ECCOMAS Thematic Conference

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10th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2025)

June 14 – 18, 2025, Rhodes, Greece

A New Global Vulnerability Database for Improved Regional Seismic Risk Assessments

Karim Aljawhari[1,2], Al Mouayed Bellah Nafeh[1], Vitor Silva[1]

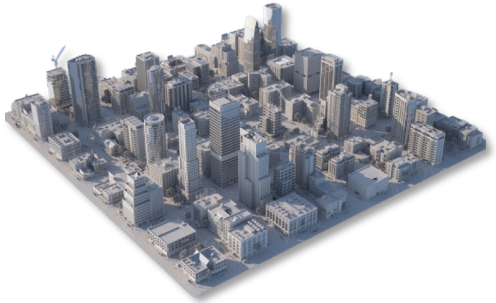
[1]Global Earthquake Model Foundation (GEM), Pavia, Italy

[2]University College London (UCL), UK

GEM GLOBAL EARTHQUAKE MODEL working together to assess risk

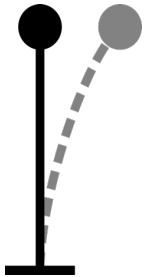
Challenges & Research Needs

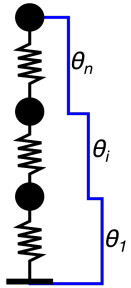
- Comprehensive databases for seismic vulnerability are limited
  - Large variety of building types
  - Different in materials, code level, ductility, strength, etc.



- Simplistic Models (Single-degree-of-freedom SDOF)

Single-degree-of-freedom (SDOF)





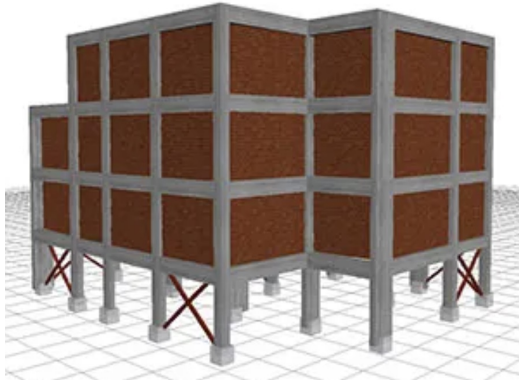
Interstorey Demands

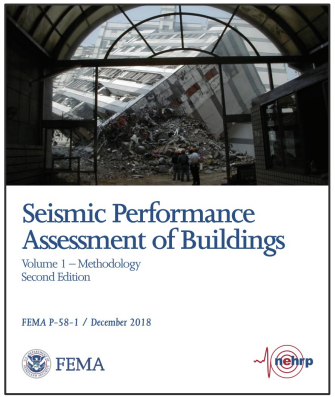


Higher-mode effects

Challenges & Research Needs

- More sophisticated models are computationally expensive

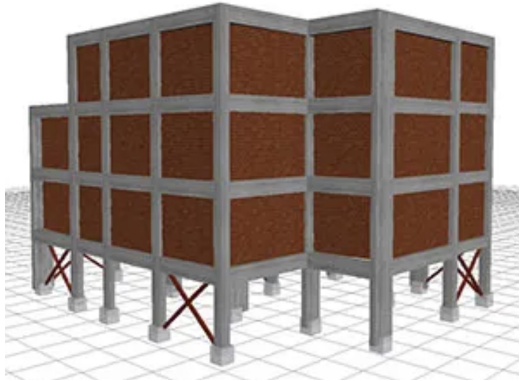


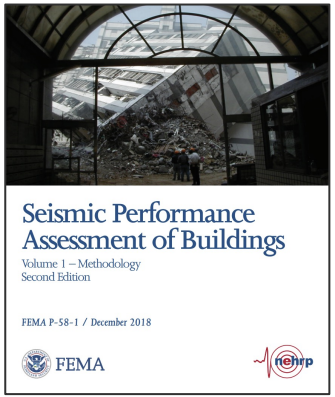


- ✓ Comprehensive vulnerability model database
- ✓ Addresses the shortcomings of SDOF models
- ✓ Simple

Challenges & Research Needs

- More sophisticated models are computationally expensive





- ✓ Comprehensive vulnerability model database
- ✓ Addresses the shortcomings of SDOF models
- ✓ Simple, **but not too simple….**
- ✓ An **open-source toolkit** that models, analyzes, and generates outputs

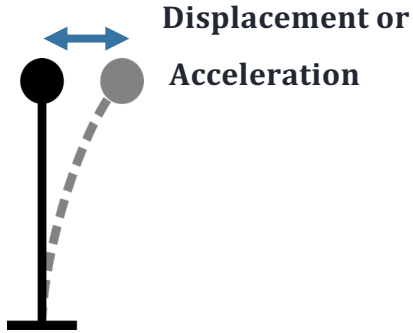
GEM's New Global Vulnerability Model

Step 1: Building Class Idealisation and Modelling

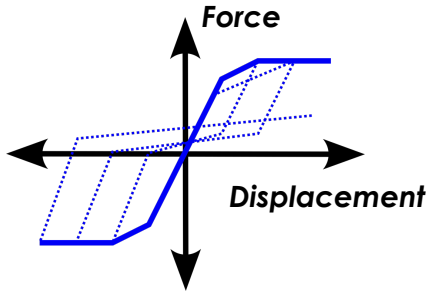
- **We did not start from scratch!**
- We started from our first Global Vulnerability Database by **Martins and Silva (2021)**
- Composed of Single-degree-of-freedom (SDOF) models
- Started with over 500 building classes, later expanded to 1400



Building Class



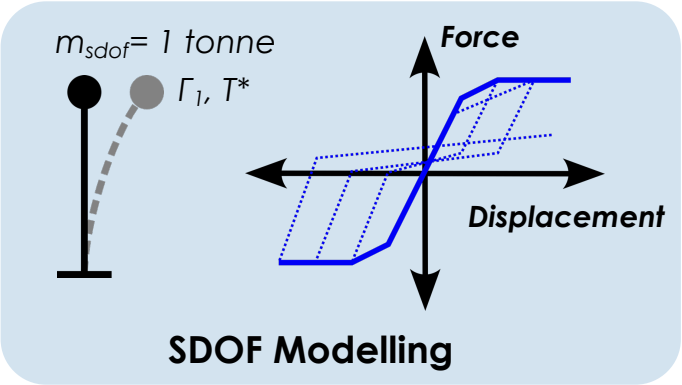
SDOF



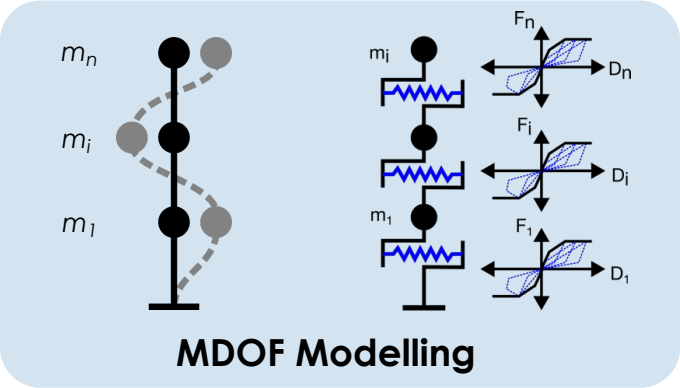
Force-displacement

Step 1: Building Class Idealisation and Modelling

- Use the capacity curves associated with each building class to build **a multi-degree-of-freedom (MDOF) "stick-and-mass"** model
- Lumped masses connected by shear springs representing storey behaviour
- Each spring models **Storey drift** vs. **Storey Shear**



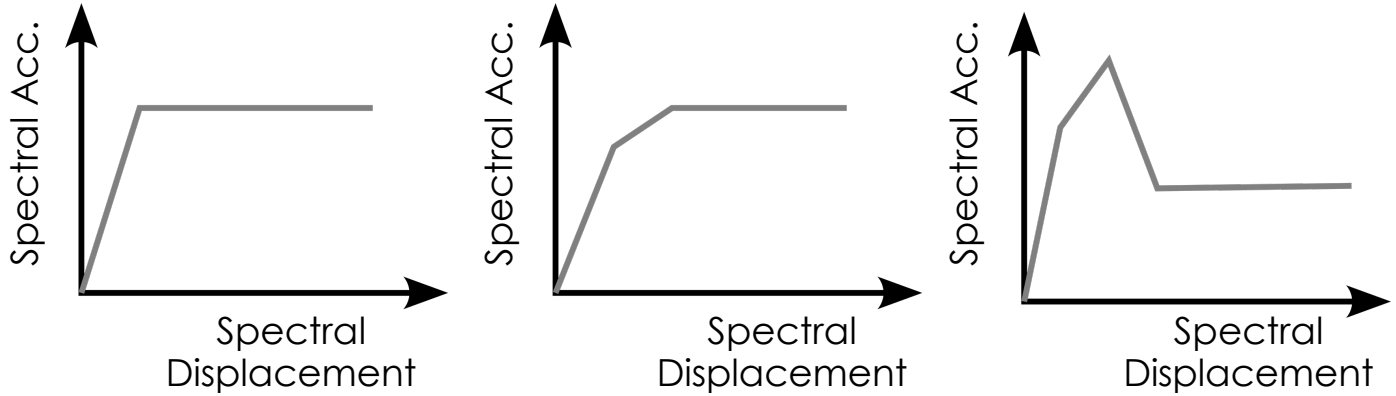
SDOF Modelling



MDOF Modelling

Step 1: Building Class Idealisation and Modelling

- Start with the capacity curves (**Spectral displacement** vs. **Spectral acceleration**)

