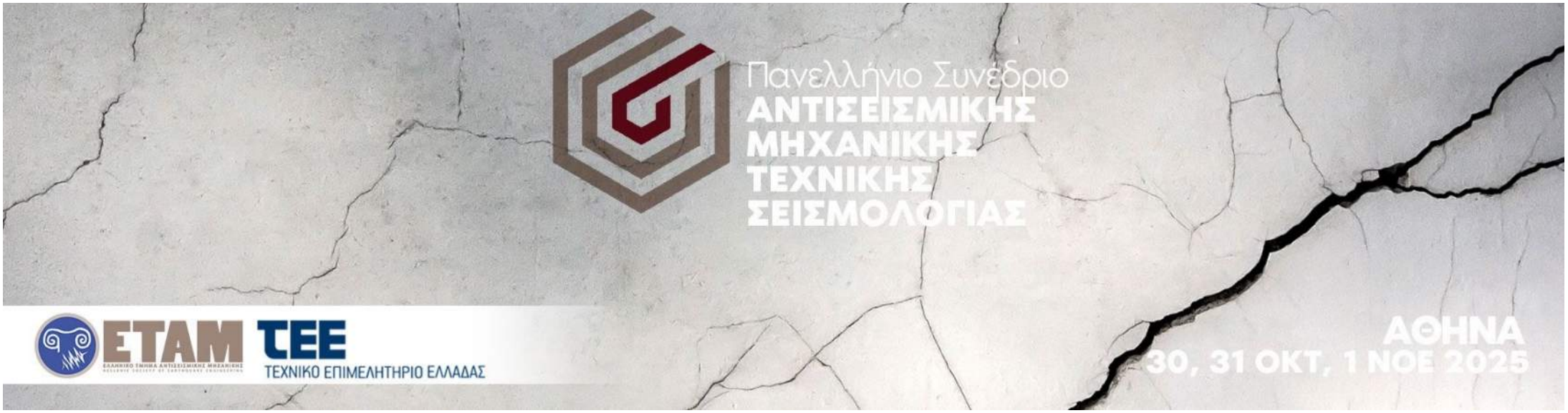


ENGINEERING THE FUTURE: HOW SEISMIC RISK MODELS CAN BUILD MORE RESILIENT SOCIETIES

Helen Crowley

30th October – 1st November 2025

GEM GLOBAL EARTHQUAKE MODEL working together to assess risk

poorly designed and/or constructed

earthquakes don't kill people, buildings do

One building standing in Kahramanmaras: The Chamber of Civil Engineers

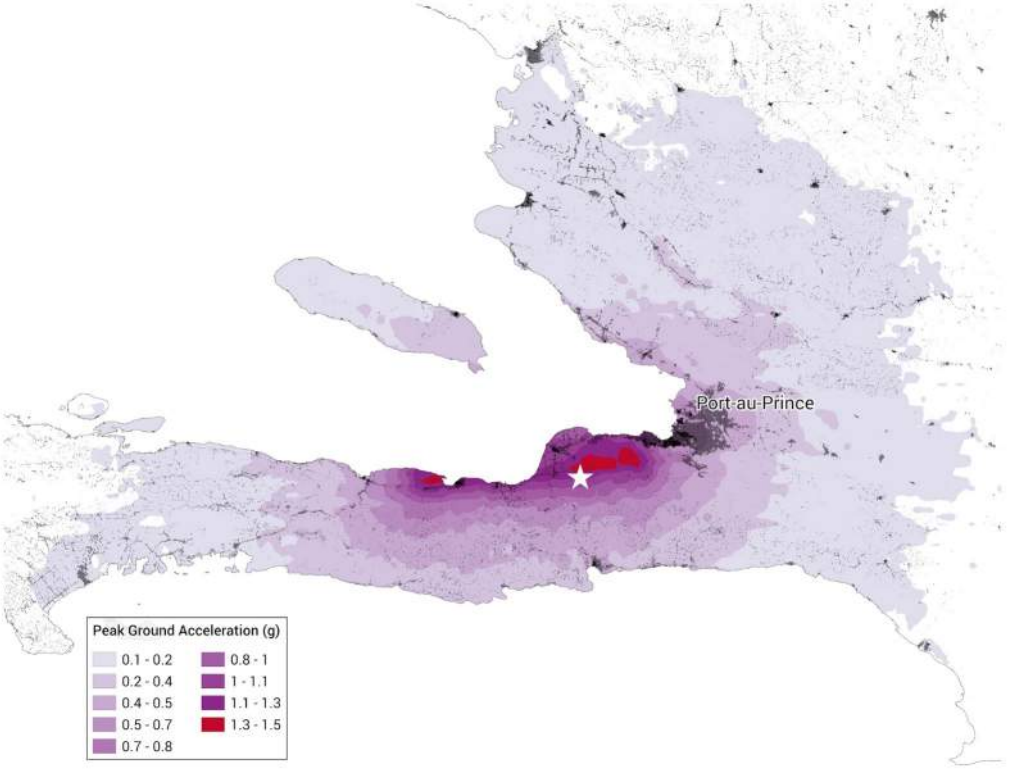
2023 M7.8 Kahramanmaraş earthquake
> 50,000 fatalities

poorly designed and/or constructed

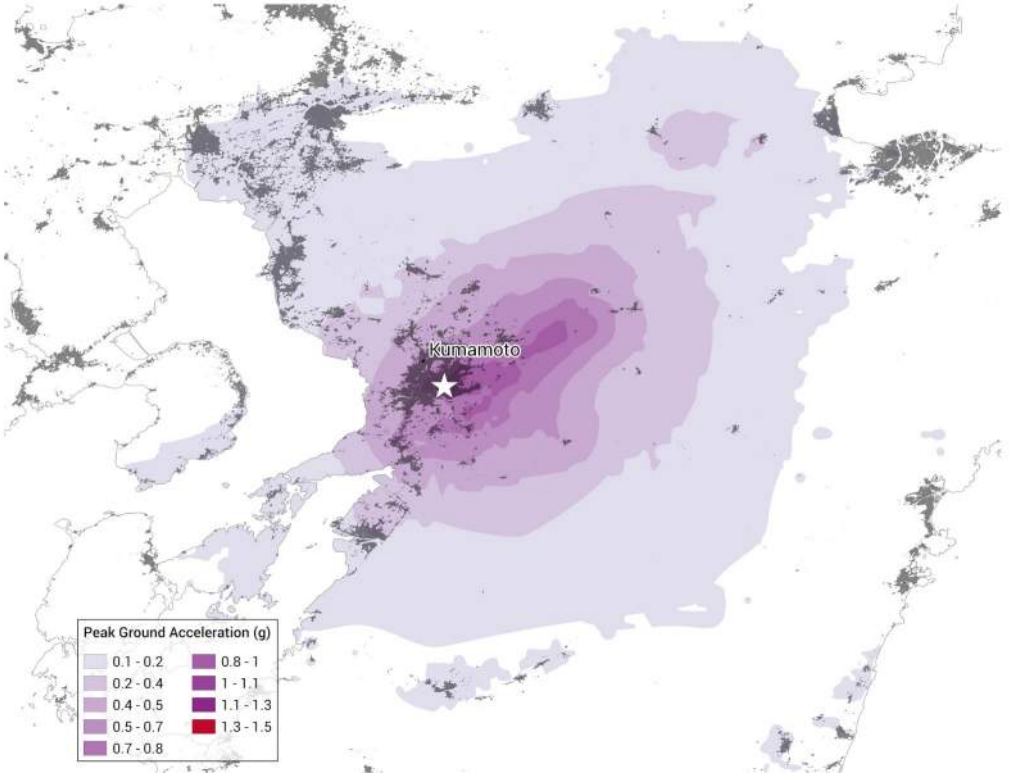
earthquakes don't kill people, buildings do

and the devastation is far greater in societies that are unaware and unprepared

Haiti, 2010

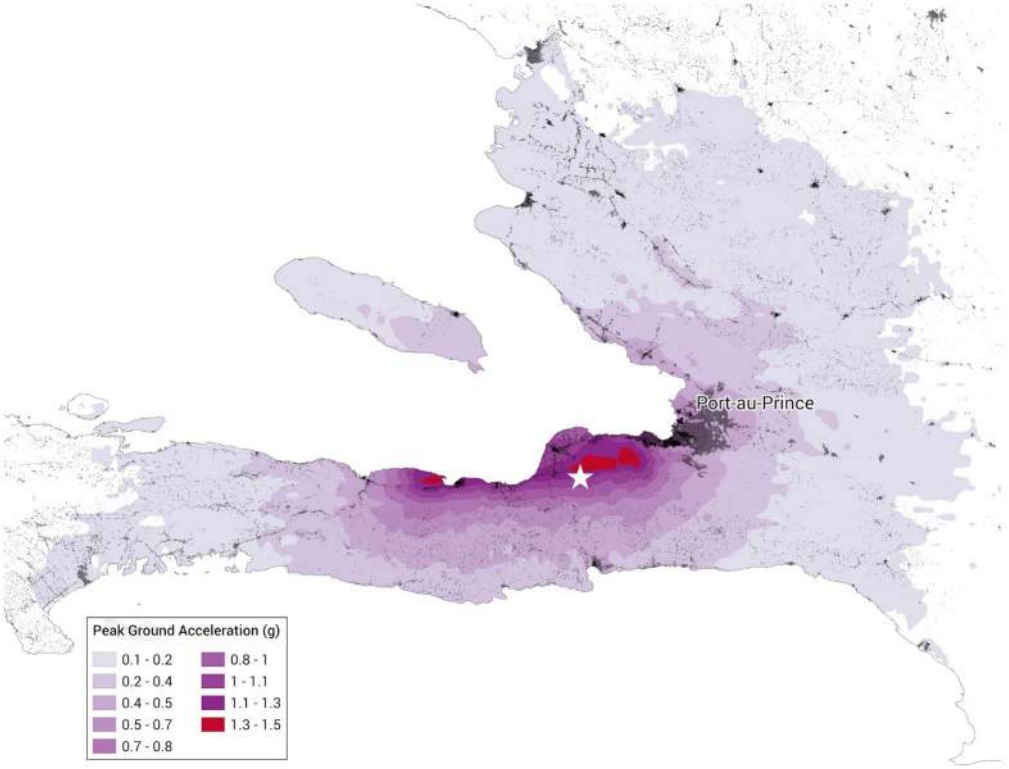


Kumamoto, Japan 2016



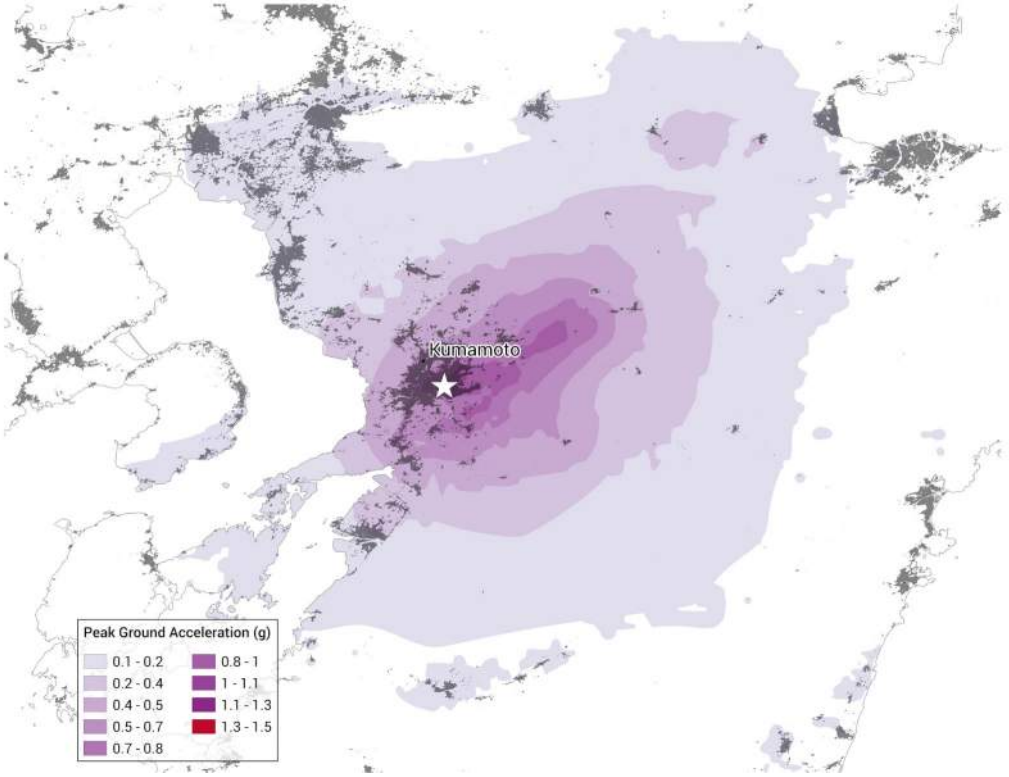
Both Magnitude 7 strike-slip earthquakes, both exposed similar numbers of people to similar levels of ground shaking intensity

Haiti, 2010



~300,000 lives lost, millions displaced, vital urban infrastructure destroyed

Kumamoto, Japan 2016



~200 fatalities, less damage and fewer displaced individuals.

