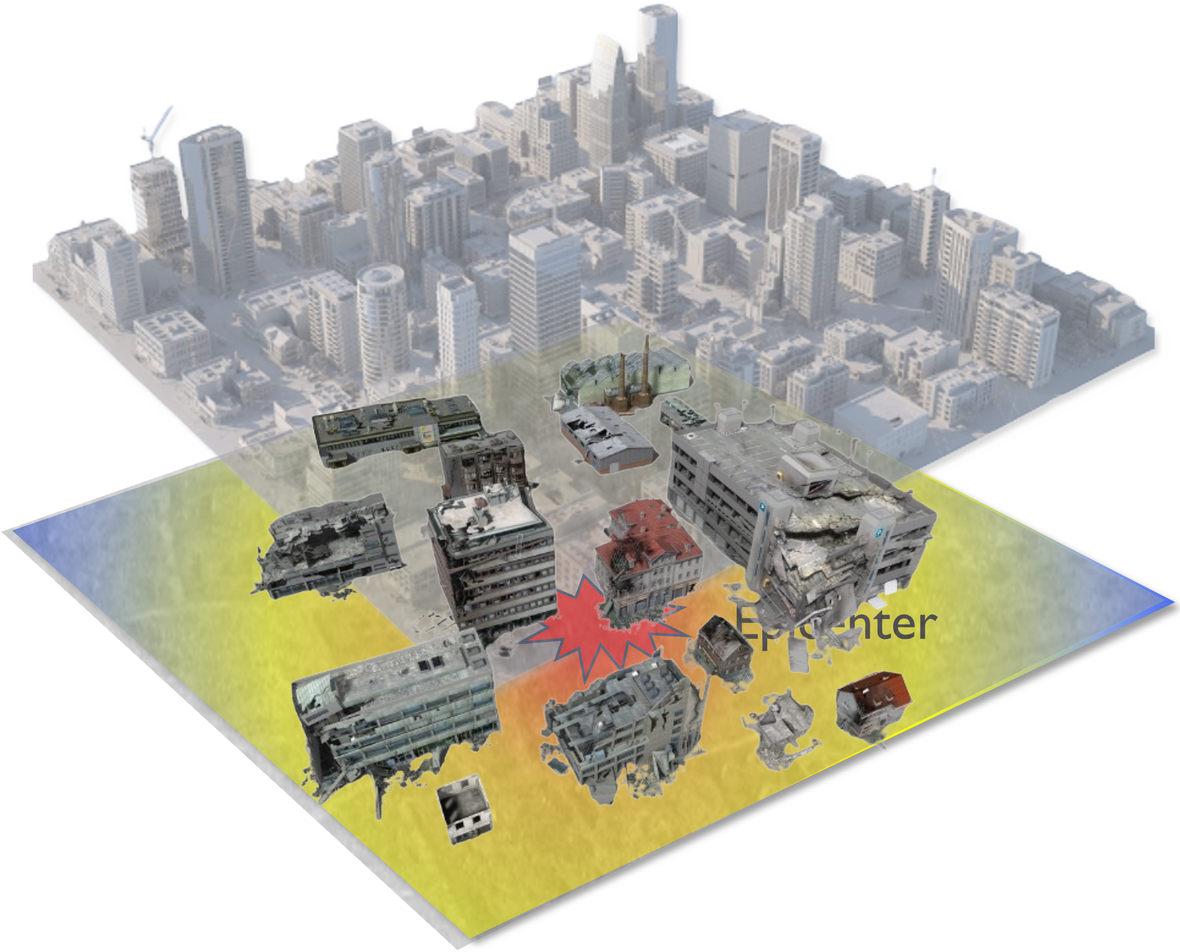


Empirical Fragility Functions

- Empirical fragility functions are the end result of convolving two layers of information in combination with robust statistical tools

  - ➢Observed damage to buildings

  - ➢Ground-motion fields (GMFs)