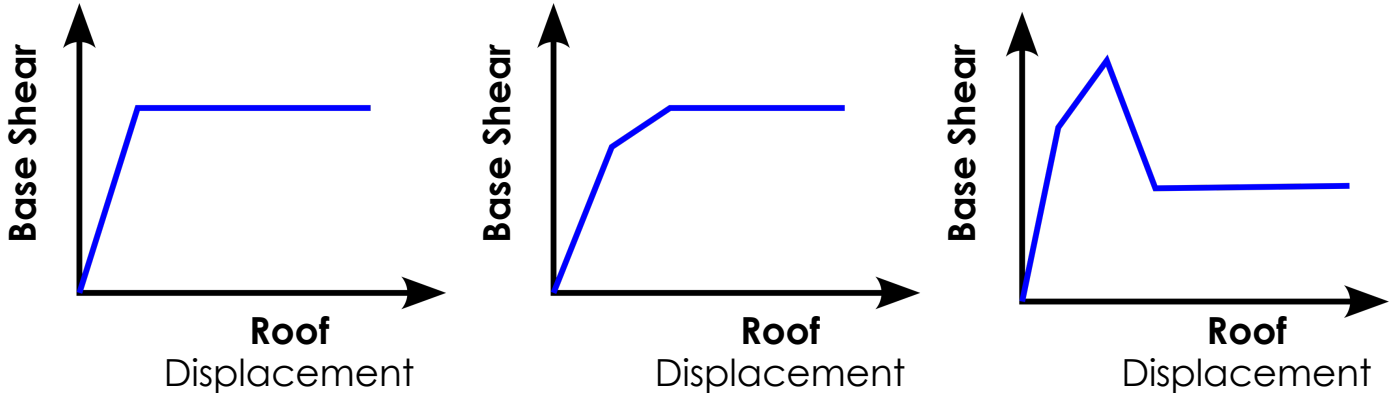


- $\text{Roof Disp} = \text{SD} \times \Gamma$
- $\text{Base Shear} = \text{SA} \times \Gamma \times \text{m}_{\text{SDOF}}$

- ***SD***: *Spectral Displacement*
- ***SA***: *Spectral Acceleration*
- ***Γ***: *Modal Transformation Factor*
- m_{sdof}: *Equivalent SDOF Mass*

Step 1: Building Class Idealisation and Modelling

- Convert them to **pushover curves** (**Roof Displacement** vs. **Base Shear**)



- Roof Disp $= SD \times \Gamma$
- Base Shear $= SA \times \Gamma \times m_{SDOF}$

- ***SD***: *Spectral Displacement*
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Step 1: Building Class Idealisation and Modelling

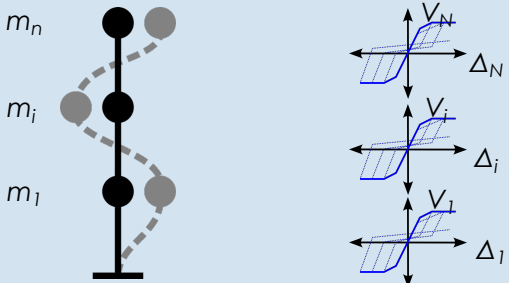
- Derive **Storey Drift** vs. **Storey Shear** on the basis of modal information

$$\text{Story Shear} = \frac{\sum_{j=i}^{n_s} \phi_{1,i}\, m_i}{\sum_{k=1}^{n_s} \phi_{1,i}\, m_i} \text{ Base Shear}$$

$$\text{Story Drift} = \left(\phi_{1,i} - \phi_{1,i-1}\right) \text{Roof Displacement}$$



Building Class

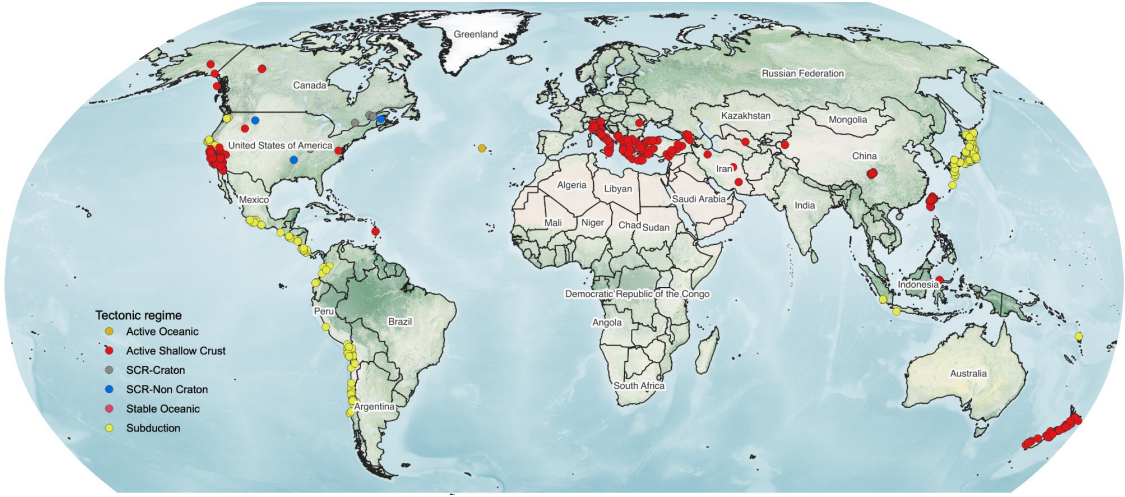


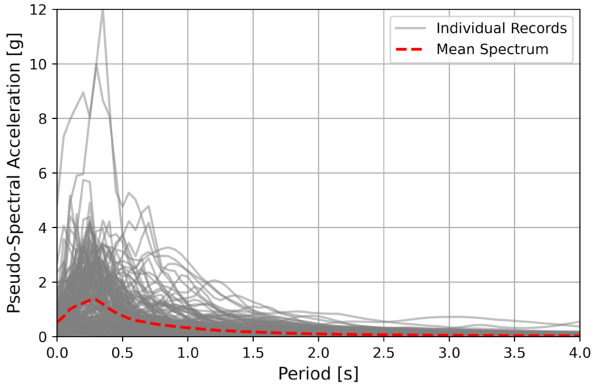
MDOF Idealisation

- m_{mdof}: *Equivalent MDOF Mass*
- m_i: *Mass at Floor i*
- ϕ_1: *First-mode Shape*

Step 2: Ground-Motion Characterisation

- Development of a global ground-shaking set of **700 records**
- Various characteristics and tectonic settings:
  - ✓ Frequency content
  - ✓ Duration
  - ✓ Active shallow crust
  - ✓ Subduction zones
  - ✓ Stable continental regions
- Source databases: NGA-West, NGA-East, Kik-Net, NGA-Sub



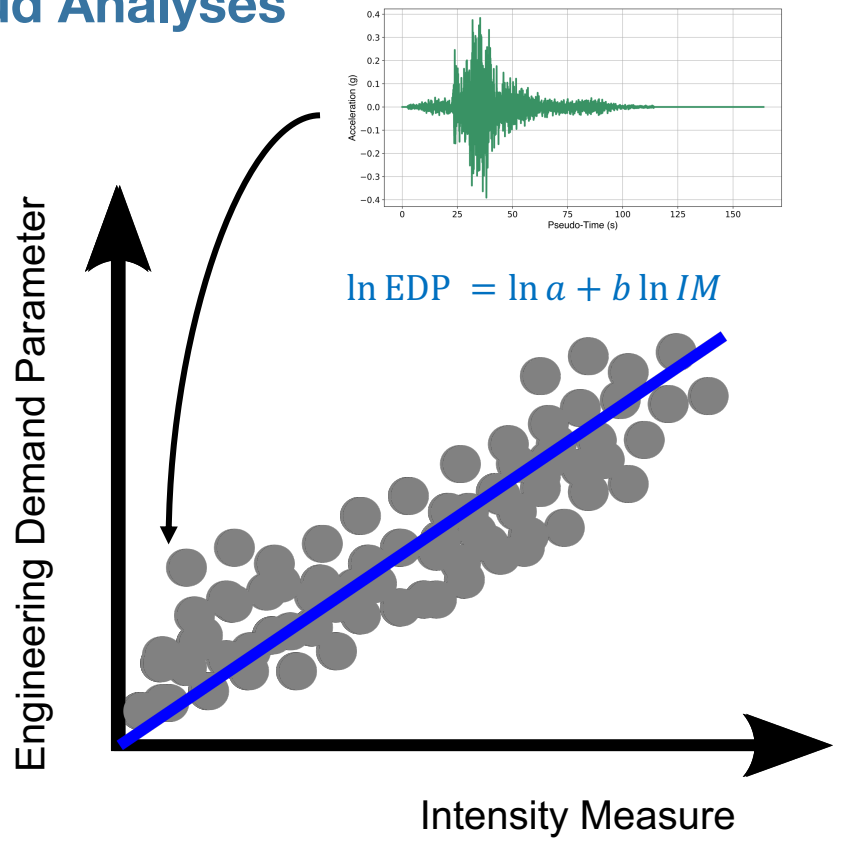


Step 3: Nonlinear Assessment via Cloud Analyses

- Nonlinear time-history analysis procedure
- **Large set of "unscaled" earthquake records** covering all structural responses