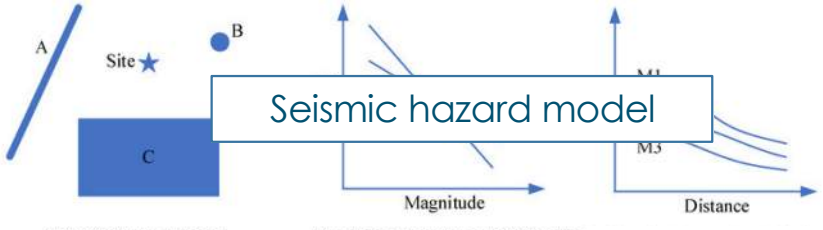
National seismic risk models help us:

understand

..the impacts from earthquakes, and how frequently we can expect them to occur

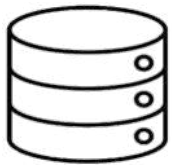
Using national seismic risk models…to understand frequency of impacts

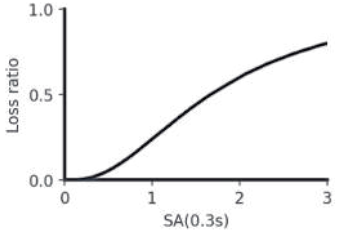
Seismic source characterisation + Ground motion/failure characterisation



National exposure

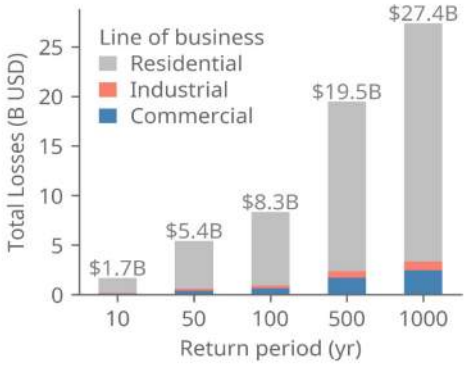
National vulnerability





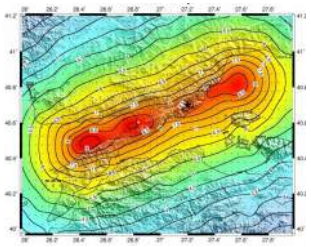
OPENQUAKE

- Buildings lost
- Area lost (m^2)
- Economic loss (USD)
- Fatalities
- Displaced



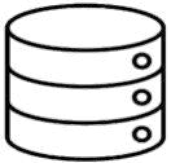
Using national seismic risk models…to rapidly assess impacts

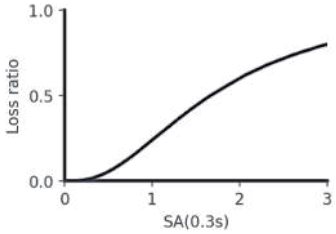
Local ShakeMap



National exposure

National vulnerability





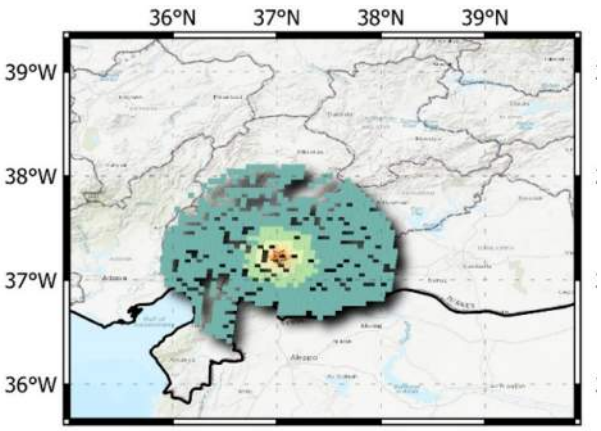
OPENQUAKE

- Buildings lost
- Area lost (m^2)
- Economic loss (USD)
- Fatalities
- Displaced

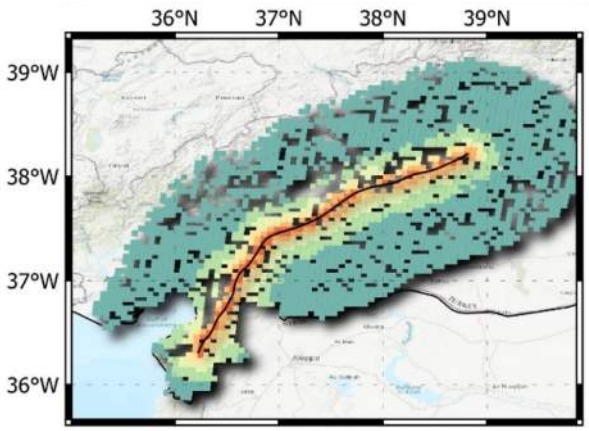
Using national seismic risk models…to rapidly assess impacts

The underlying probabilistic seismic hazard model can also be used to rapidly define the rupture and assign appropriate ground shaking models to calculate a more reliable ShakeMap:

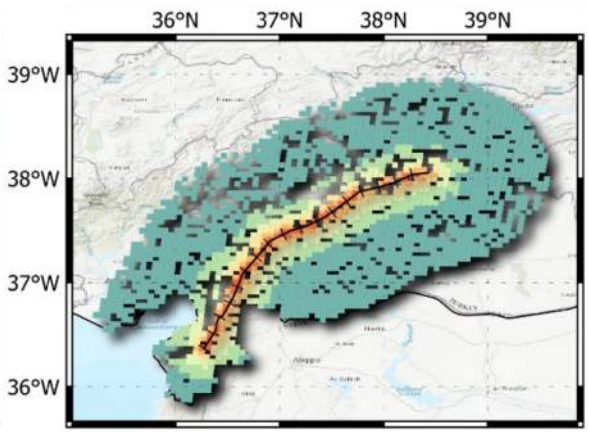
Point source



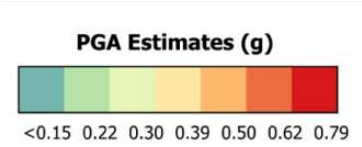
Rupture from hazard model



Complex "true" rupture



2023 M7.8 Kahramanmaraş earthquake

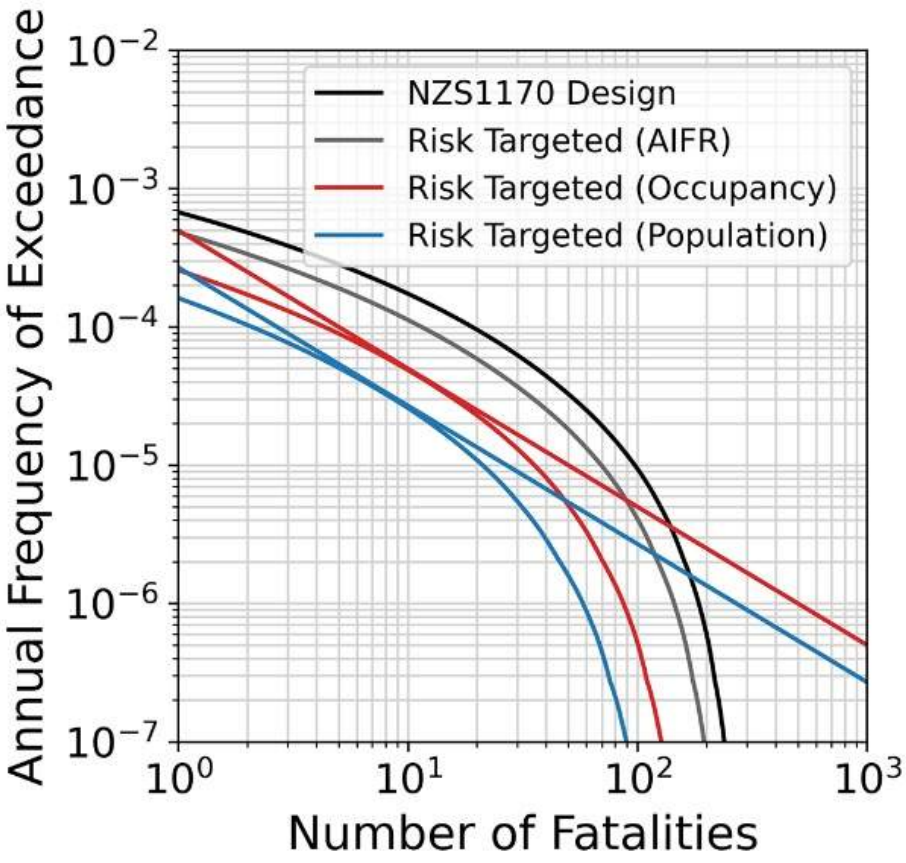


National seismic risk models help us:

understand	*..the impacts from earthquakes, and how frequently we can expect them to occur*
make plans	*..for cost-effective risk management efforts, so that we can reduce the impacts and recovery times for future earthquakes*

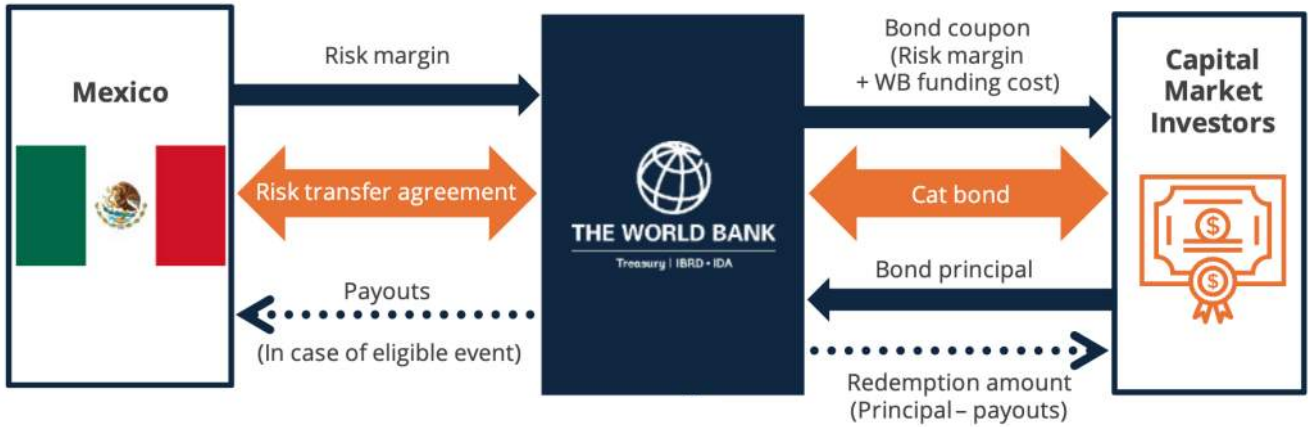
Using national seismic risk models…for targeted structural resilience

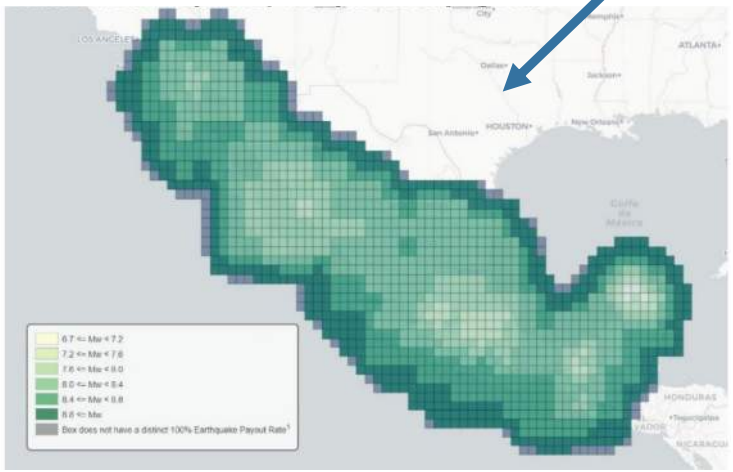
Seismic actions based on 10% probability of exceedance in 50 years



Horspool et al. (2023)

Using national seismic risk models…for financial resilience





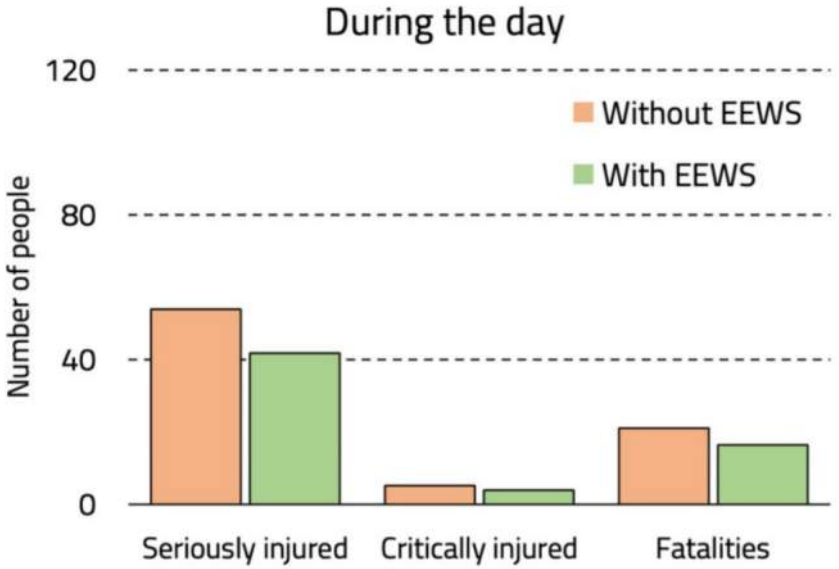
Cat-in-a-grid trigger based on magnitude, location and depth of earthquakes