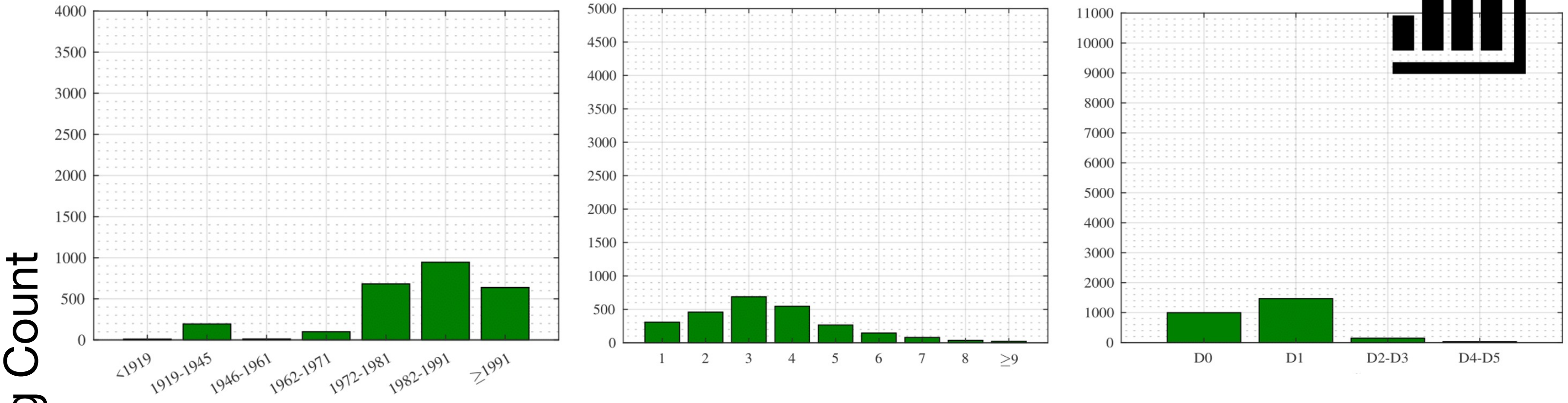


Observed Building Damage

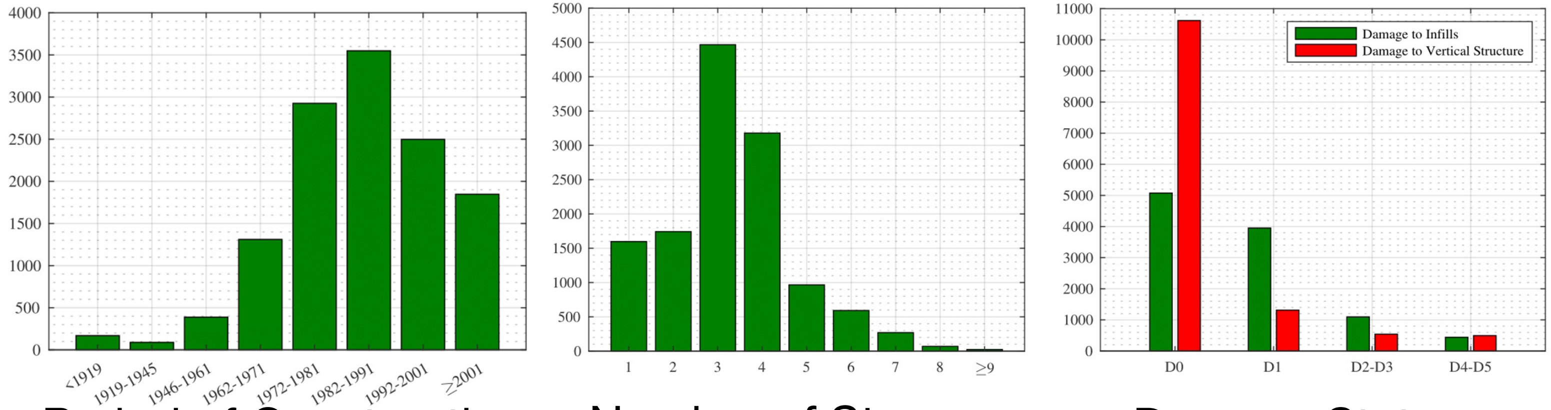
EUCENTRE
FOR YOUR SAFETY.