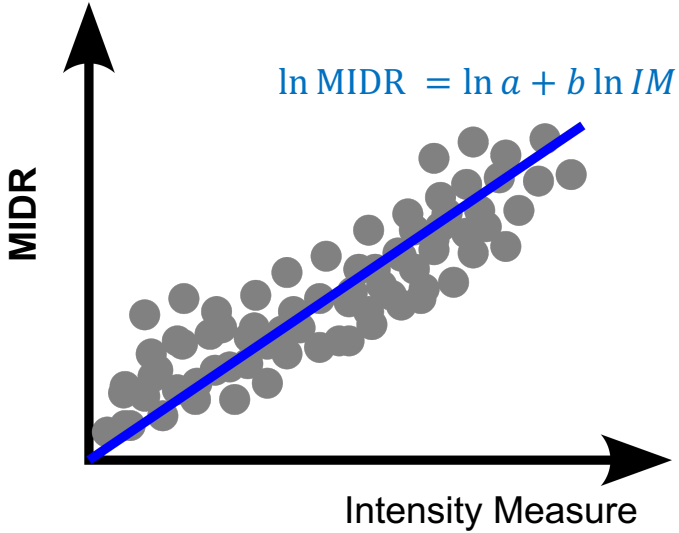
$$\ln EDP = \ln a + b \ln IM$$

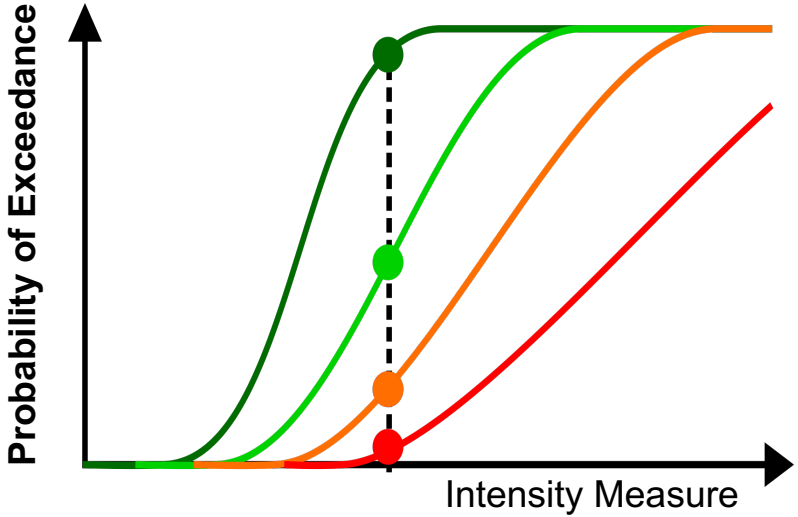
- $\boldsymbol{EDP}$: Engineering demand parameter
- $\boldsymbol{IM}$: Intensity measure
- **a, b**: regression coefficients
- $\boldsymbol{\sigma_{ln\ EDP}}$: dispersion



Step 4: Structural Fragility and Vulnerability

- Structural damage is inferred via the **maximum interstorey drift ratio (MIDR)**
- Fragility functions express the **probability of exceeding a Damage State (DS)**, given the ground-shaking intensity

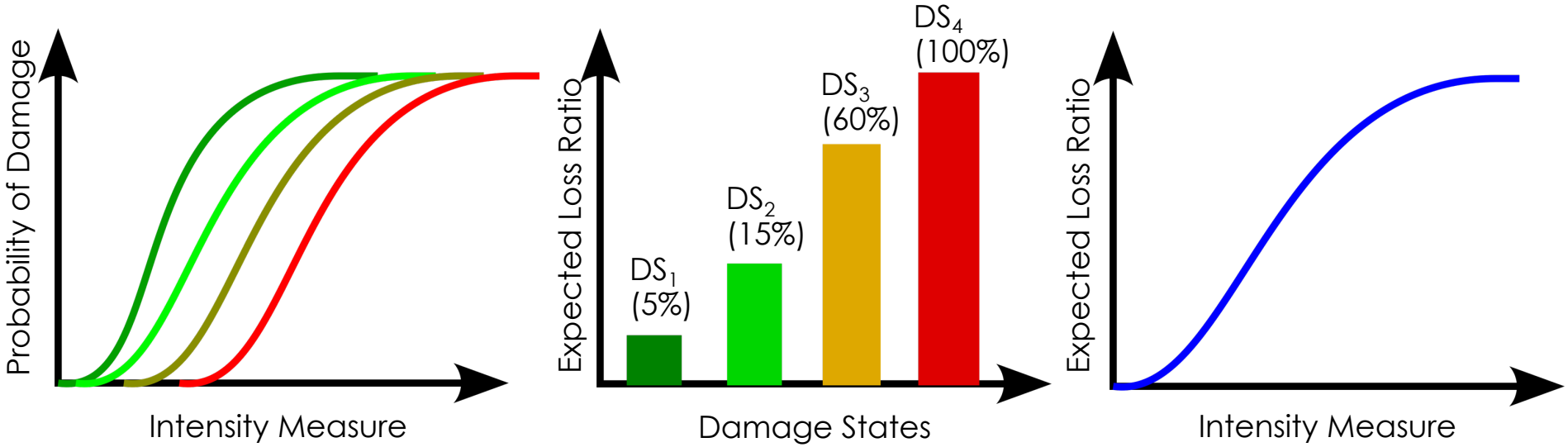




Step 4: Structural Fragility and Vulnerability Functions

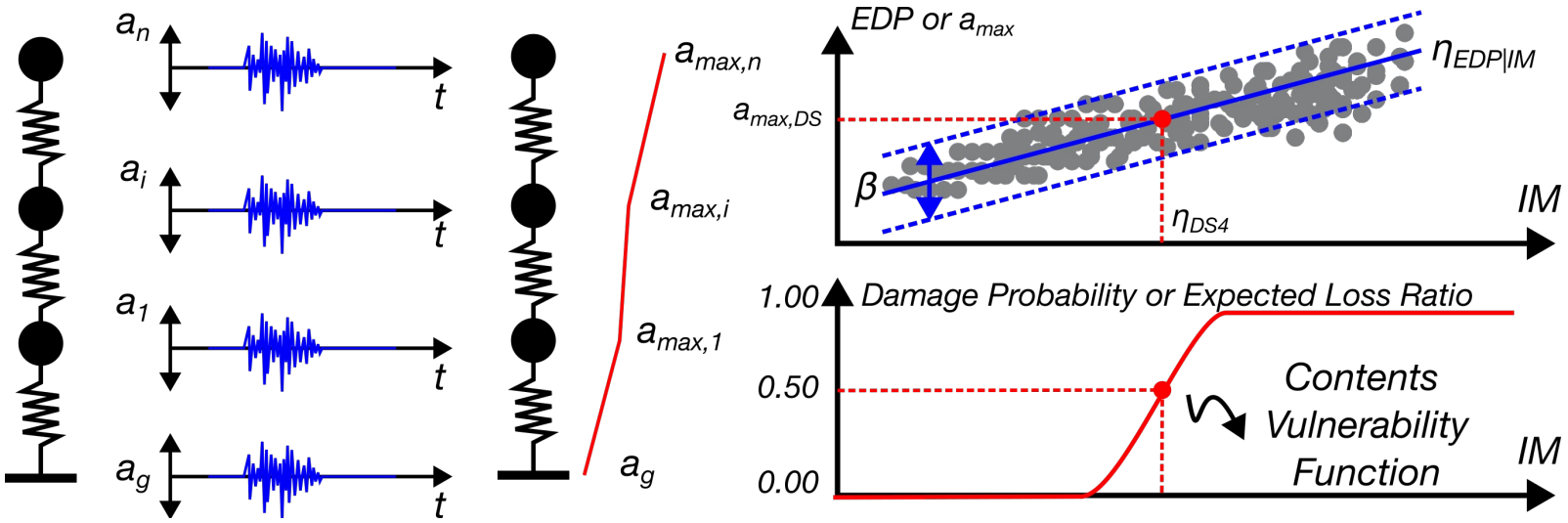
- Vulnerability model express the expected **Loss Ratio** vs ground-shaking **Intensity**
- Combine fragility curves with the damage-to-loss models (a.k.a. consequence)

$$E[LR|IM] = \sum_{i=1}^{nDS} E[LR|DS = DS_i].P(DS = DS_i|IM)$$



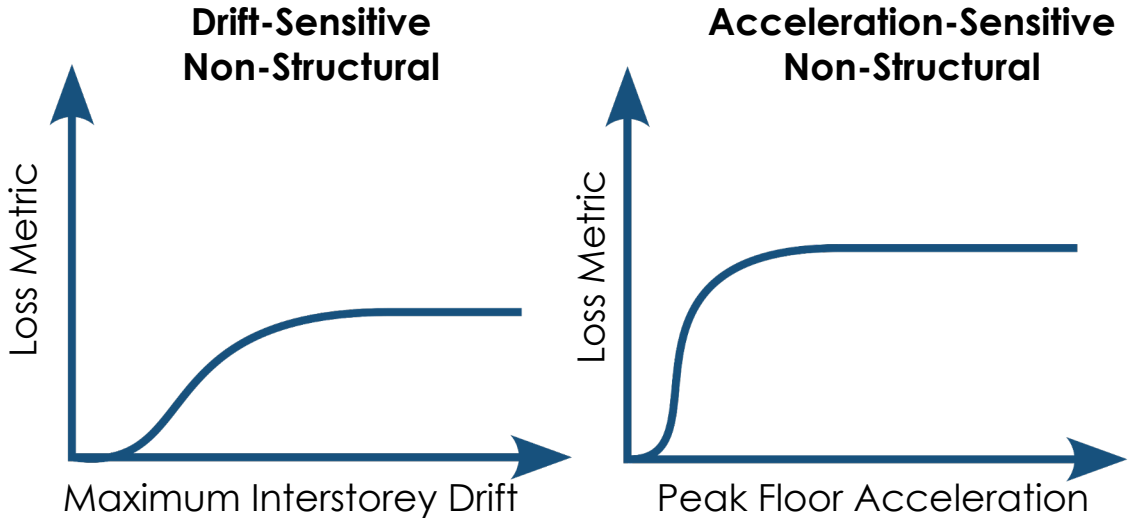
Step 5: Contents Fragility and Vulnerability Functions