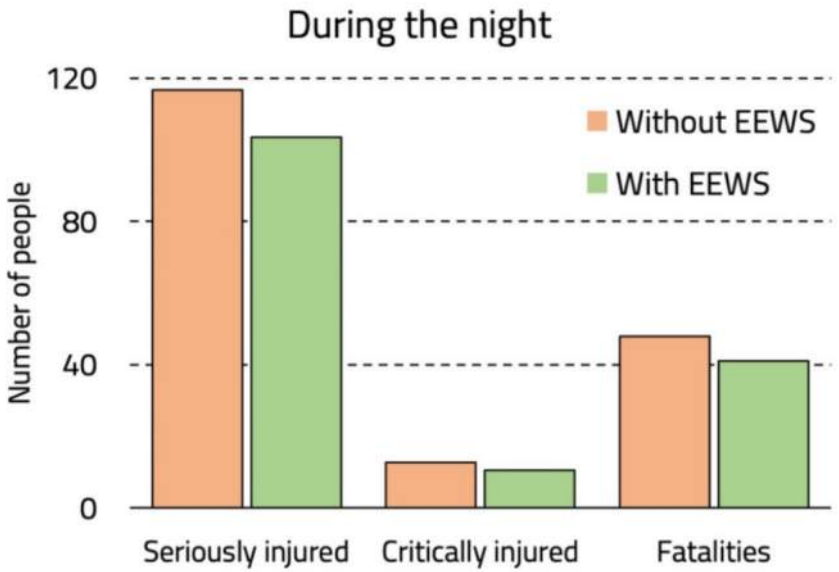
Triggers are optimised by running many simulated scenarios through risk models, calibrating thresholds until the payout pattern:

- Matches the sponsor's (e.g. Mexico's) expected losses,
- Keeps investor yields attractive,
- And minimises basis risk (difference between government's actual disaster losses and bond payout)

Using national seismic risk models for…earthquake early warning

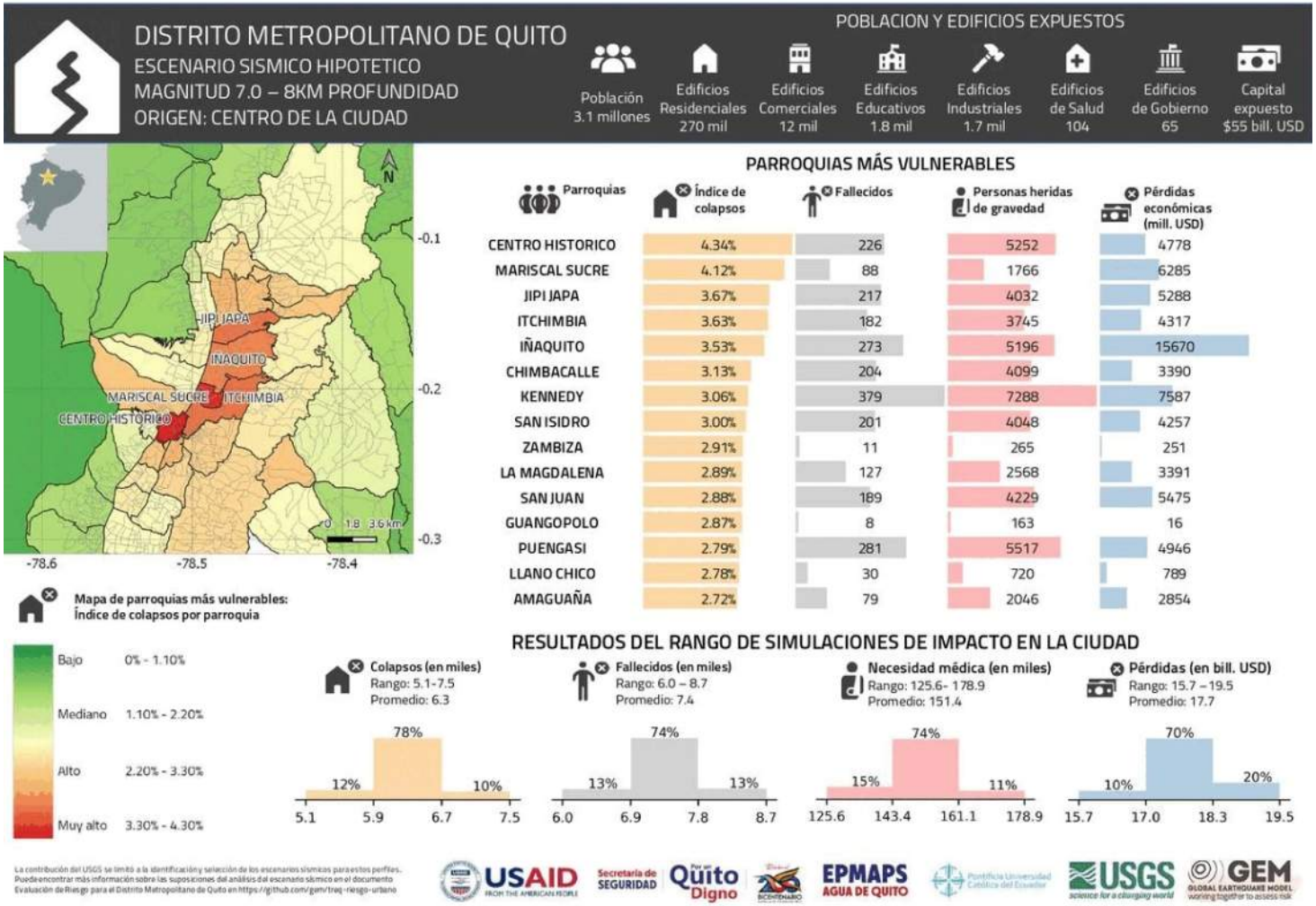
Average annual number of injured and fatalities with and without earthquake early warning systems (EEWS) for Portugal:





Silva et al. (2023 BEE)

Using national seismic risk models…for emergency management

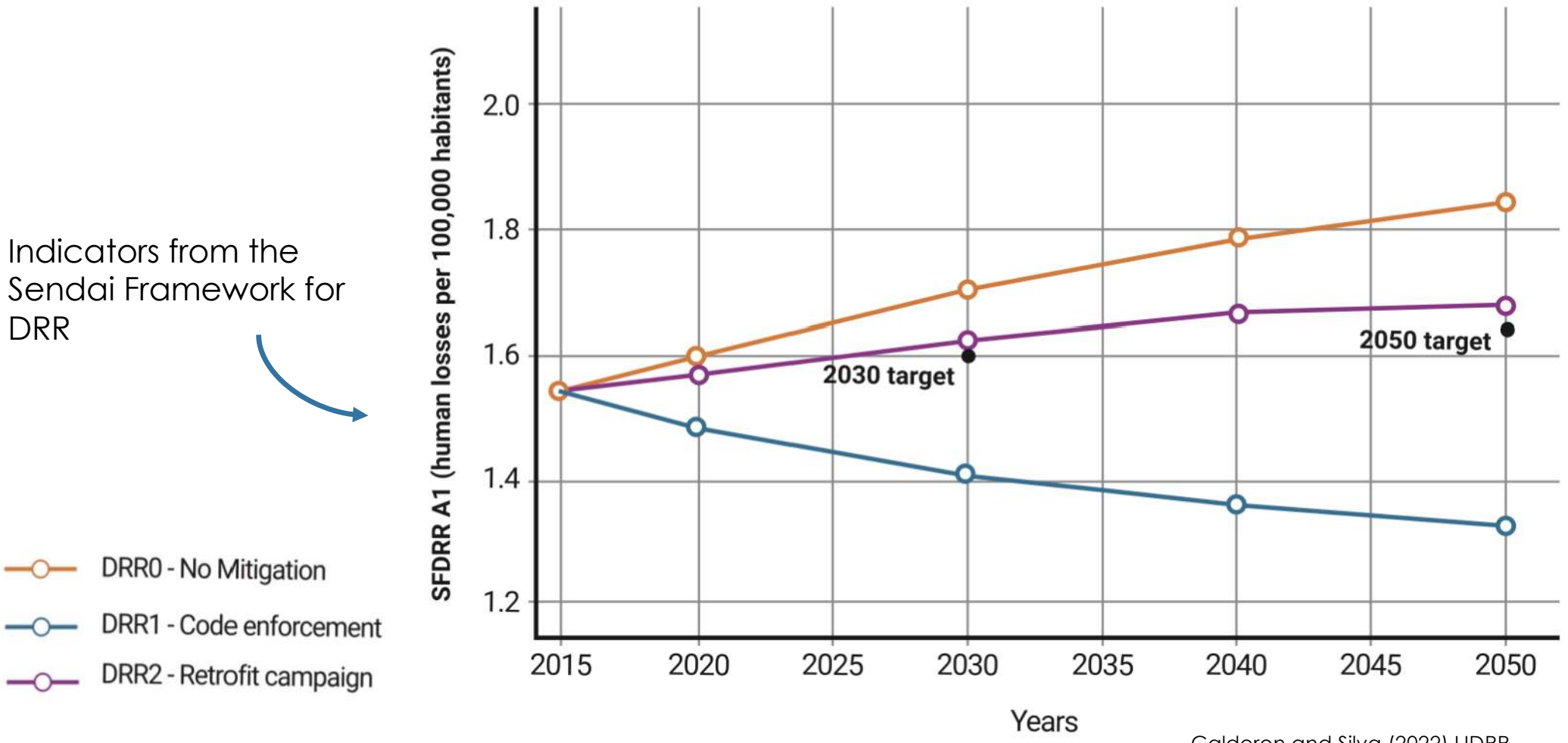


National seismic risk models help us:

understand	*..the impacts from earthquakes, and how frequently we can expect them to occur*
make plans	*..for cost-effective management efforts, so that we can reduce the impacts and recovery times for future earthquakes*
forecast	*.. the expected impacts under different future scenarios to encourage more action to be taken today*

Using national seismic risk models for…future visioning

Indicators from the Sendai Framework for DRR



Calderon and Silva (2022) IJDRR

what GEM has built

Global Earthquake Model (GEM)

The Foundation

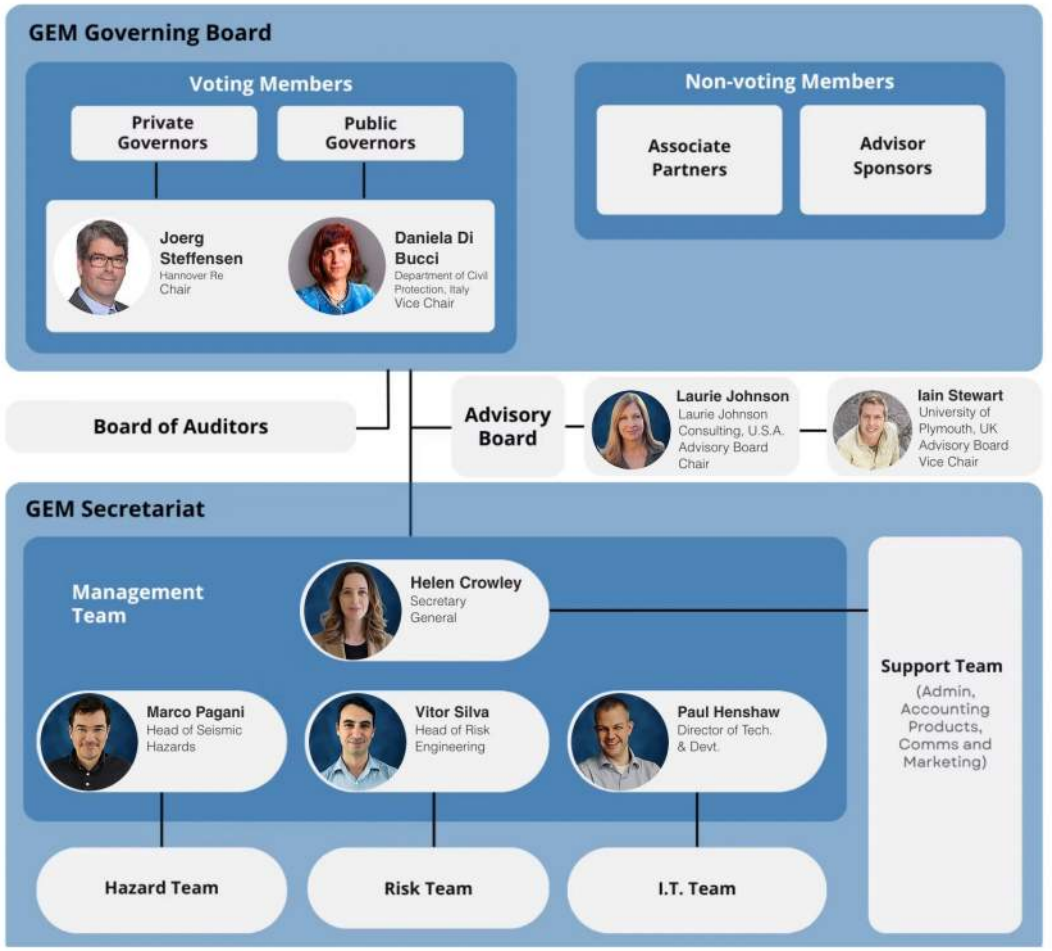
Non-profit foundation and UN accredited NGO, headquartered in Pavia, Italy, governed as a public-private partnership