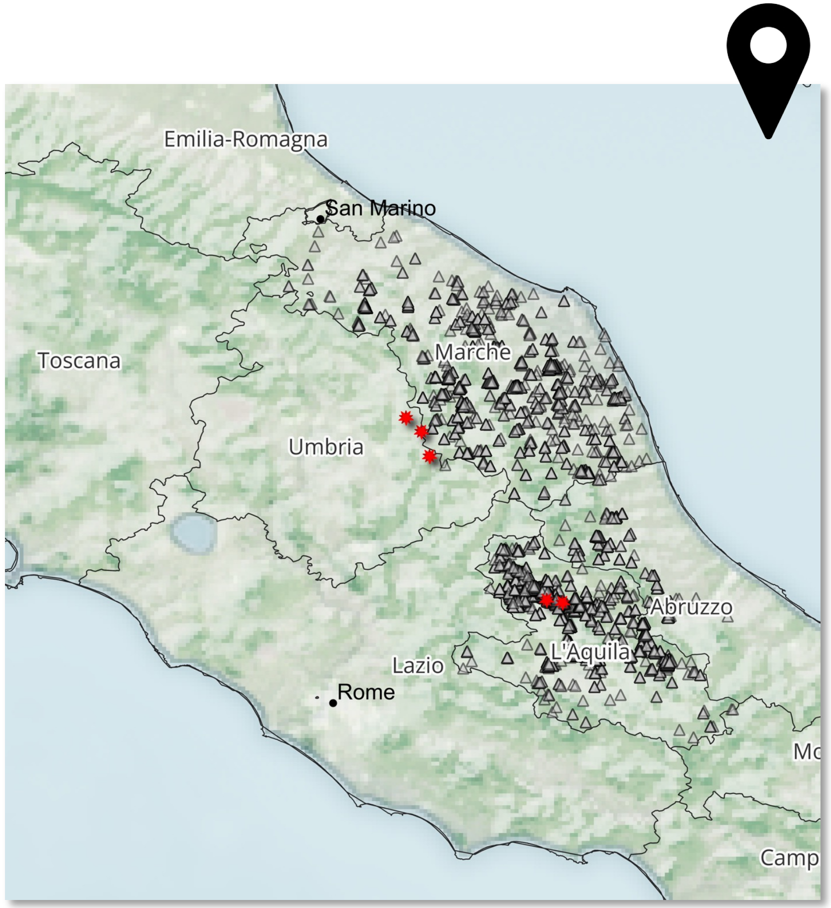
- Building characteristics and spatial distributions (DaDO)

Umbria-Marche 1997 (2164 Buildings)



L'Aquila 2009 (8502 Buildings)