- **Content damage** is inferred through **peak floor acceleration (PFA)**
- **A binary damage** system is used (undamaged or damaged/to be replaced)



Step 5: Vulnerability Analysis for Nonstructural Components

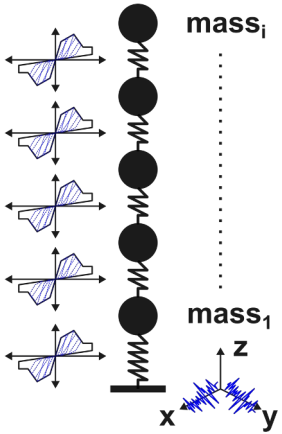
- A refined approach for quantifying non-structural loss is **story-loss functions** (**SLFs**)
- SLFs describe the expected loss **at a storey level as a function of the engineering demand parameters that trigger non-structural component damage**

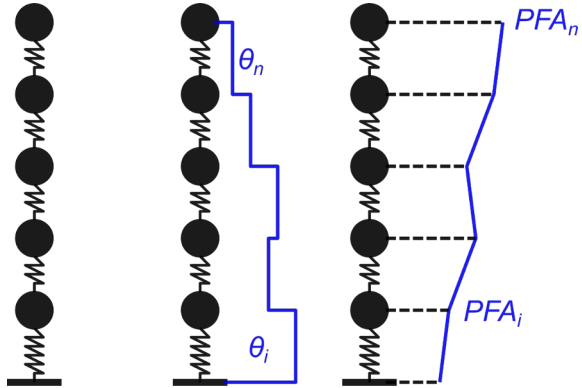


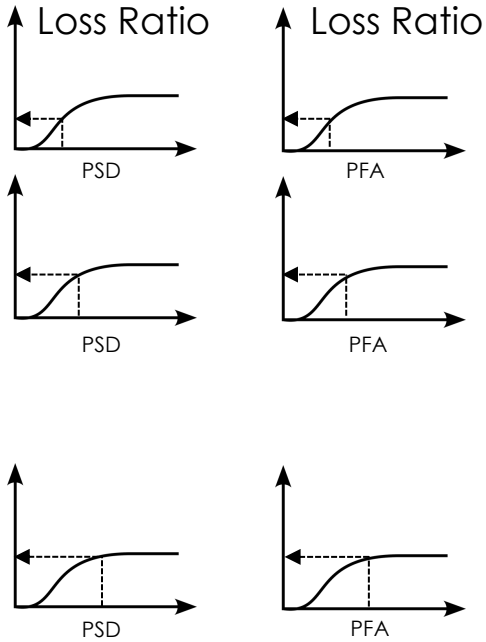
Step 5: Vulnerability Analysis for Nonstructural Components

- A refined approach for quantifying non-structural loss is **story-loss functions** (**SLFs**)
- SLFs describe the expected loss **at a storey level as a function of the engineering demand parameters that trigger non-structural component damage**









Step 5: Vulnerability Analysis for Nonstructural Components

- We need adequate **component inventory** (residential, commercial, industrial) and reasonable **component quantities**