Our Mission

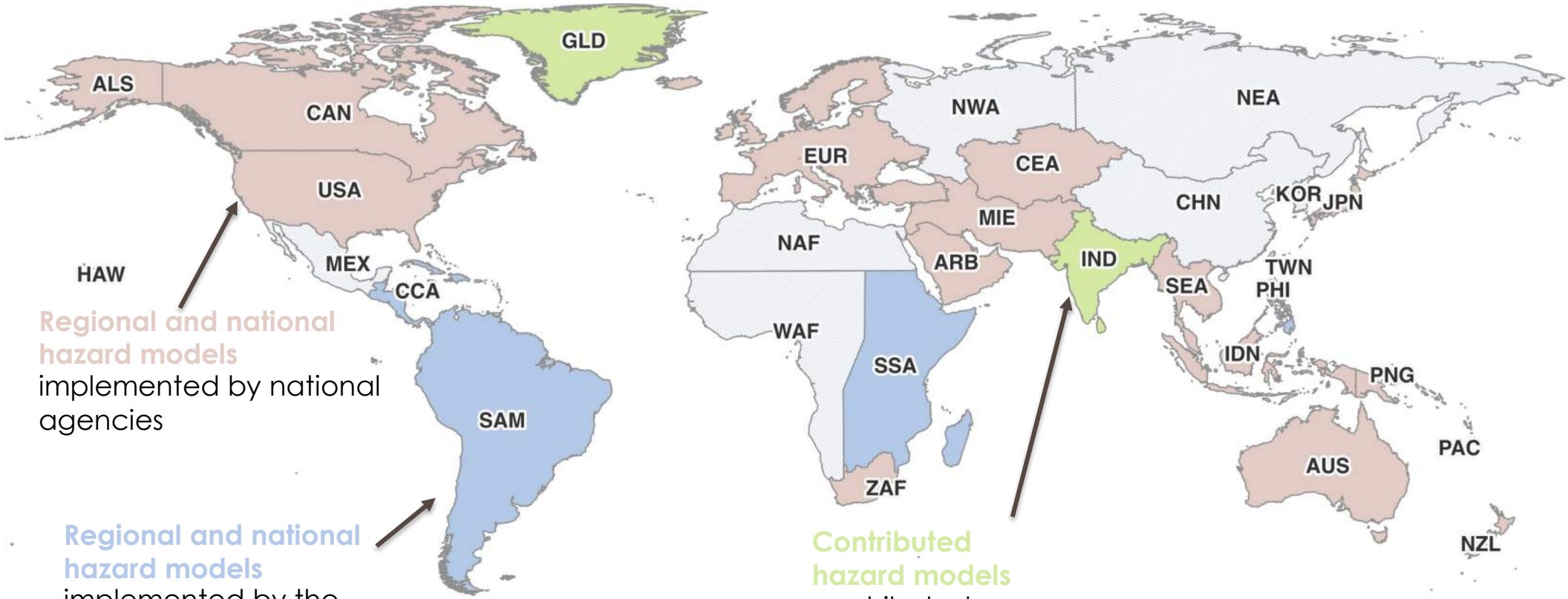
To develop, together with the global community, scientific resources for transparent earthquake hazard and risk assessment, and to facilitate their application for risk management

Our Core Values

Openness | Collaboration | Credibility | Public Good



16 years of harmonising seismic hazard models



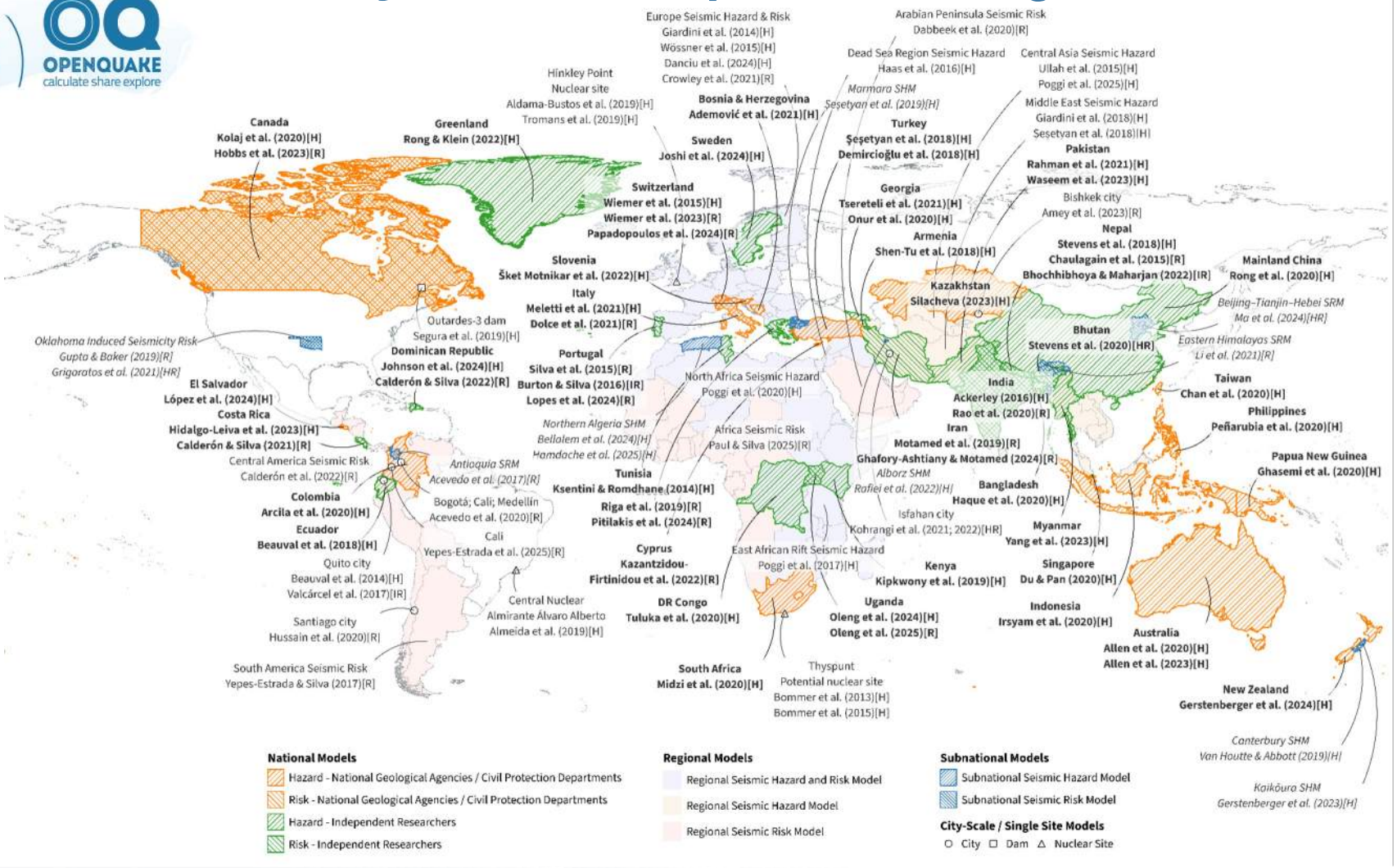
Regional and national hazard models implemented by national agencies

Regional and national hazard models implemented by the GEM Hazard Team within collaborative projects

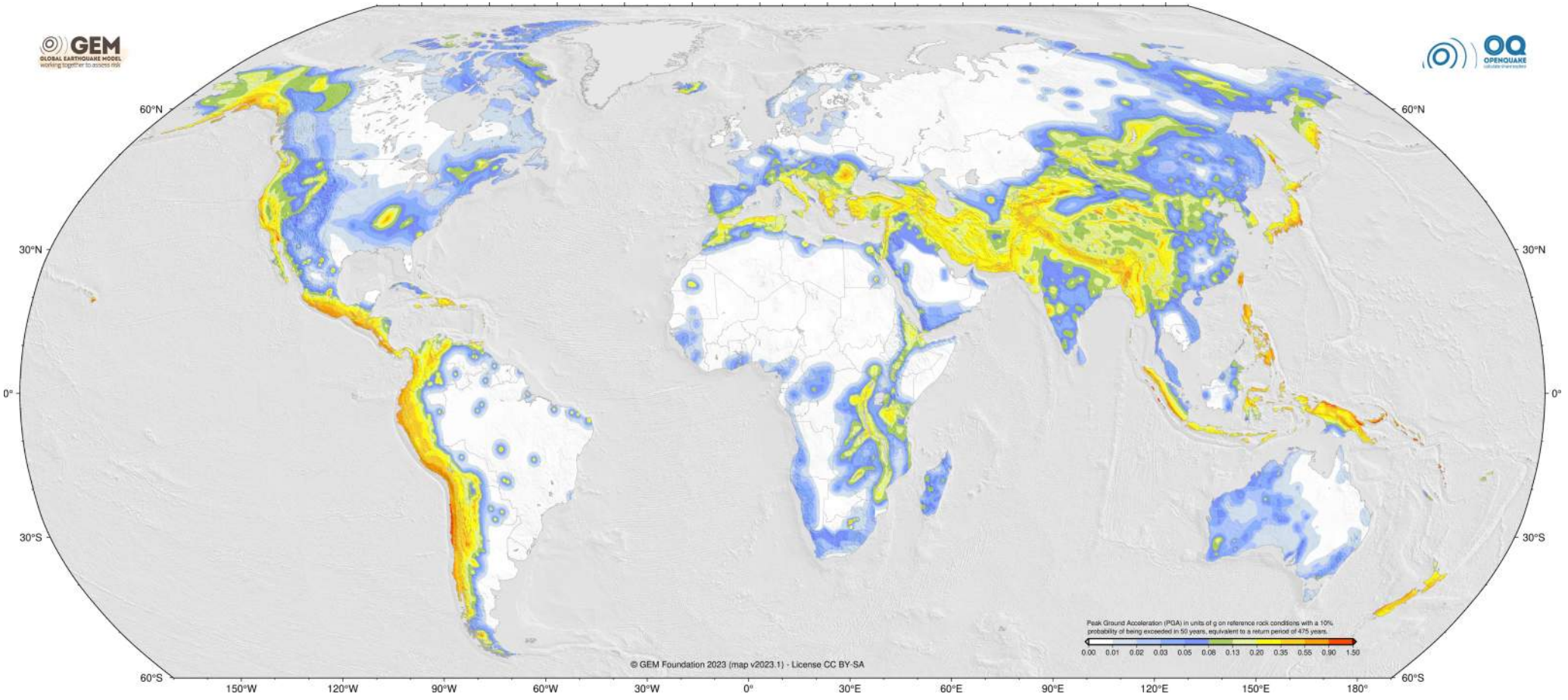
Contributed hazard models contributed, or implemented using information from scientific publications

GEM internal hazard models implemented by the GEM Hazard Team

15 years of the OpenQuake Engine

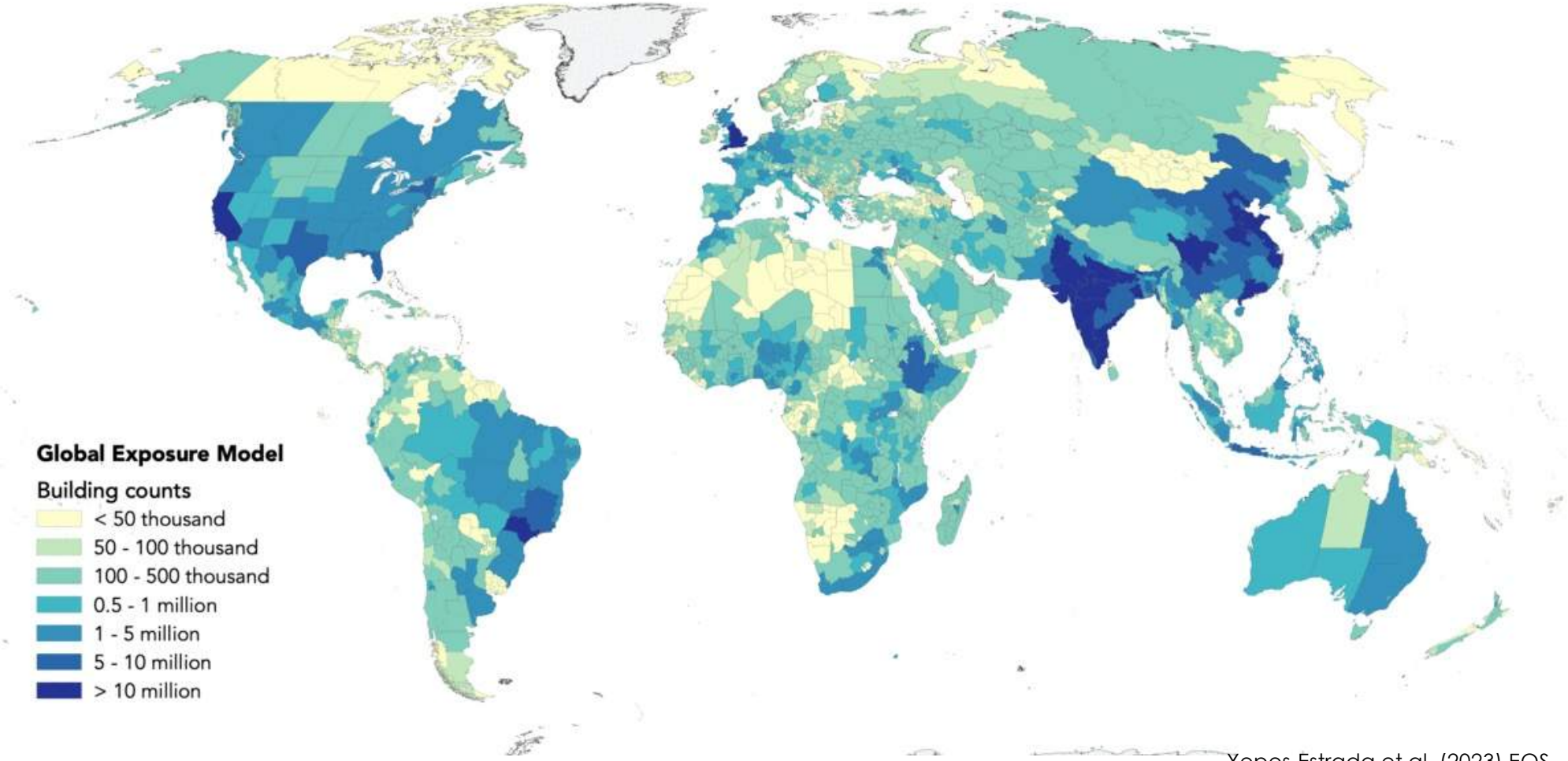


A global seismic hazard model (v2023)