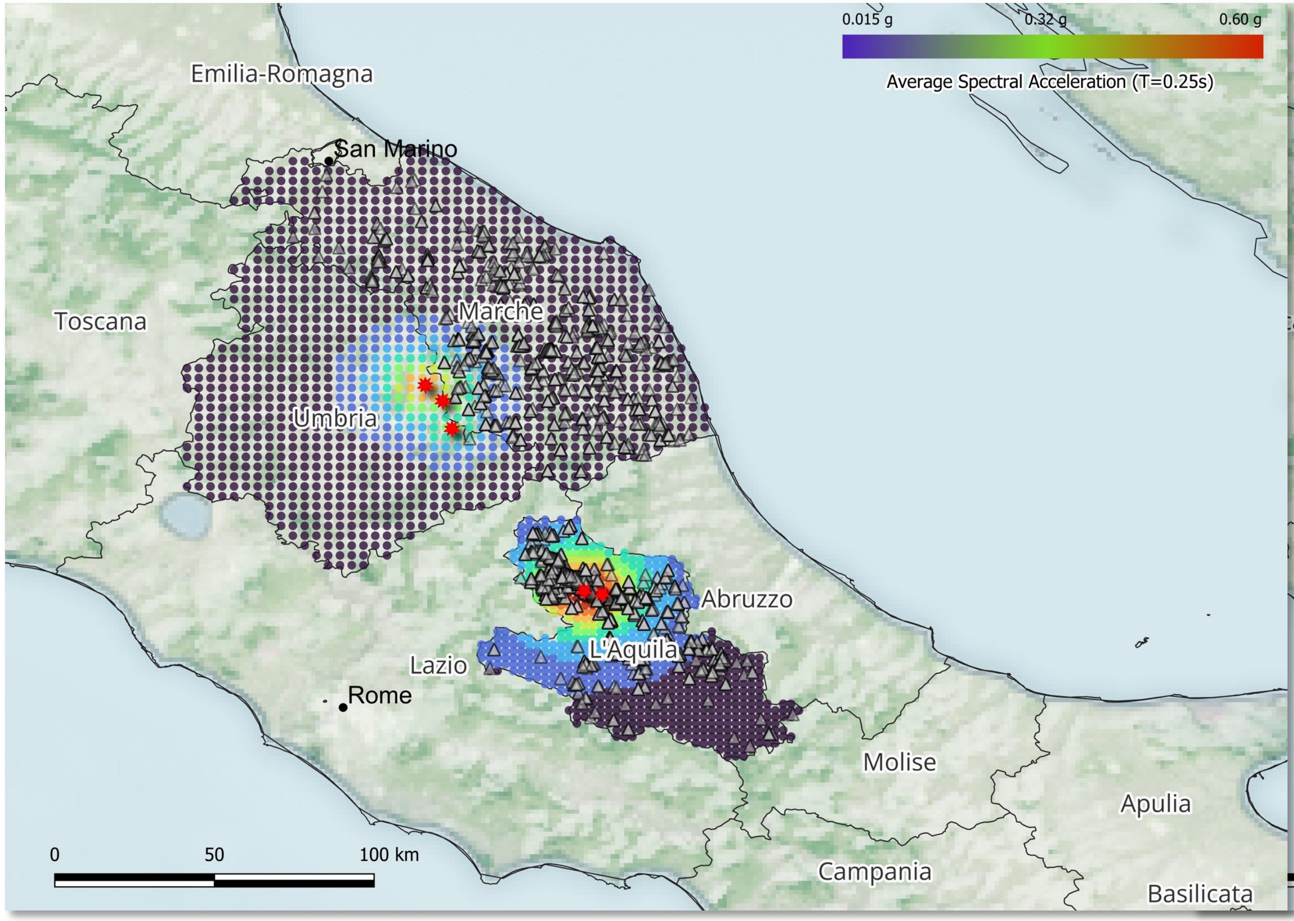




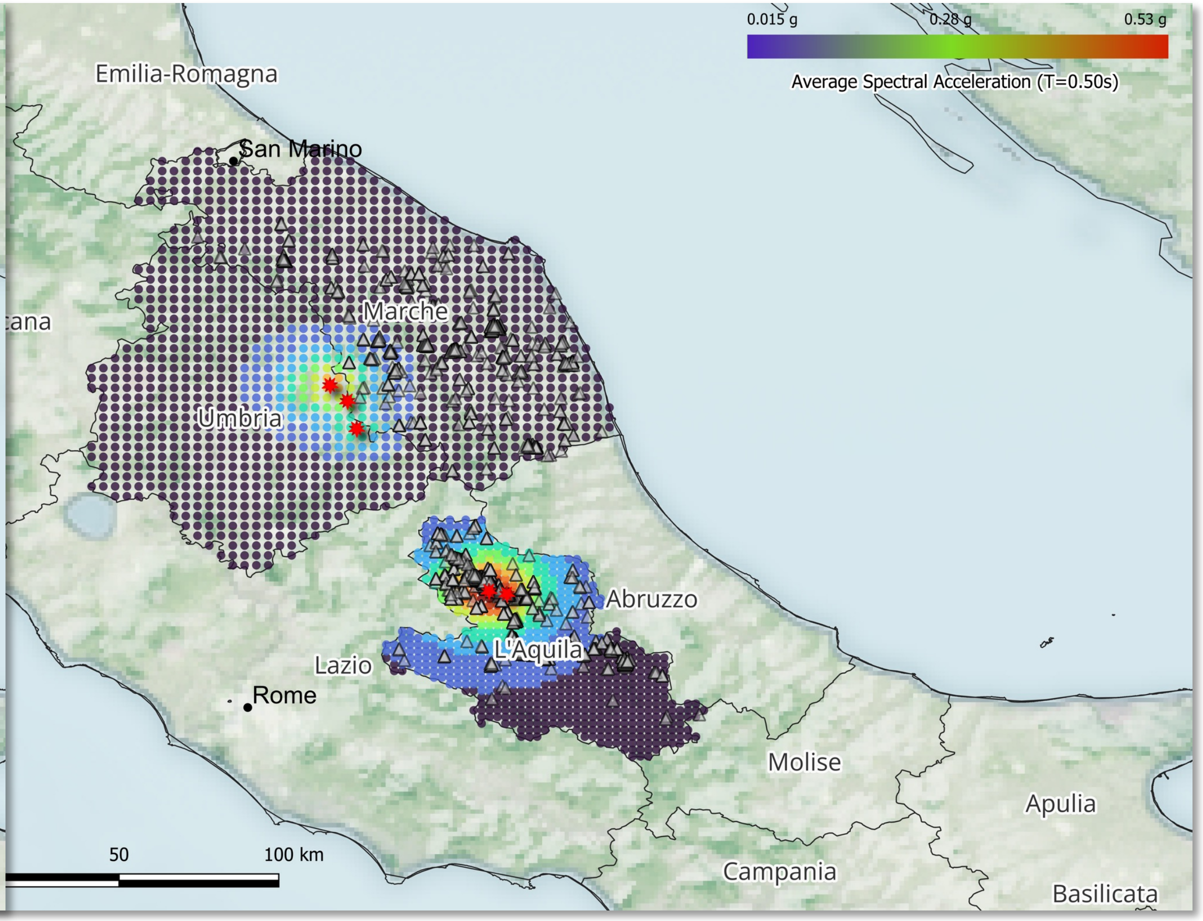
Period of Construction | Number of Storeys | Damage States | Inspected Building Locations

Sa_{avg}–based Ground-Motion Fields

EUCENTRE
FOR YOUR SAFETY.