Residential

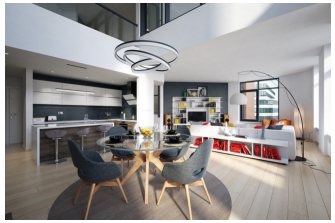


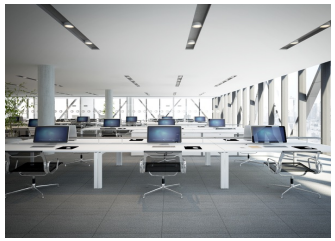
Commercial

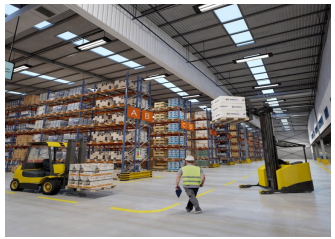


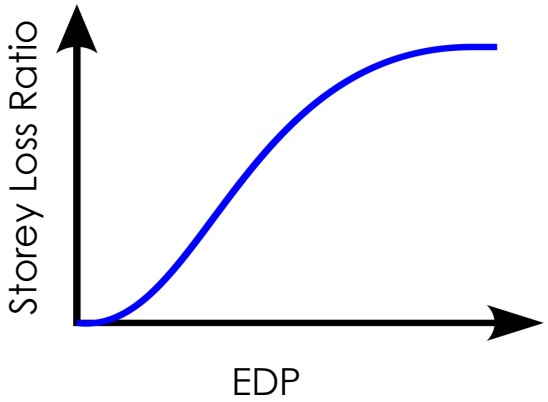
Industrial



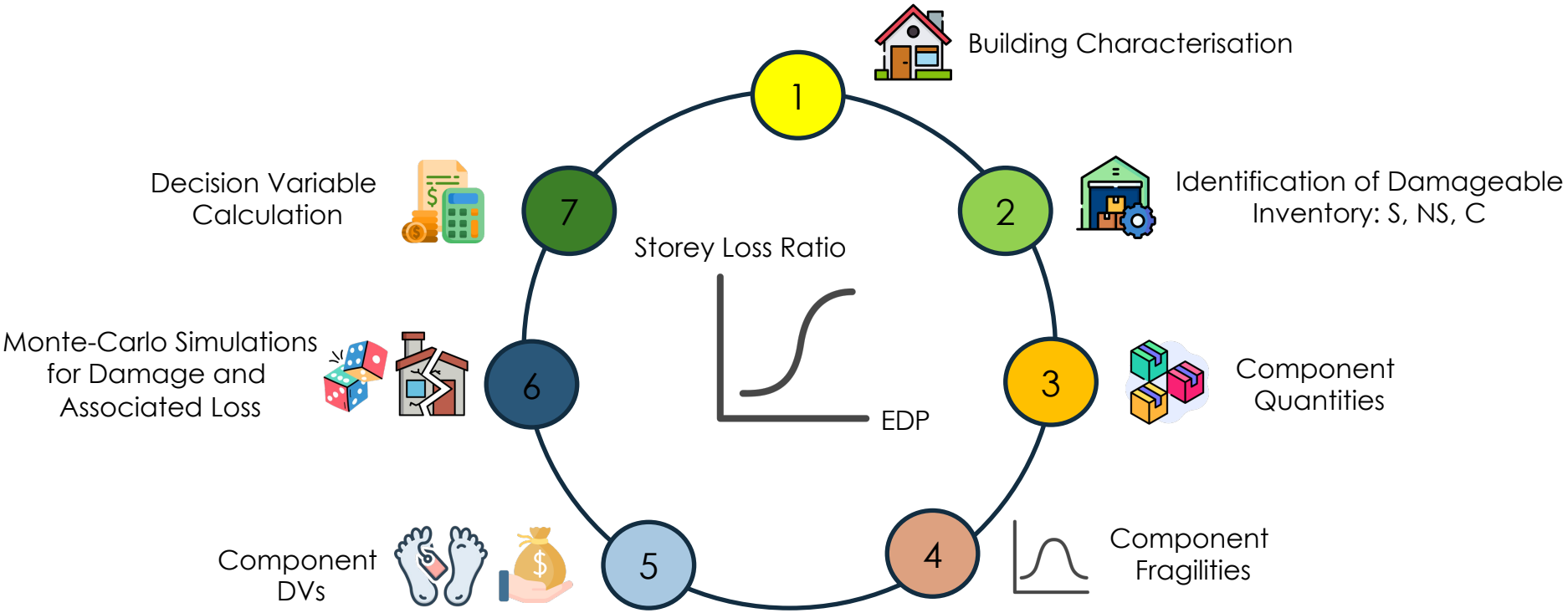




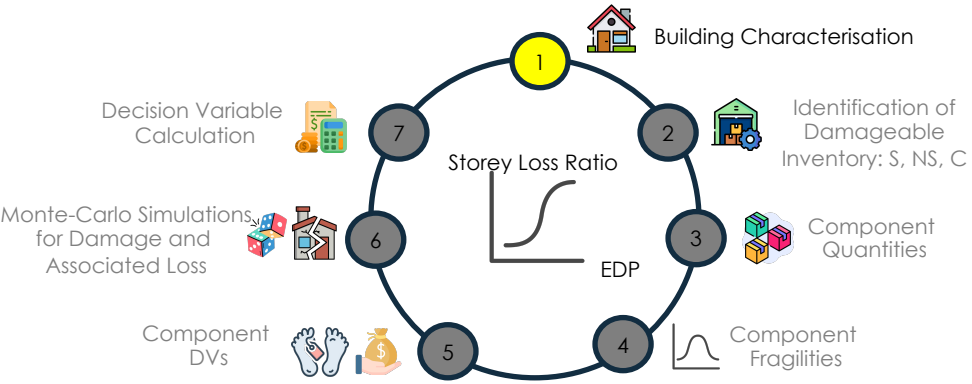




Step 5: Vulnerability Analysis for Nonstructural Components



Step 5: Vulnerability Analysis for Nonstructural Components





Reinforced Concrete



Earth Construction

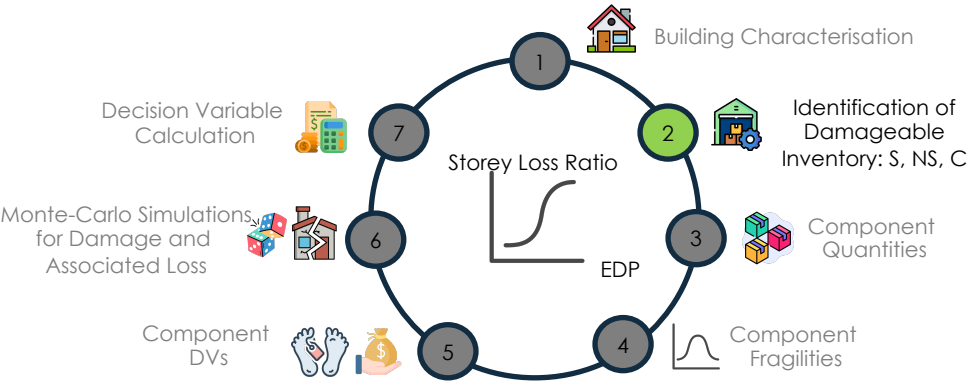


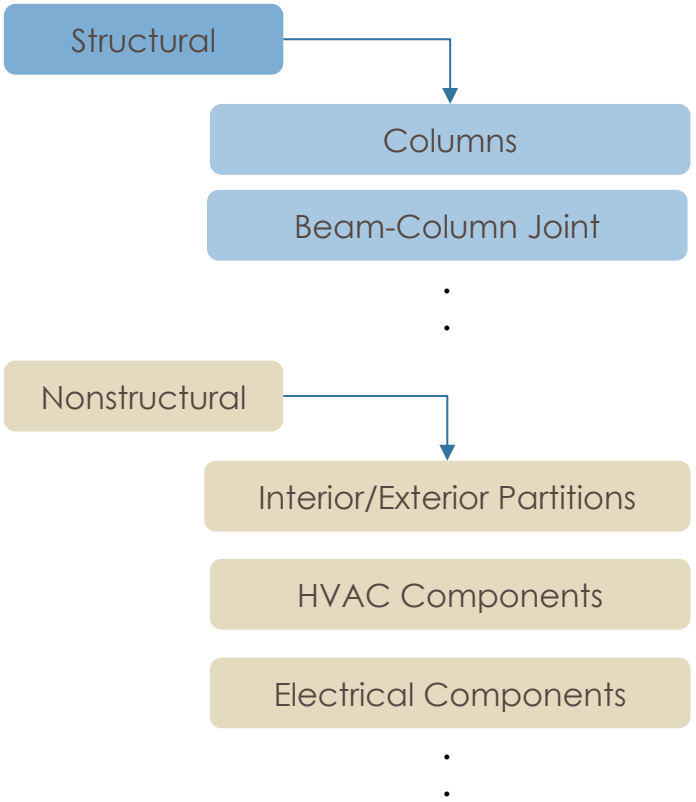
Dressed Stone MUR



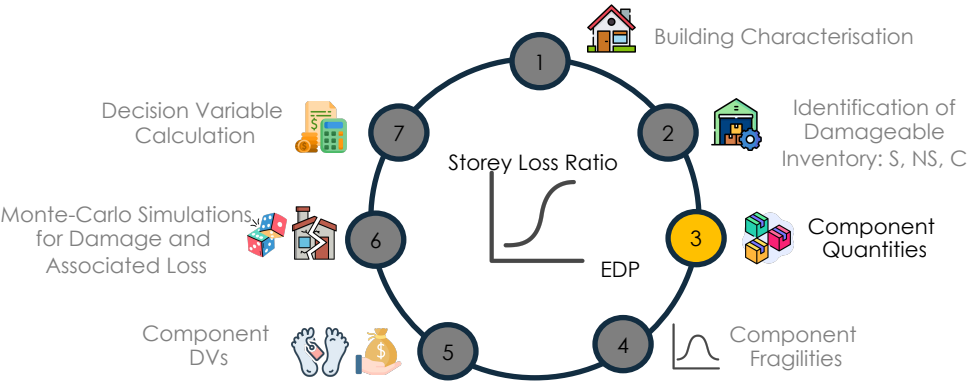
Timber

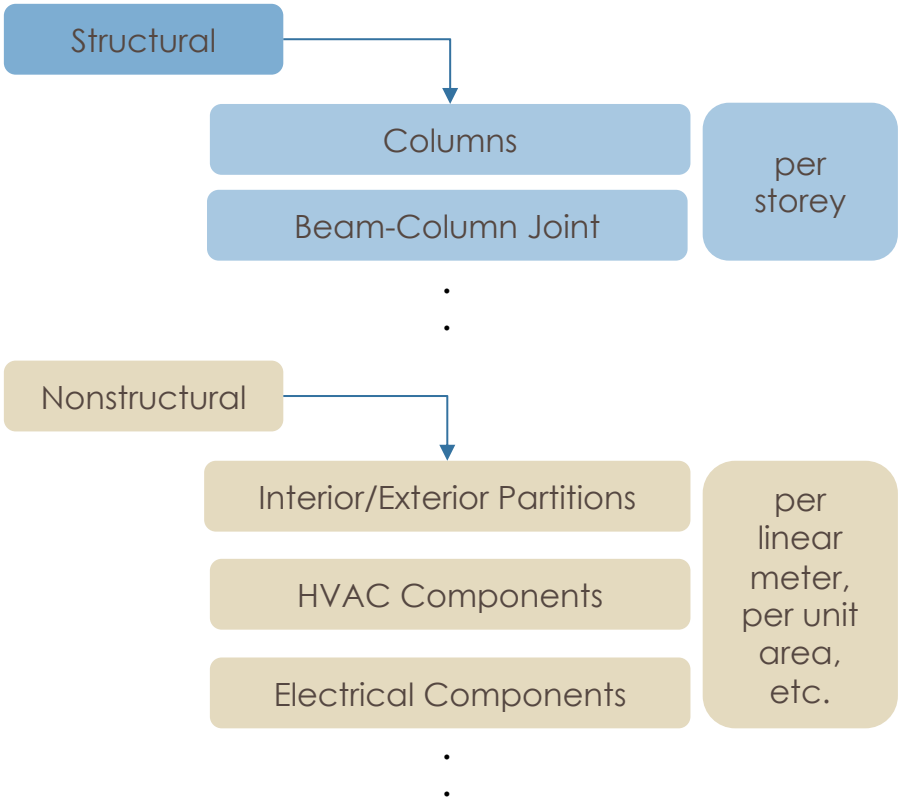
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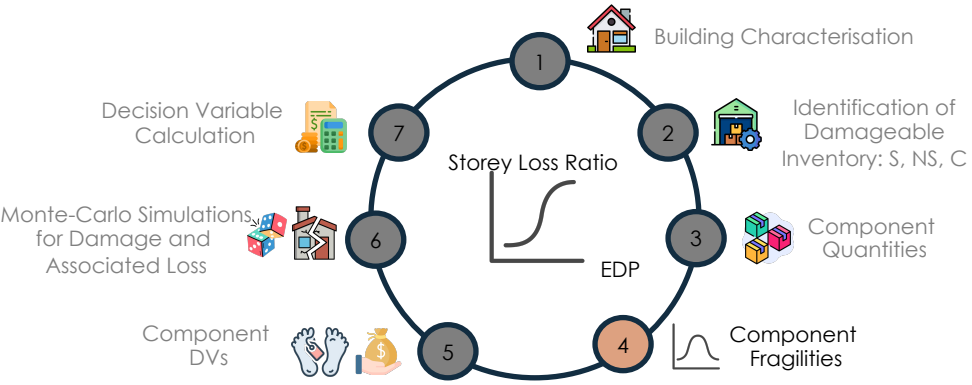


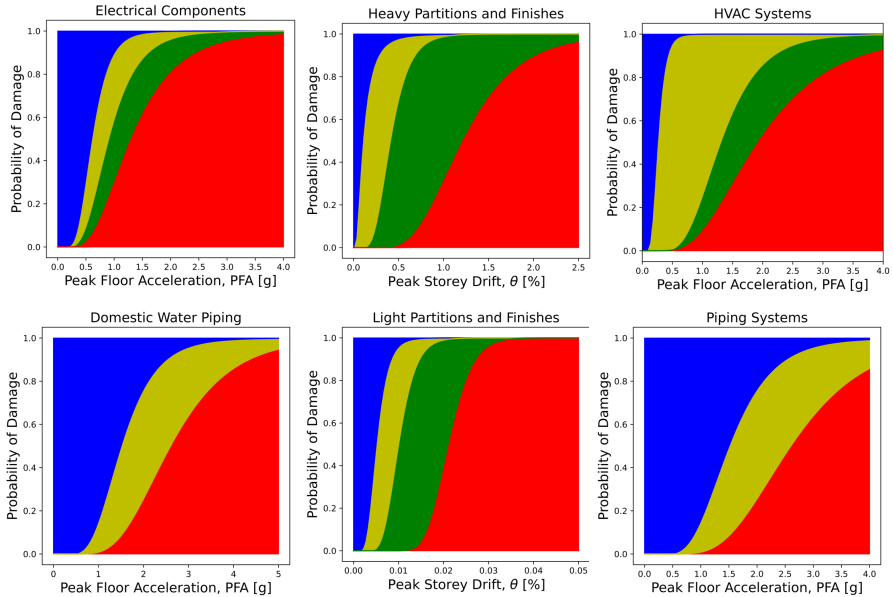
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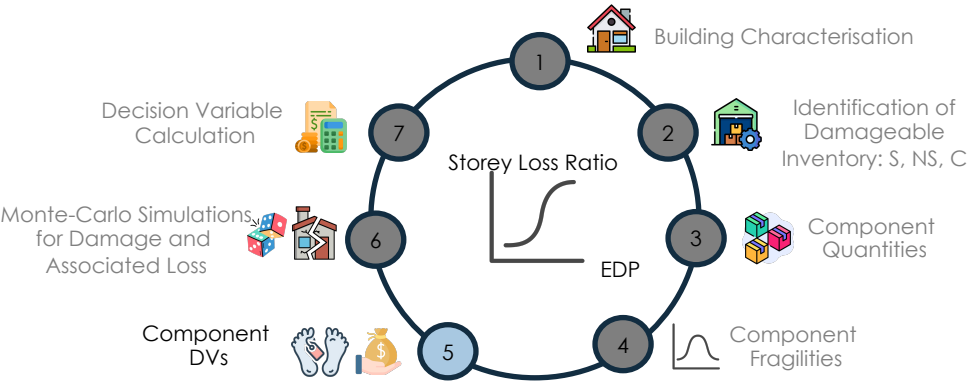