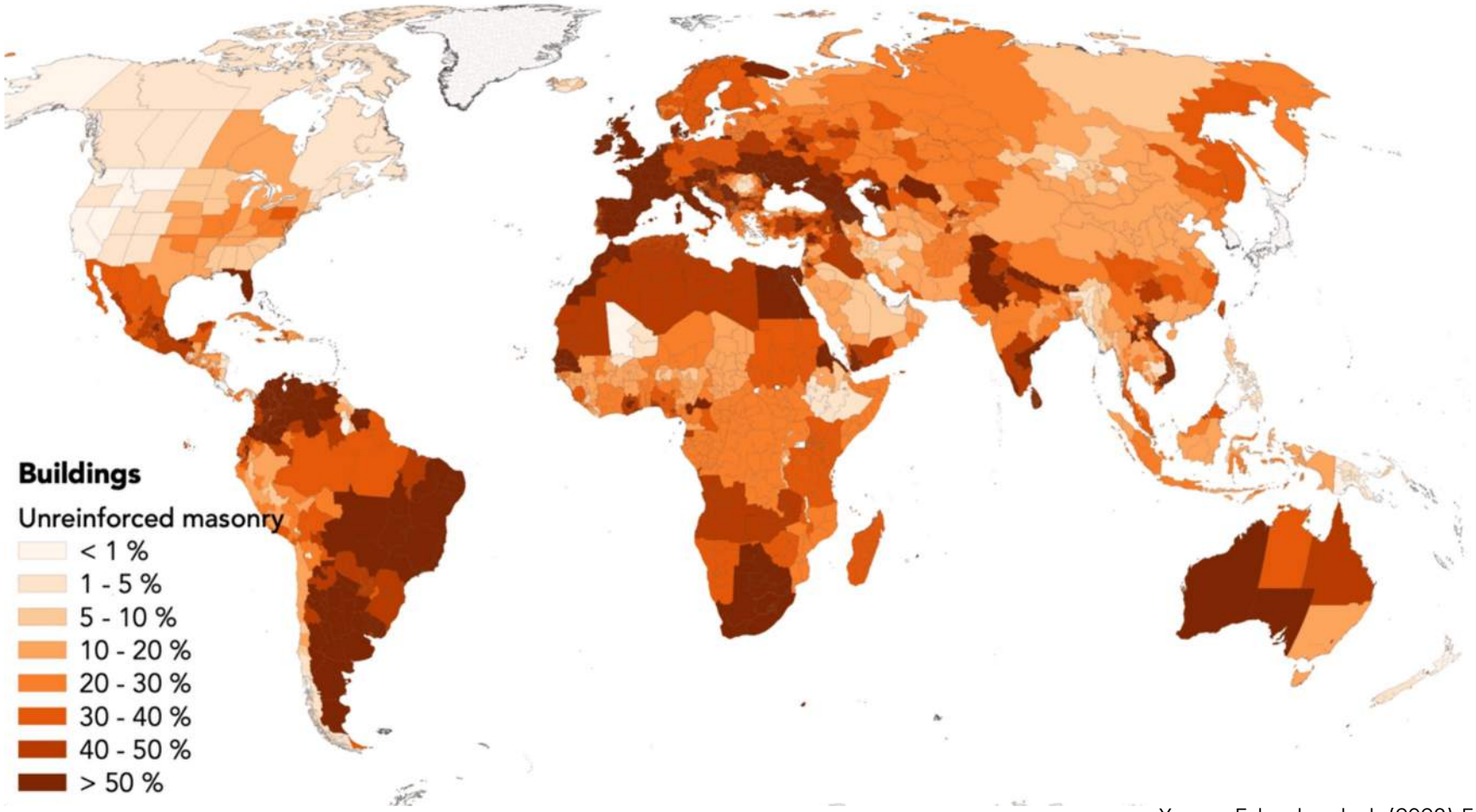
This map shows peak ground acceleration (PGA) on reference rock with a 10% probability of exceedance in 50 years (Pagani et al., 2020 EQS)

A global database of national exposure models



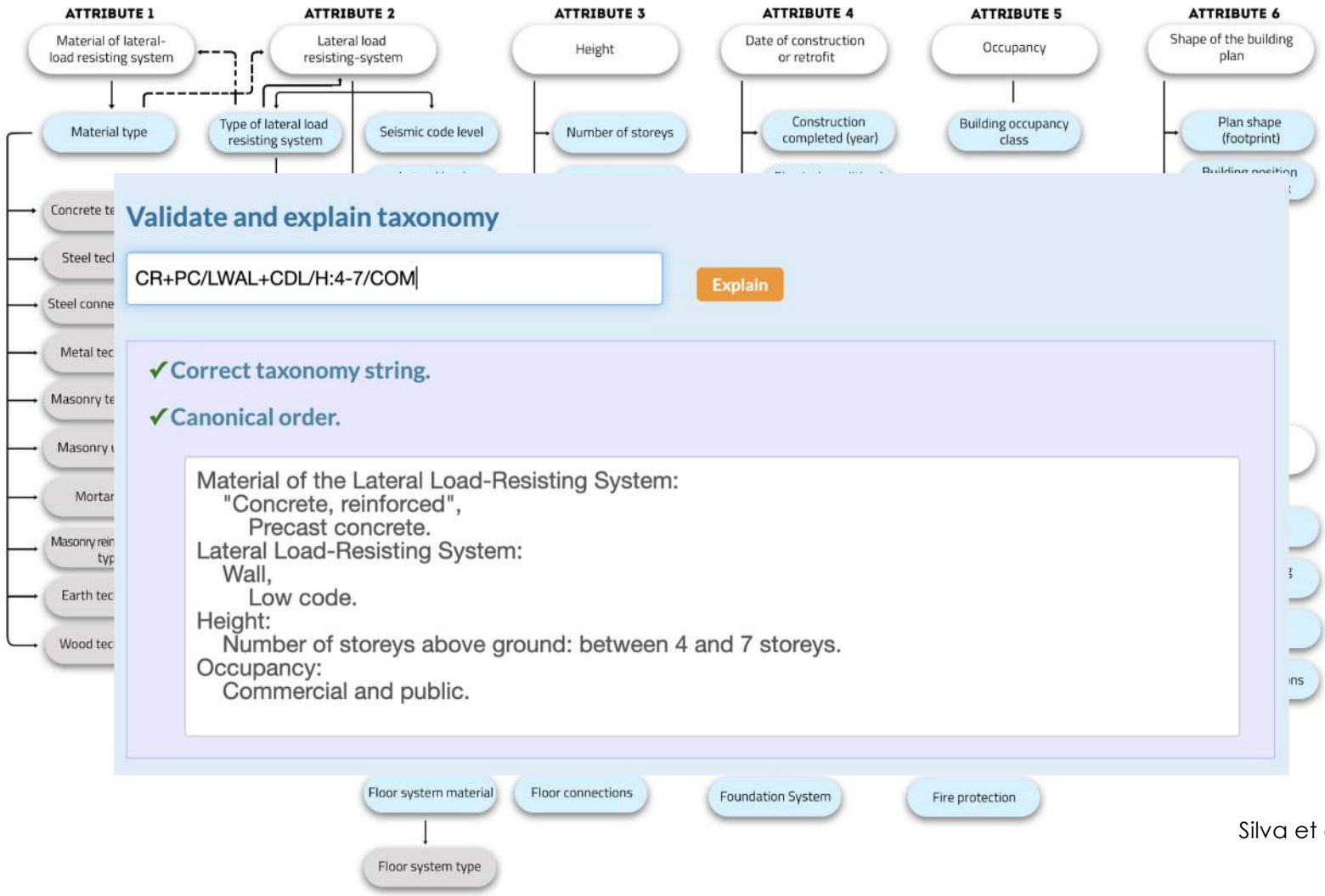
Yepes-Estrada et al. (2023) EQS

A global database of national exposure models



Yepes-Estrada et al. (2023) EQS

GEM building taxonomy

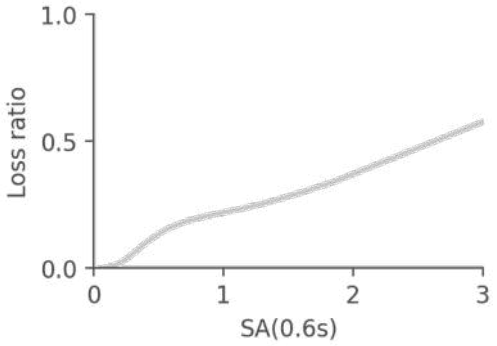


Silva et al. (2022) IJDRS

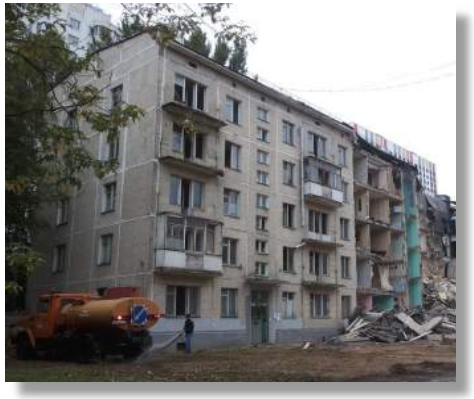
A global database of (analytical) vulnerability models

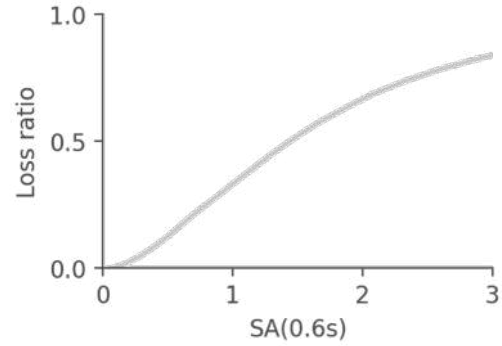
Current model covers **1200+** building classes (for each occupancy type: residential, commercial and industrial)

Bamboo houses

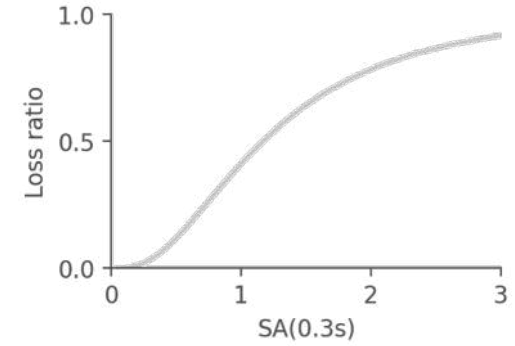


Large panel buildings

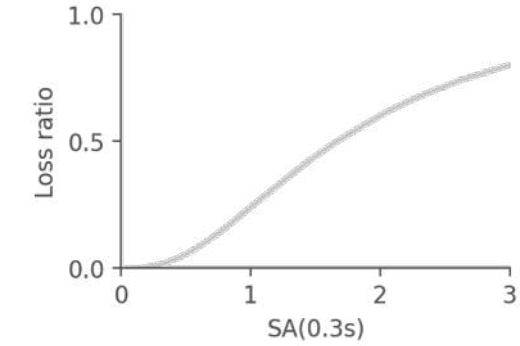




Rubble stone masonry

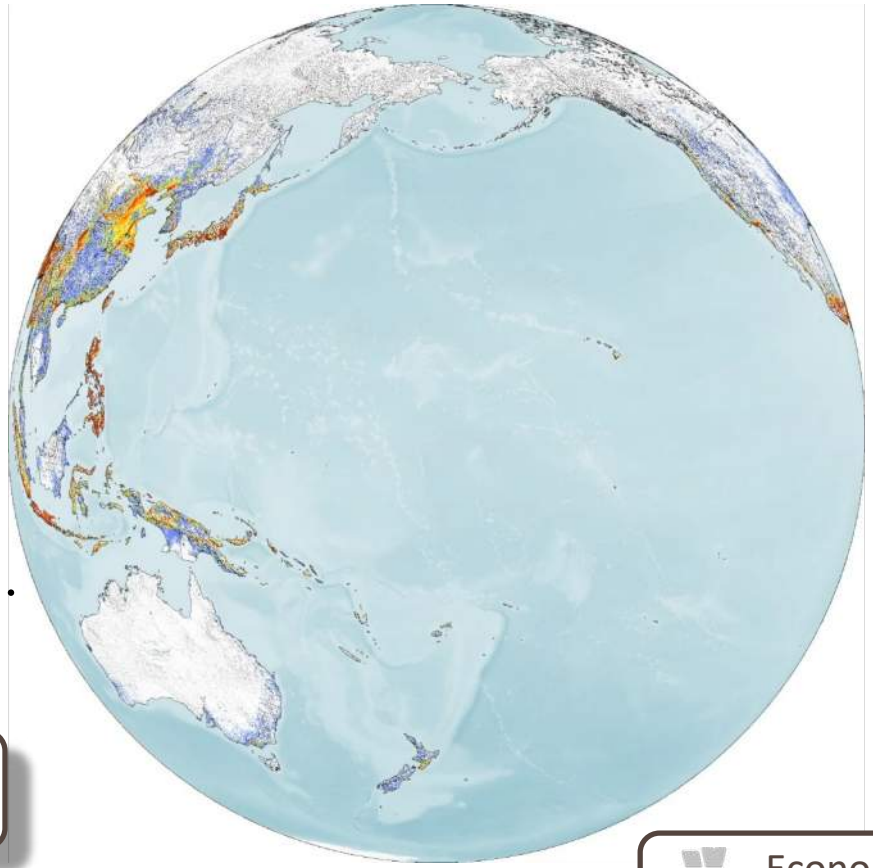


Concrete bricks masonry



Martins and Silva (2021) BEE

And a global seismic risk model (v2023)



Buildings lost

~ 380,000

Fatalities

~23,000

each year, on average..