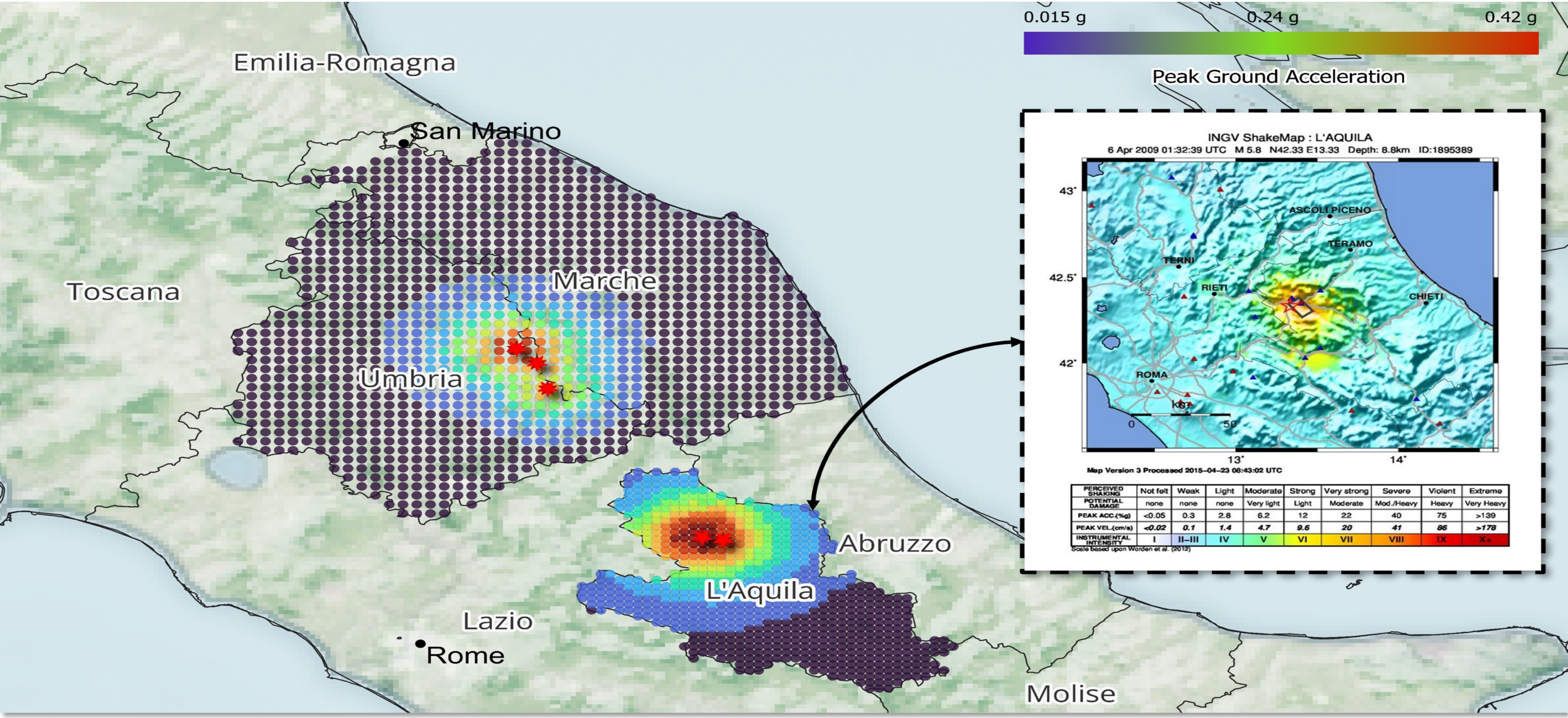
Sa_{avg} (0.25s)-based GMFs for Low-Rise Buildings