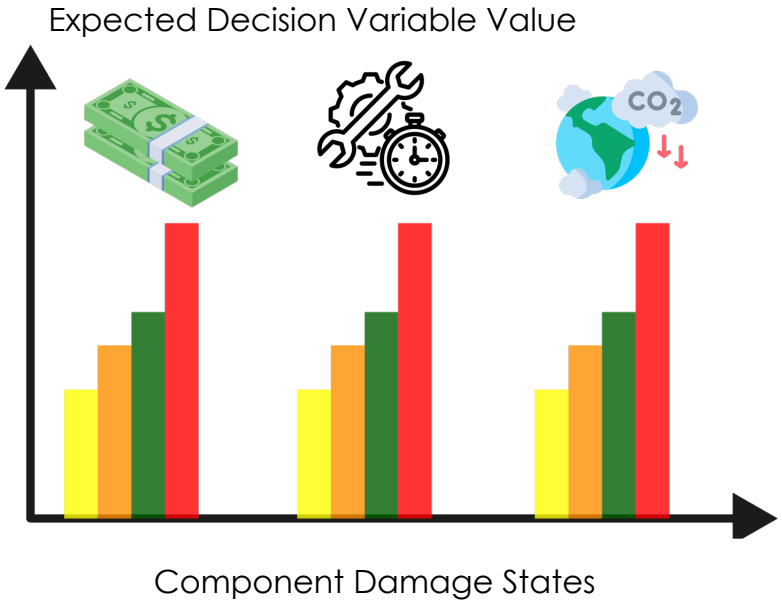
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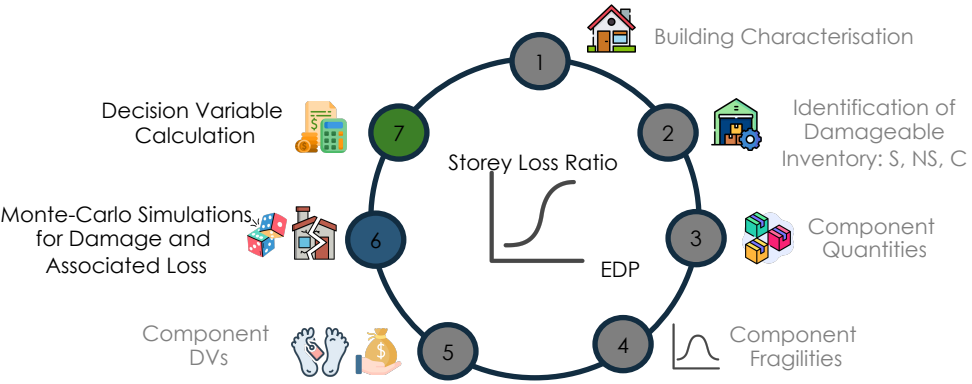


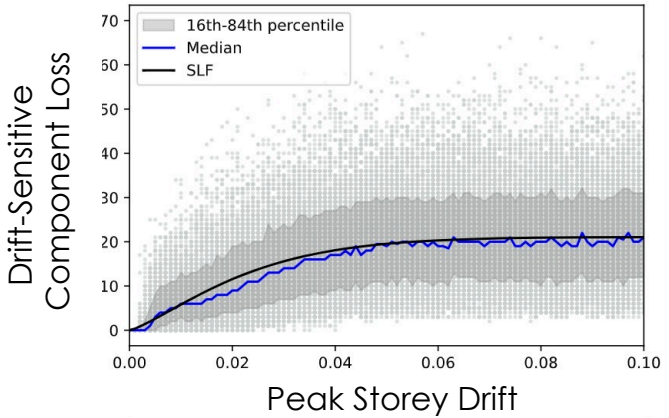
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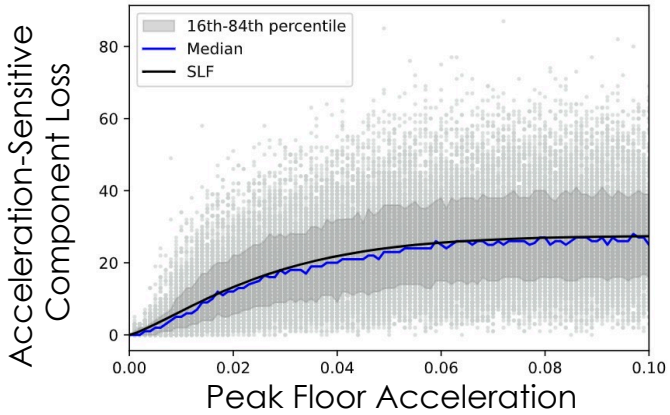