Displaced

~ 3.4 Million

Area lost

~110 Million m^2

Economic loss

~ 85 Billion USD

Keeping our models up to date is a race against time

From GEM's first global seismic risk model (v2018) to the latest version (v2023) we saw increases in exposure equivalent to:

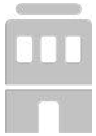
+ 375 million people

Equivalent to the population of United States + Canada

+ 98 million dwellings

Equivalent to all dwellings in Indonesia + South Korea

+ 73 million buildings

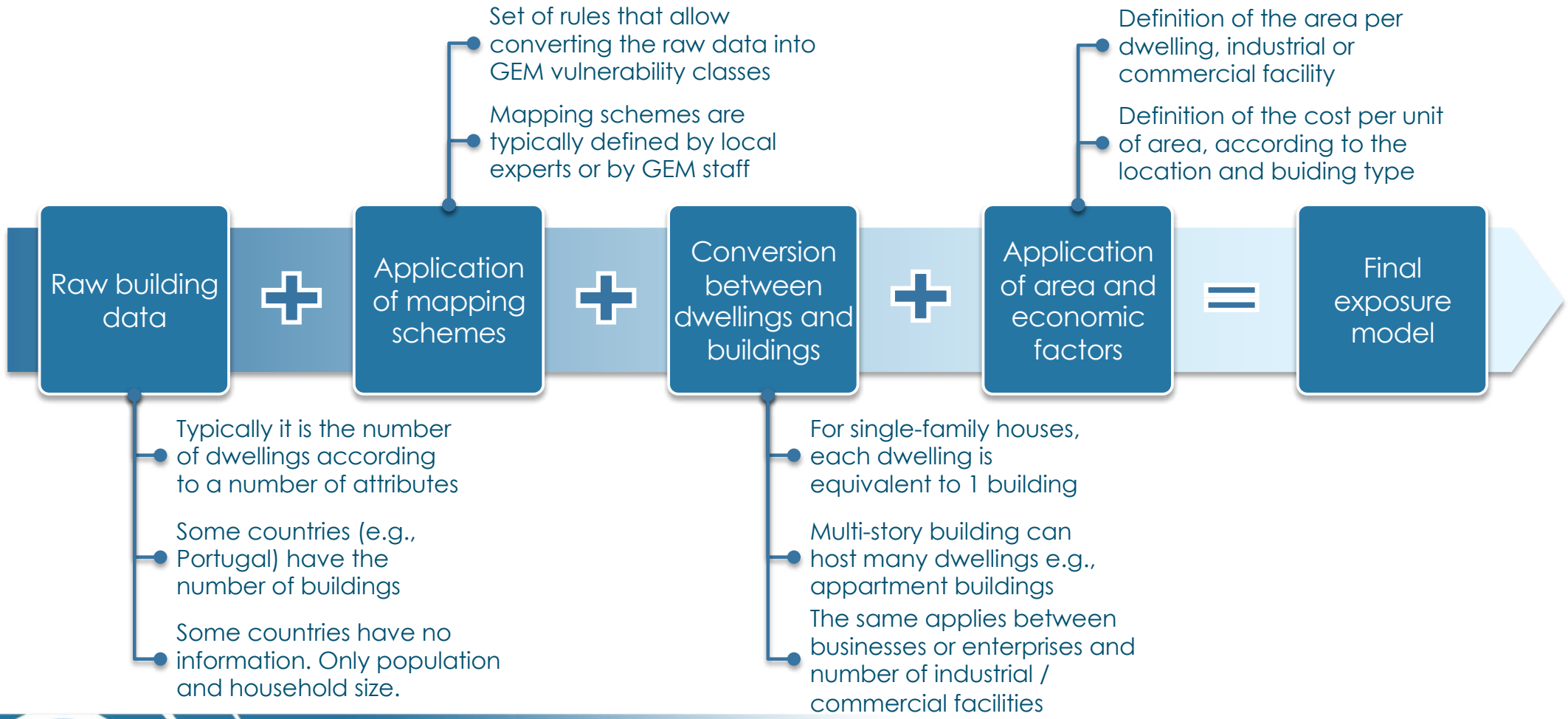


Equivalent to all buildings in Brazil + Argentina

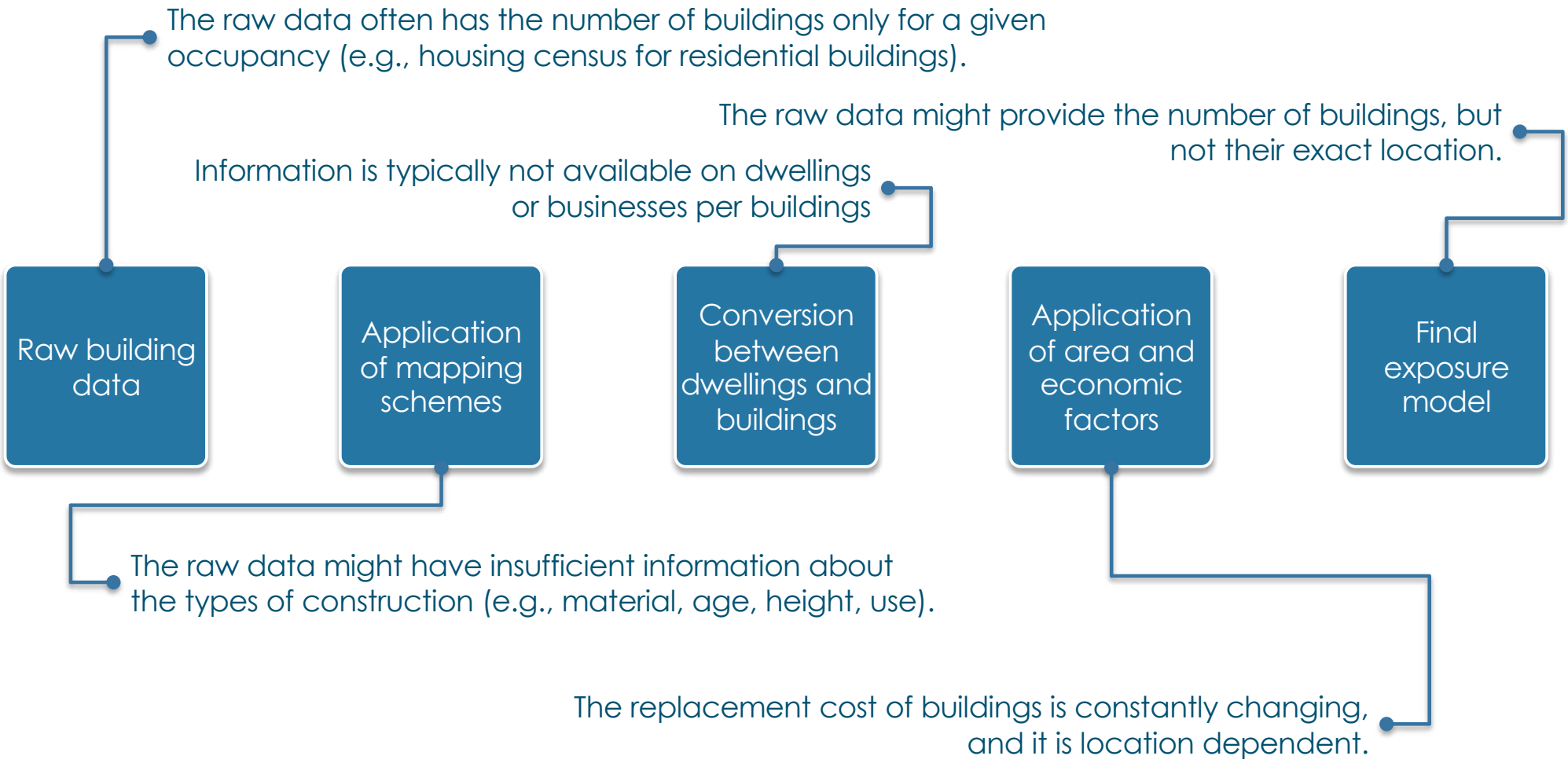
And we also need to account for significant inflation in the construction sector

a deeper dive into exposure modelling

The recipe of a “good” exposure model



But this recipe has some limitations



emerging potential from remote sensing and AI


Burger King
AT&T
El Pollo Loco
Super 8 Hotel
IHOP
Vons
Walmart
Deseret Industries Thrift Store & Donation Center
Los Taquitos
Omega Industrial
7-Eleven
Jack in the Box
Nestor United Espiscopalian Church
Circle A
Bank of America
Montgomery-Waller Recreation Center
Jack in the Box
YMCA
San Ysidro Health Beyer Senior Health Services
Vista Terrace Park and Pool Center
Colonel Irving Salomon San Ysidro Community Activity Center
Starbucks
Carl's Jr.
McDonald's
Our Lady of Mount Carmel Church
San Ysidro Health Center
Southwestern College Higher Education Center at San Ysidro
San Ysidro Convent
San Ysidro Civic Center
El Rincon
OVERTURE MAPS FOUNDATION
OpenStreetMap | Esri Community Maps | Microsoft ML Buildings | GoogleOpen Buildings

These global footprint solutions are not without limitations..

Automatic Building Footprint Detection for Paris (e.g., Microsoft)

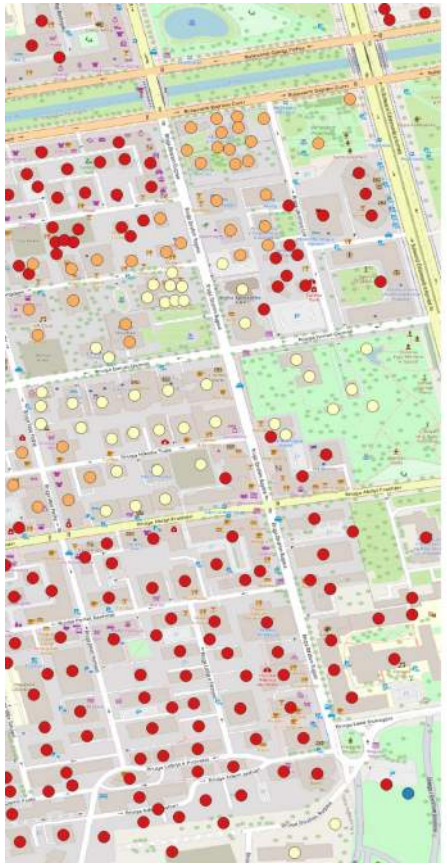
Inaccurate building footprints

Missing footprints

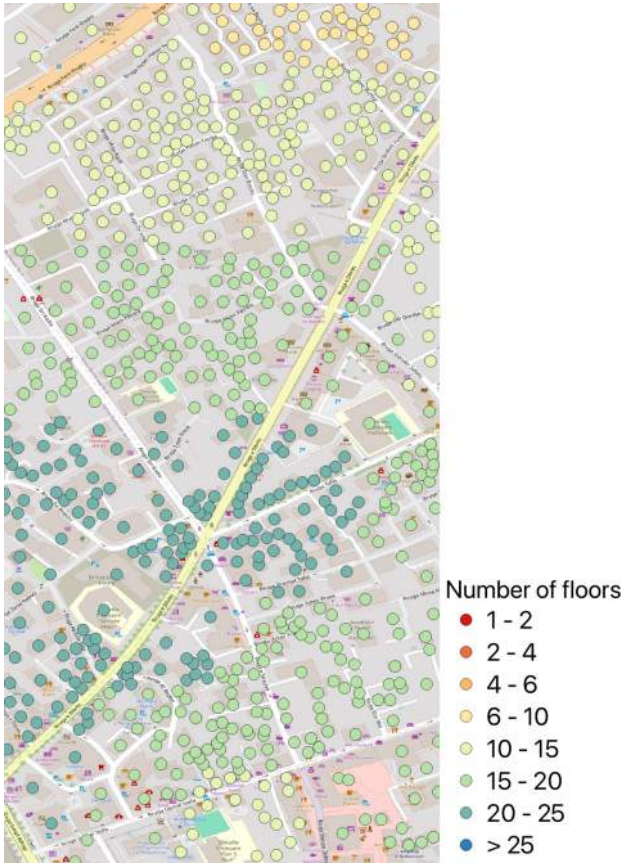
Building Attributes at footprint level

The new GHSL-OBAT dataset from the European Joint Research Centre (JRC)