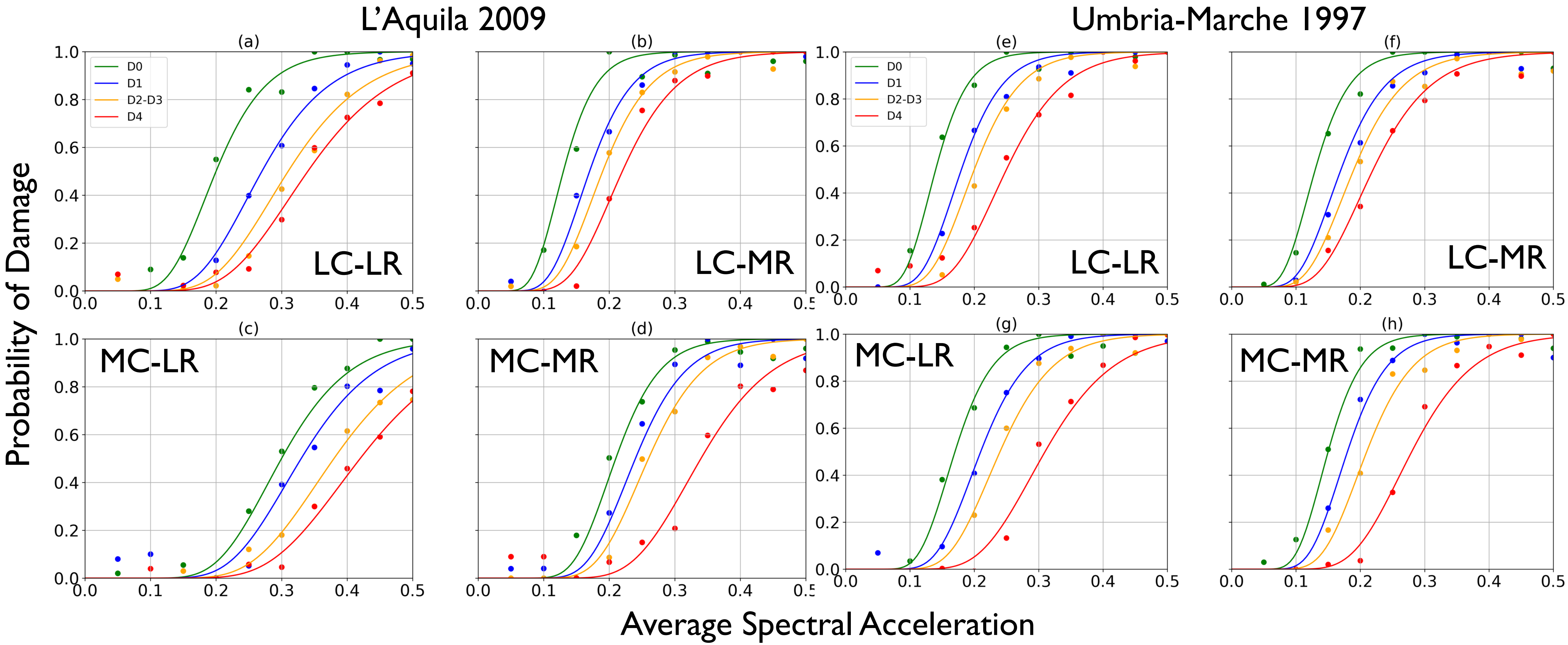
Sa_{avg} (0.50s)-based GMFs for Mid-Rise Buildings

Ground-Motion Fields Validation

EUCENTRE
FOR YOUR SAFETY.