Step 5: Vulnerability Analysis for Nonstructural Components

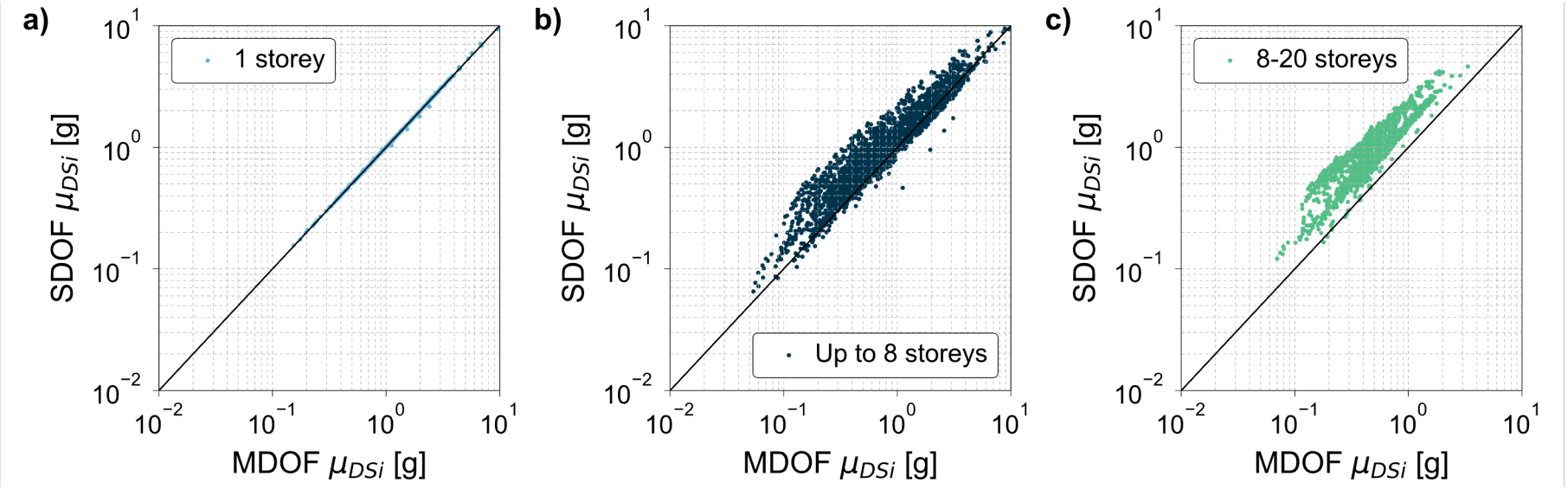






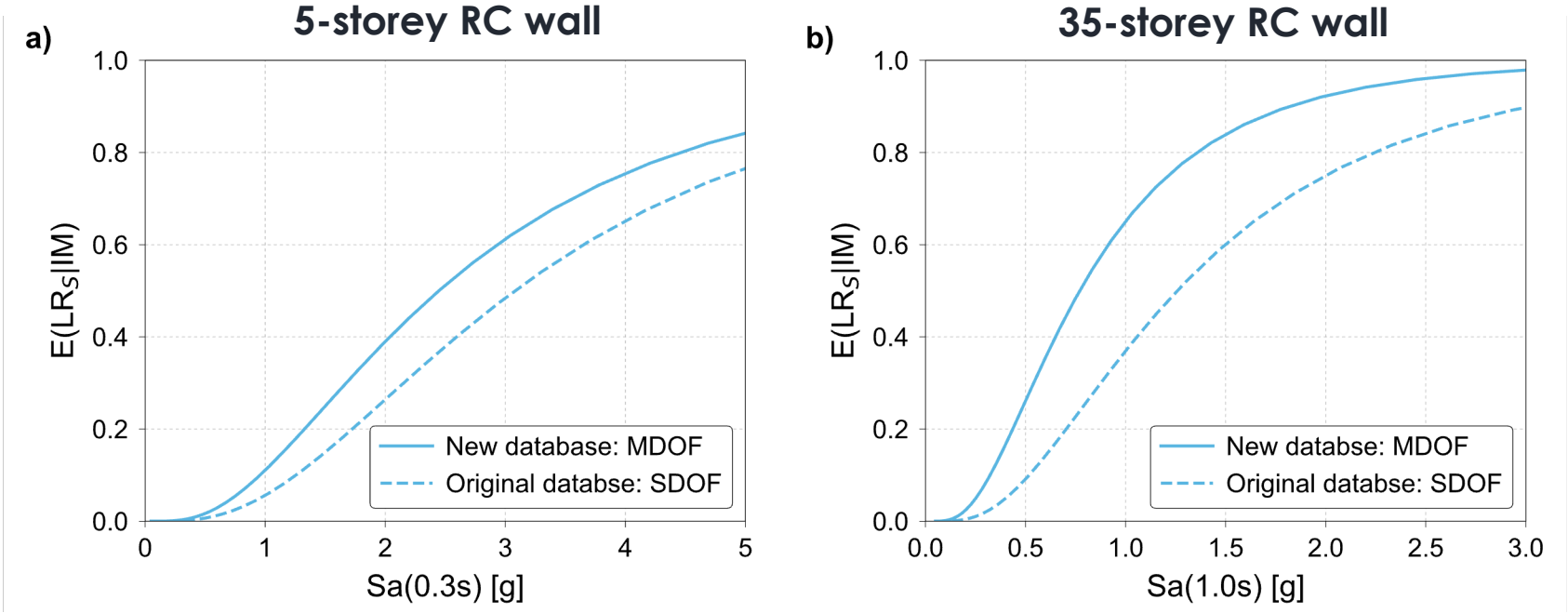
The new Global Vulnerability Model

- Fragility Median Values - comparing MDOF (x-axis) and SDOF (y-axis)



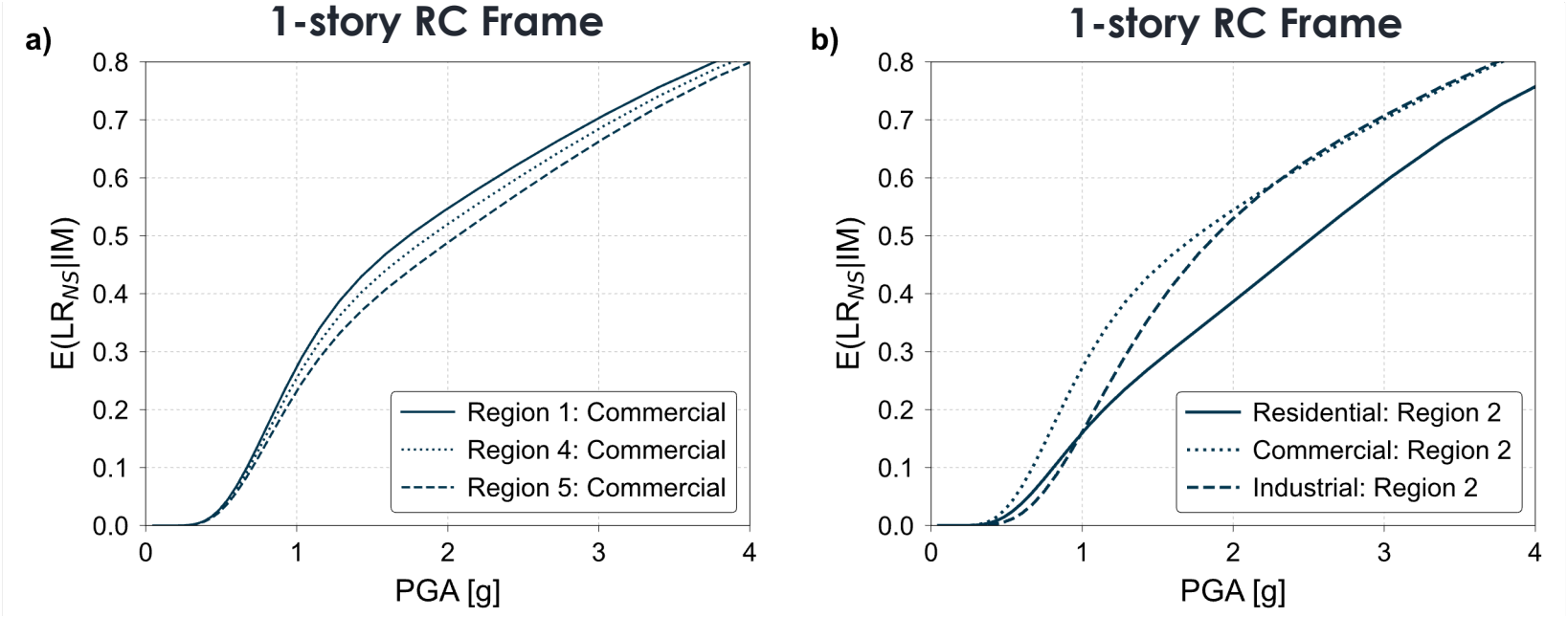
The new Global Vulnerability Model

- Vulnerability functions: **Structural Loss**



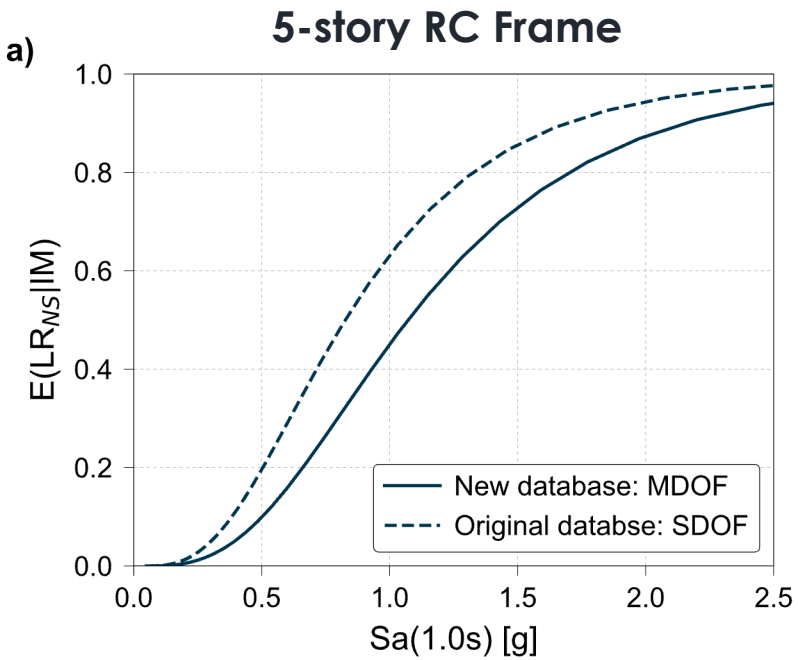
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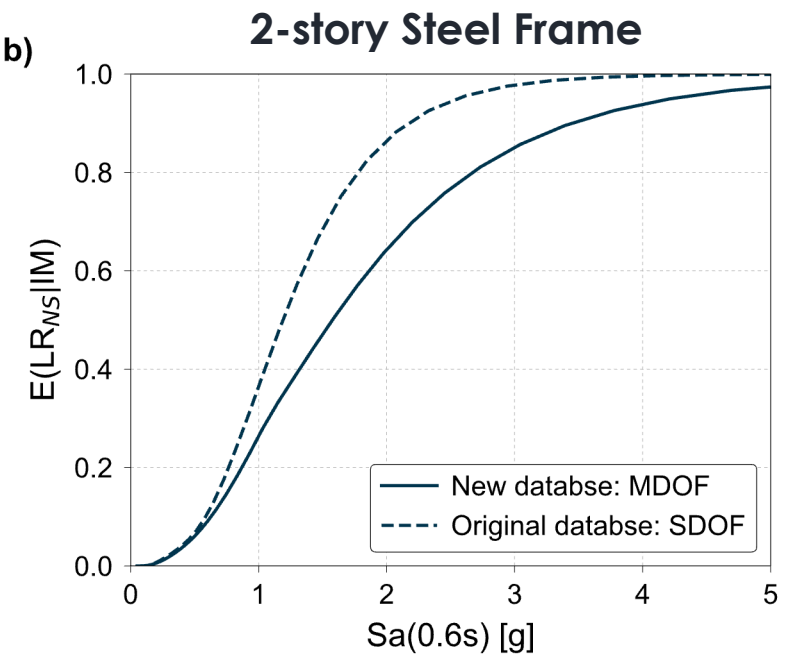
- Vulnerability functions: **Non-structural loss** (same building, different regions/occupancy)



The new Global Vulnerability Model

- Vulnerability functions: **Non-structural loss** (different building classes)