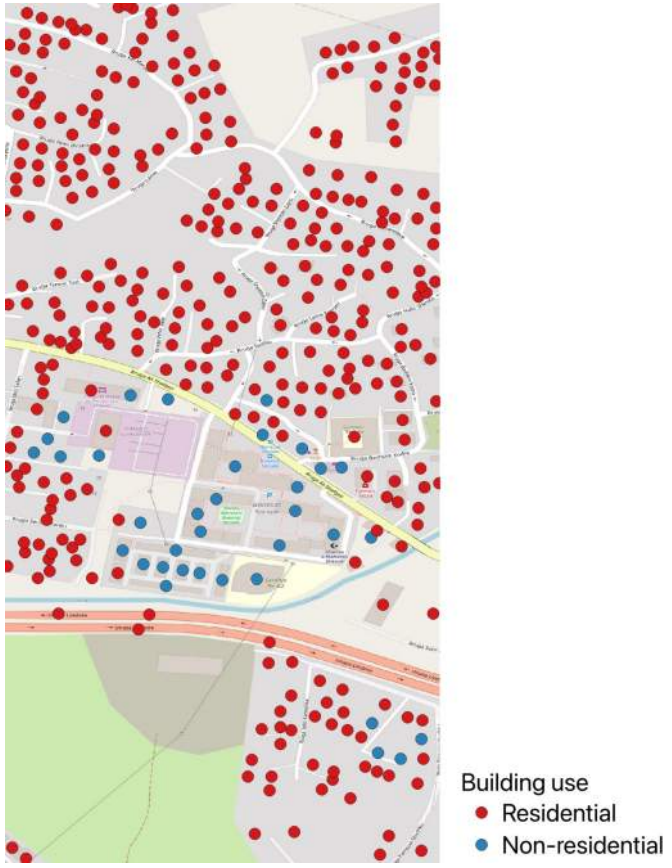
Asset vintage



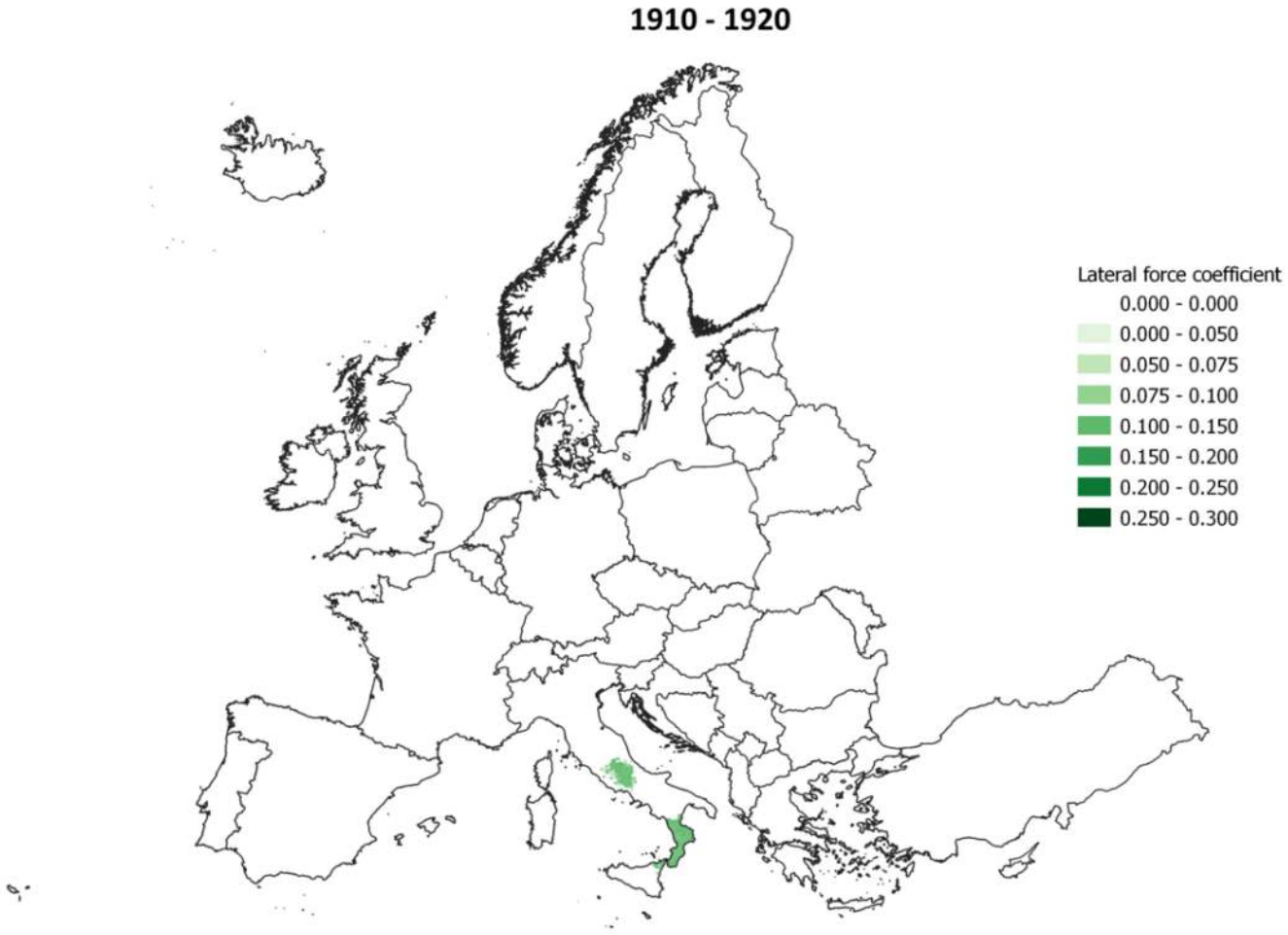
Number of storeys



Occupancy



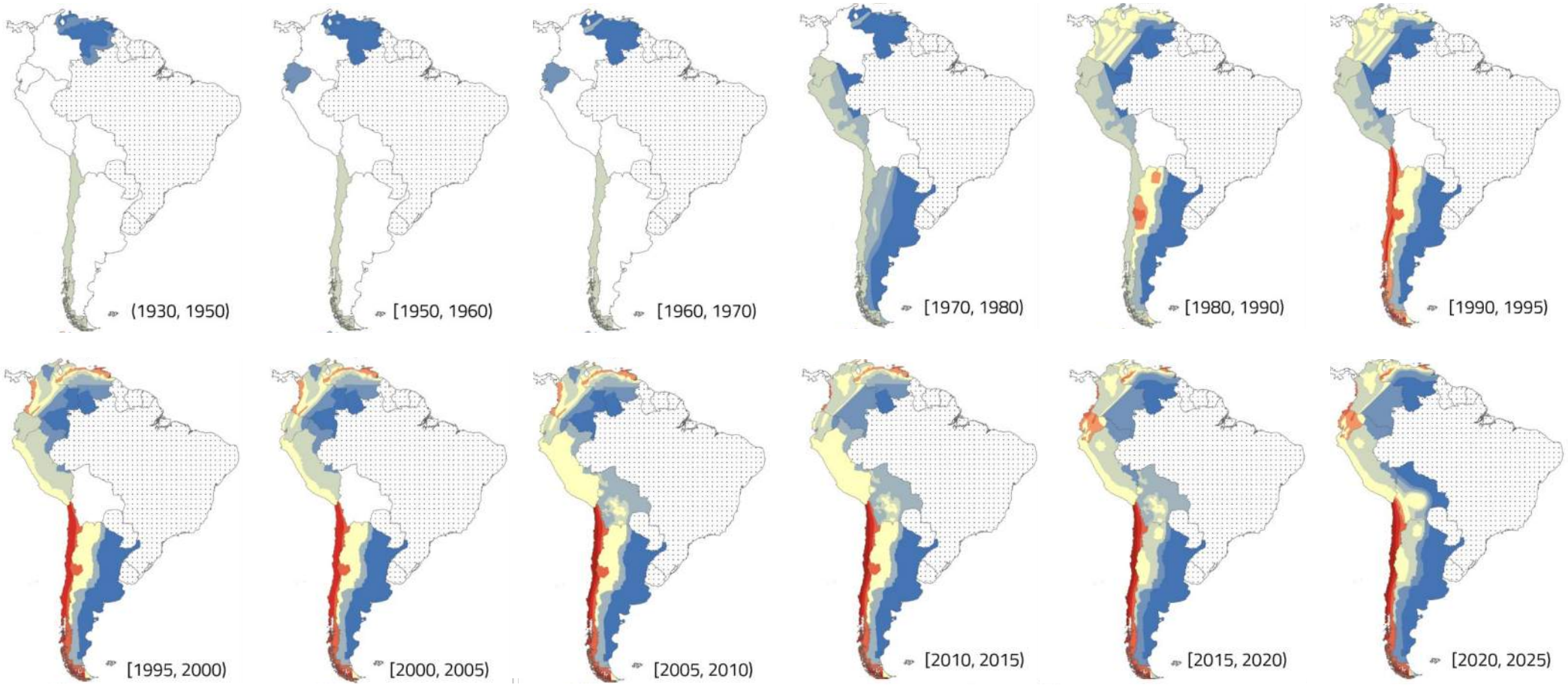
Design regulations and seismic zonation



Crowley et al. (2021)

Design regulations and seismic zonation

Associating buildings with a design regulation and seismic design level

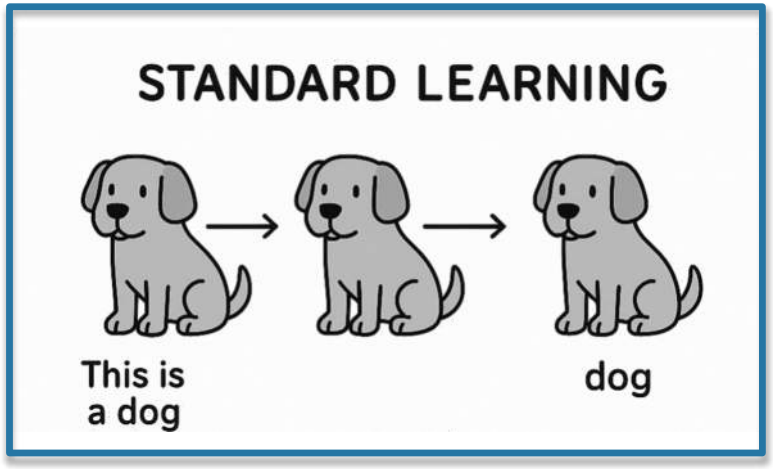


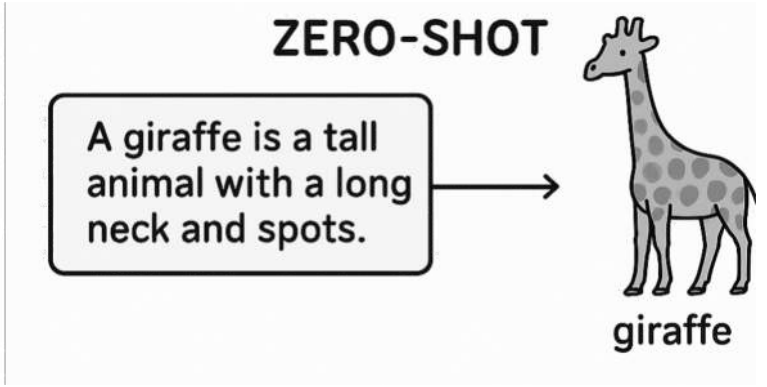
Gonzalez et al. (2025)

β <0.03 | 0.03 - 0.05 | 0.05 - 0.07 | 0.07 - 0.10 | 0.10 - 0.15 | 0.15 - 0.20 | 0.20 - 0.30 | 0.30 - 0.40 | 0.40 - 0.50 | Not considered