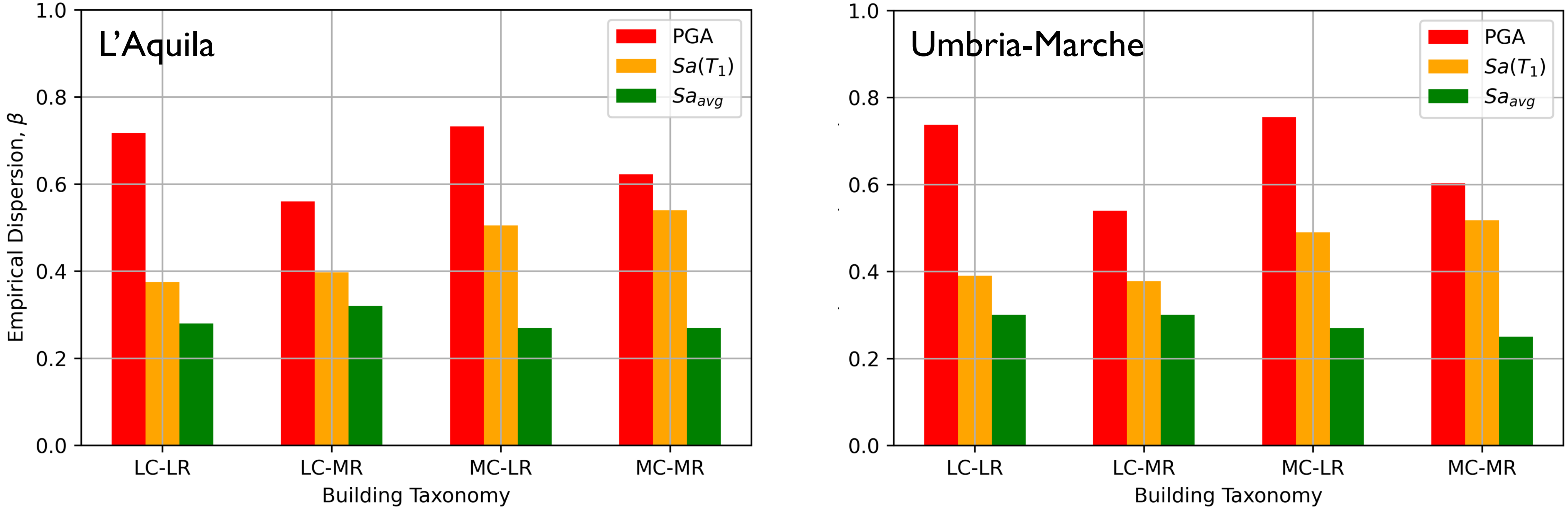


Empirical Fragility Functions



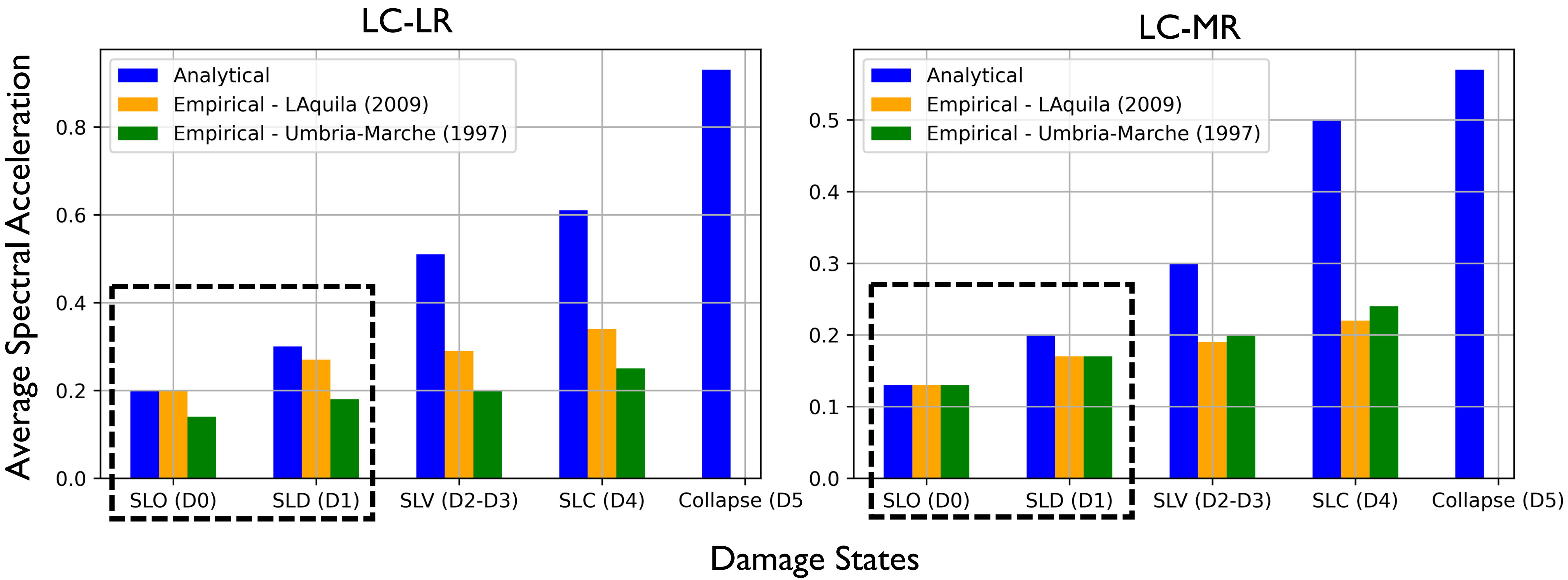
Best way to characterise damage?