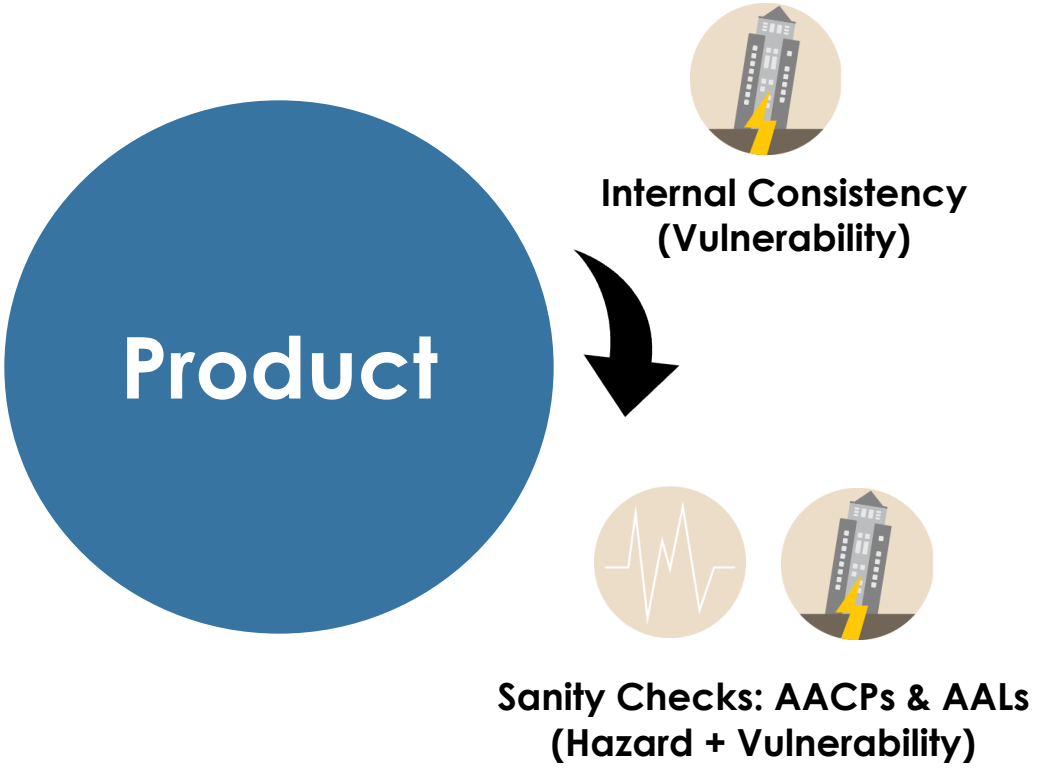
Global Vulnerability Database: Product Deployment



Internal Consistency (Vulnerability)



Global Vulnerability Database: Product Deployment



Global Vulnerability Database: Product Deployment





Internal Consistency
(Vulnerability)



Scenario Calculations: Ground-Truth
(Exposure + Vulnerability)



Sanity Checks: AACPs & AALs
(Hazard + Vulnerability)

Global Vulnerability Database: Product Deployment



Full Event-Based Risk
(Hazard + Exposure + Vulnerability)



Internal Consistency
(Vulnerability)

Product



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Global Vulnerability Database: Product Deployment



Full Event-Based Risk
(Hazard + Exposure + Vulnerability)



Internal Consistency
(Vulnerability)

Deploy Product



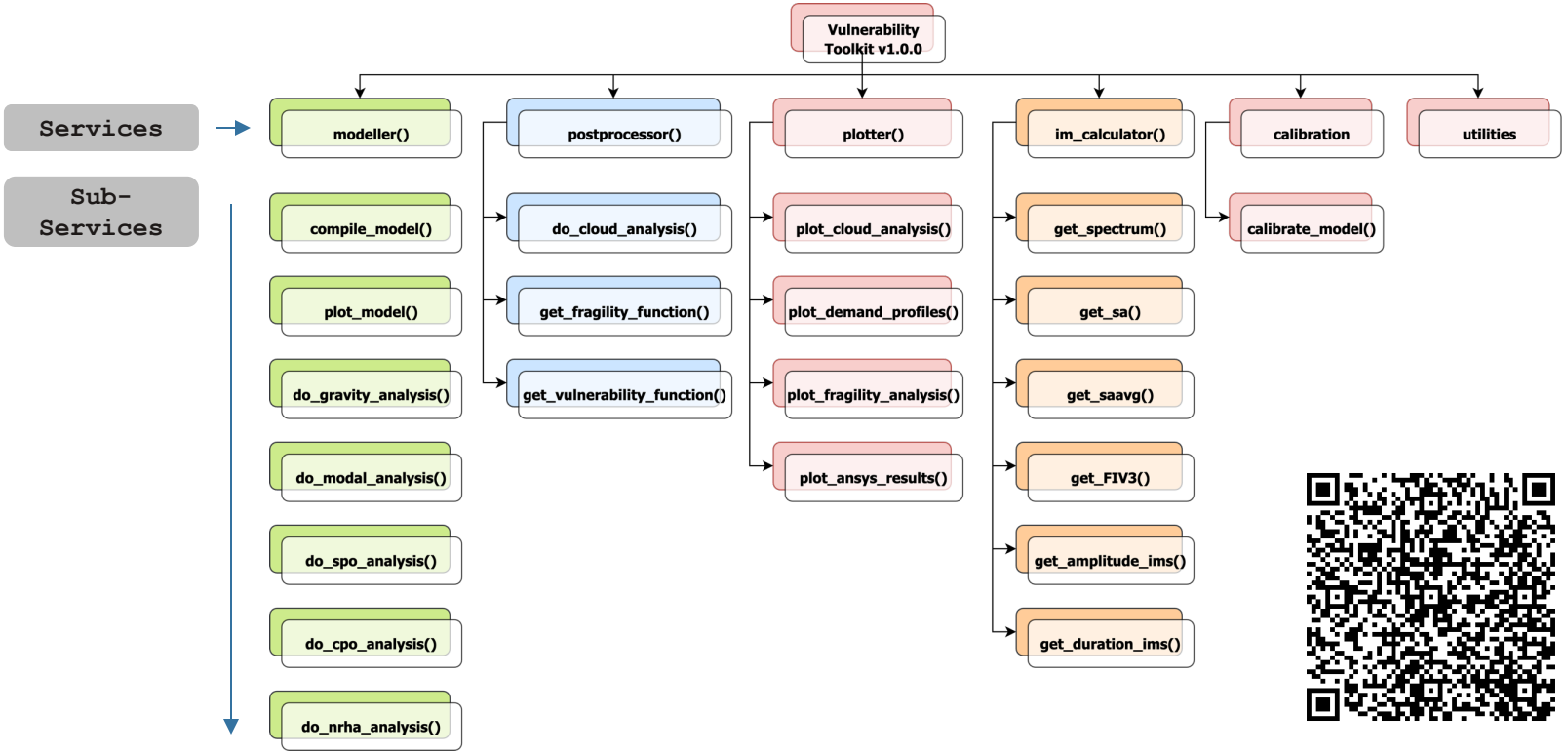
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Sanity Checks: AACPs & AALs
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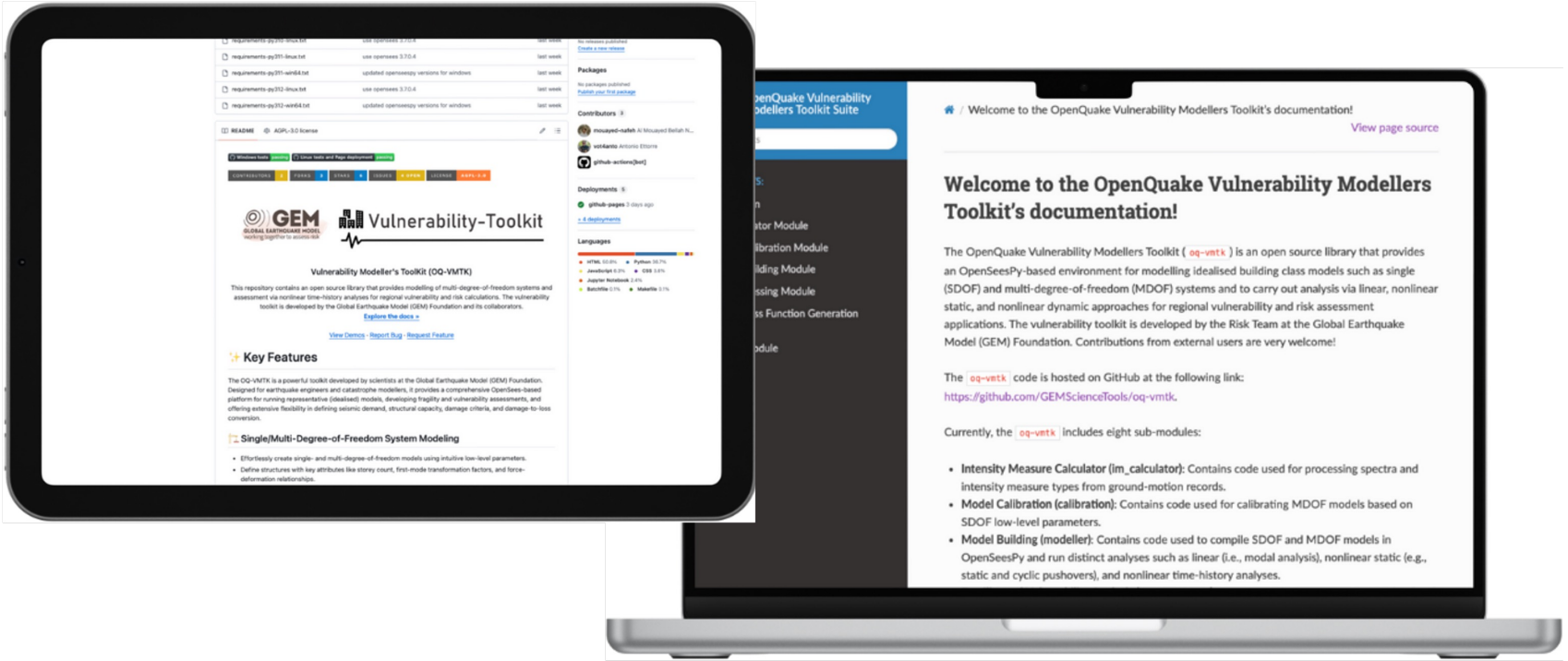
Finally, we have a nice open-source toolkit!

- Vulnerability Modeller's Toolkit (VMTK)



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- **Vulnerability Modeller's Toolkit (VMTK)**



Thank you!

Please attribute to the GEM Foundation with a link to:
https://www.globalquakemodel.org



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