- The **dispersion values** associated with the fitted empirical Sa_{avg}-based fragilities were compared to dispersions considering conventional IMs such as $Sa(T_1)$ and PGA



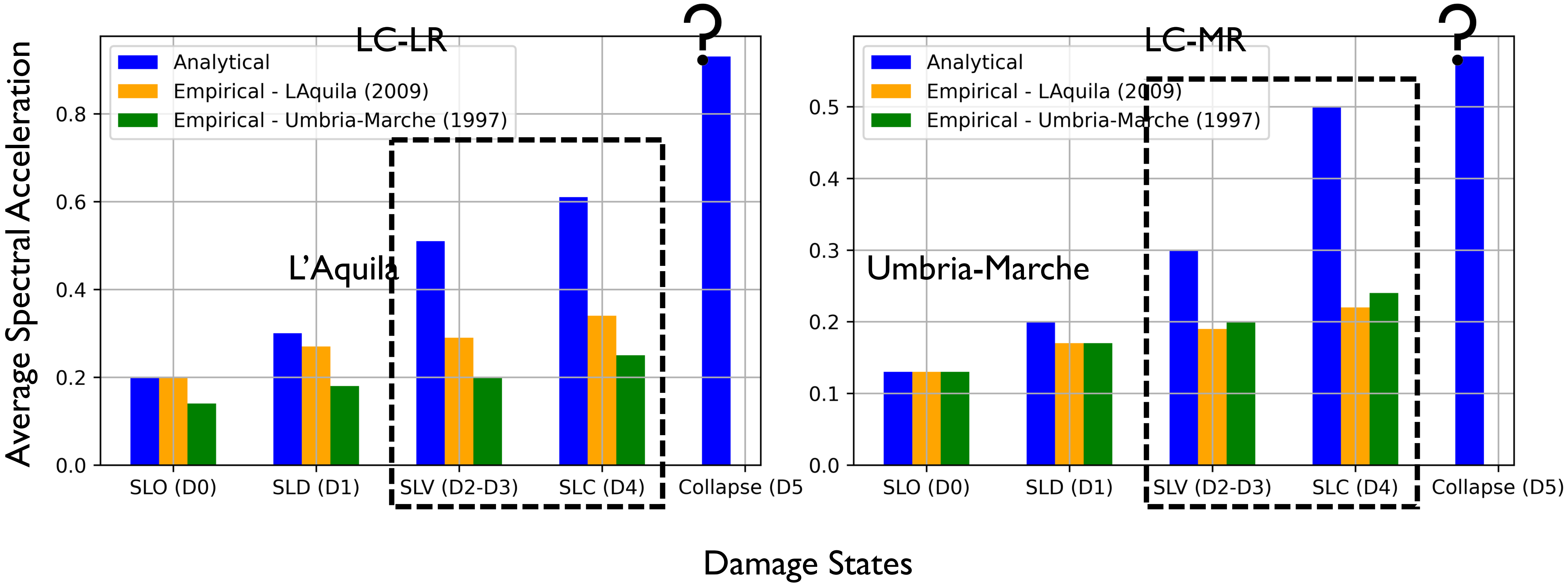
Analytical versus Empirical?

- A good match between analytical and empirical FFs with regards to the **initial damage states** (i.e., operational and damage limitation)



Analytical versus Empirical?

- For the **near-collapse damage states**, the analytical fragilities tend to consistently overestimate the median intensities with respect to the empirical observations
- Our analytical models are either too strong, or our empirical data is too conservative



Summary and future possibilities

EUCENTRE
FOR YOUR SAFETY.

- This presentation has focused on the seismic vulnerability of the built environment
- A powerful tool **BED: Simulated Design** was presented help recreate designs and numerically model existing structures for risk analysis
- A recent example application of this to compare and evaluate empirical and analytical fragility functions was carried out
- This can be extended to losses and other impacts to model vulnerability
- With modest modifications, this can be extended to other contexts: tsunami, wind, etc.
- Overall aim is to make these tools available and integrate them on the broader sphere of EPOS

Built Environment Data

www.builtenvdata.eu

EPOS
EUROPEANPLATEOBSERVINGSYSTEM

Acknowledgements: The work presented here was a combination of simultaneous efforts at the Eucentre Foundation, IUSS Pavia, University of Porto and the GEM Foundation. Special thanks to the work carried out by Volkan Ozsarac, Davit Shahnazaryan, Al Mouayed Nafeh and the input of Helen Crowley, Xavier Romao and Rui Pinho