Exploring AI for building classification

There are **two options** for AI Building Classification

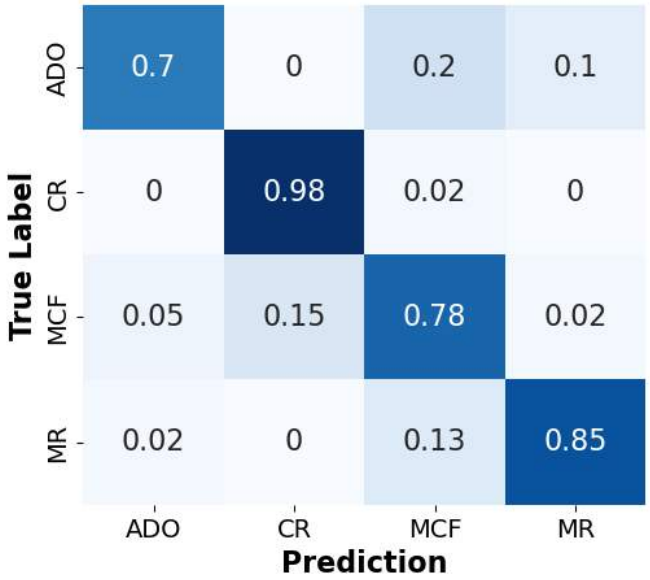




Exploring AI for building classification

AI Building Classification using **Standard Learning**

Training and testing of convolutional neural network model

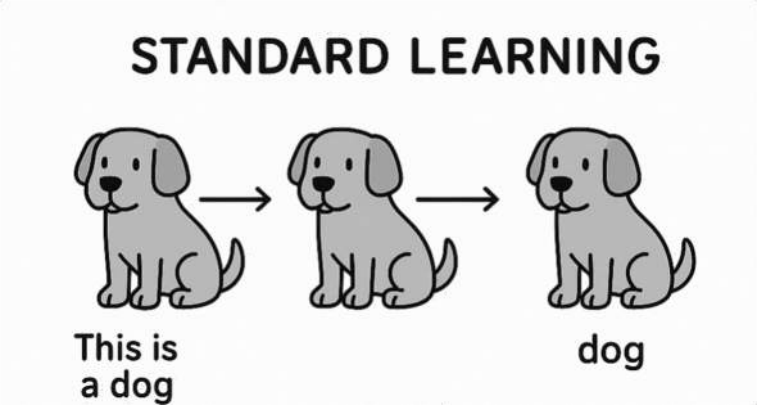


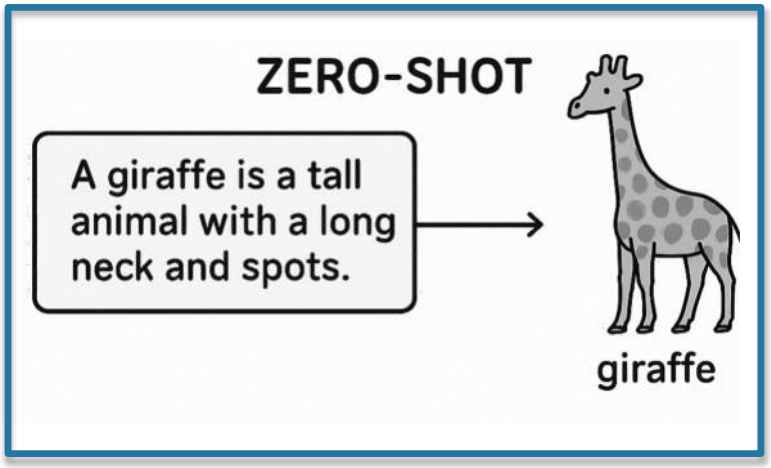
Between GEM and our partners, we have now more than **50,000 images** of buildings labelled according to the **GEM Building Taxonomy**

Gomez et al (2025) EQS

Exploring AI for building classification

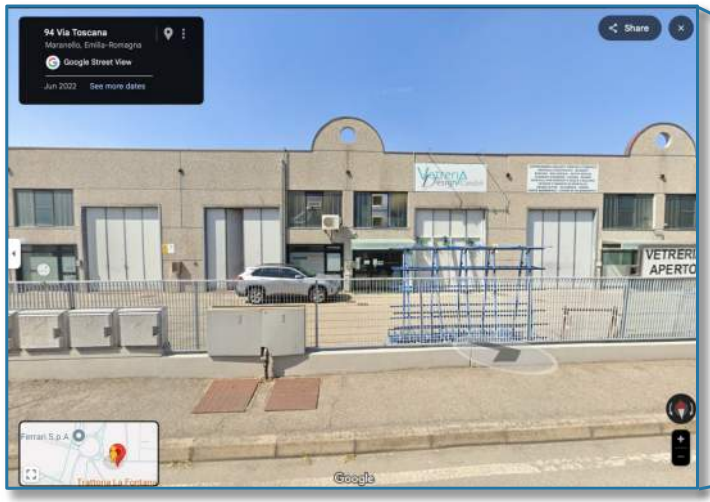
There are **two options** for AI Building Classification





Exploring AI for building classification

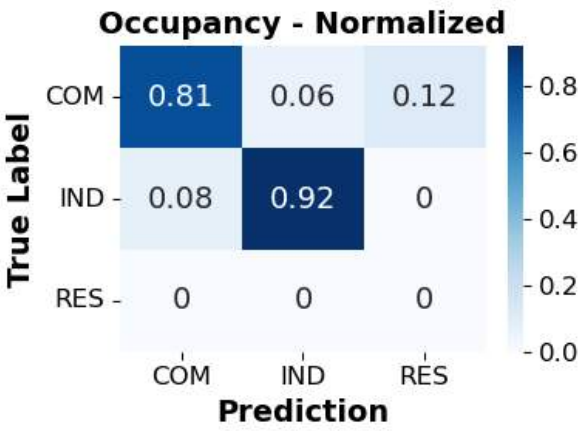
AI Building Classification using **Zero-Shot**

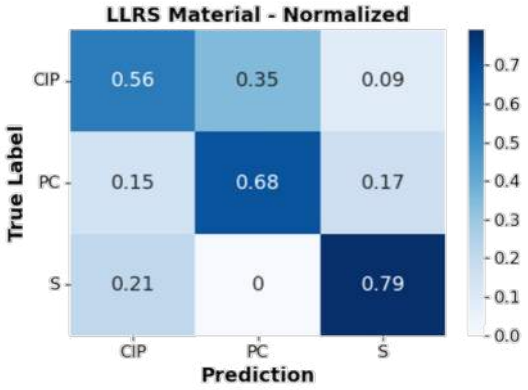


Non-residential area in Emilia-Romagna, Italy

Exploring AI for building classification

AI Building Classification using **Zero-Shot**





Exploring AI for construction costs

AI Chatbots can search recent online sources for construction costs

We asked three different AI bots for the exact same information:
Give me the average construction costs per square meter for urban, suburban and rural areas in Italy.

ChatGPT

Urban areas:
1200 -1600 € / m²

Sub-urban areas:
1000 -1300 € / m²

Rural areas:
800 -1200 € / m²

Claude

Urban areas:
1200 -1800 € / m²

Sub-urban areas:
900 -1400 € / m²

Rural areas:
700 -1200 € / m²

deepseek

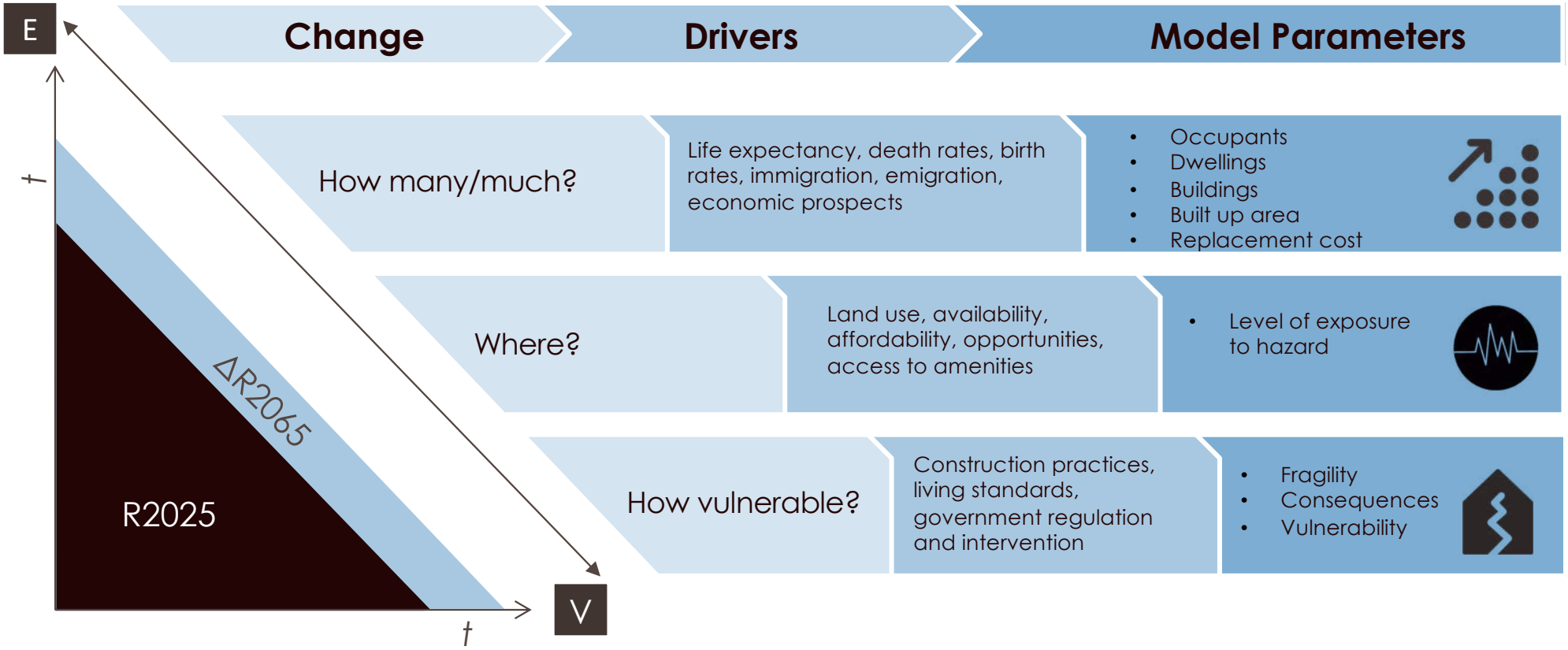
Urban areas:
1500 -2000 € / m²

Sub-urban areas:
1200 -1600 € / m²

Rural areas:
800 -1400 € / m²

It is possible to request only recent information and to list all sources of information.

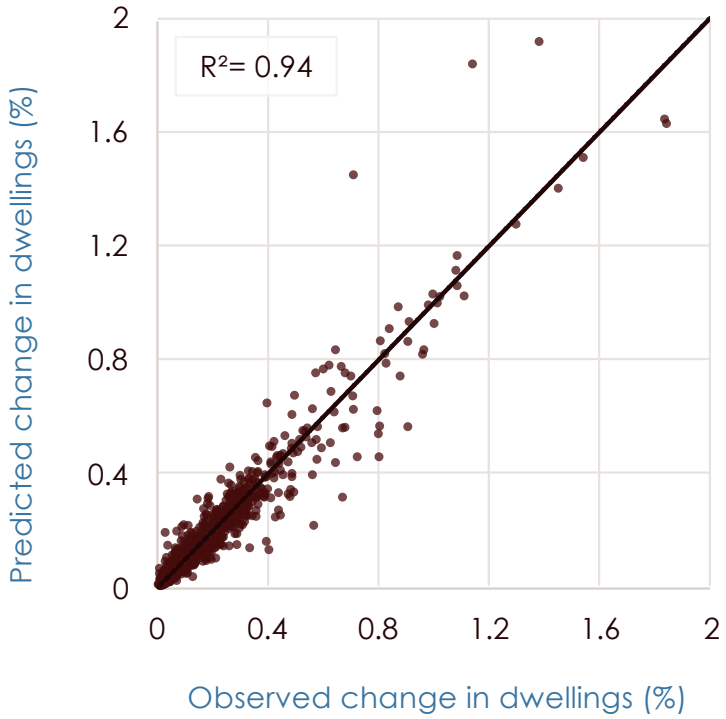
Forecasting exposure/risk



We use supervised learning to train models to predict past growth

Target	Drivers
Number of dwellings	Longitude - Latitude
	Geographic region
	Economic region
	GDP
	GDP per capita
	HDI
	Number of inhabitants
	Occupants per dwellings

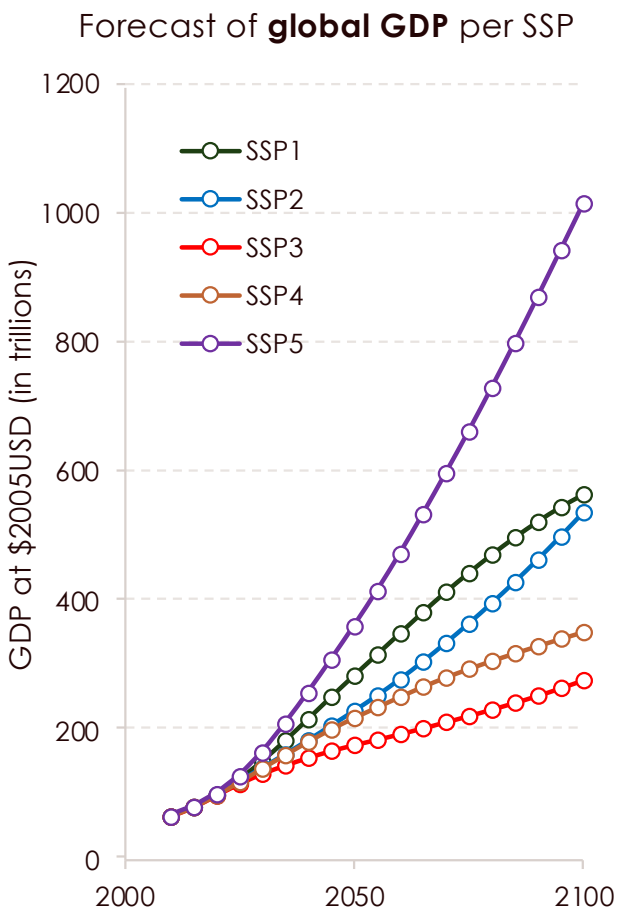
- **Method:** Random Forests
- **Folds:** 5
- **Forests:** 10
- **Train obs.:** 4,625
- **Test obs.:** 1,082
- M.A.E.: 3.2%

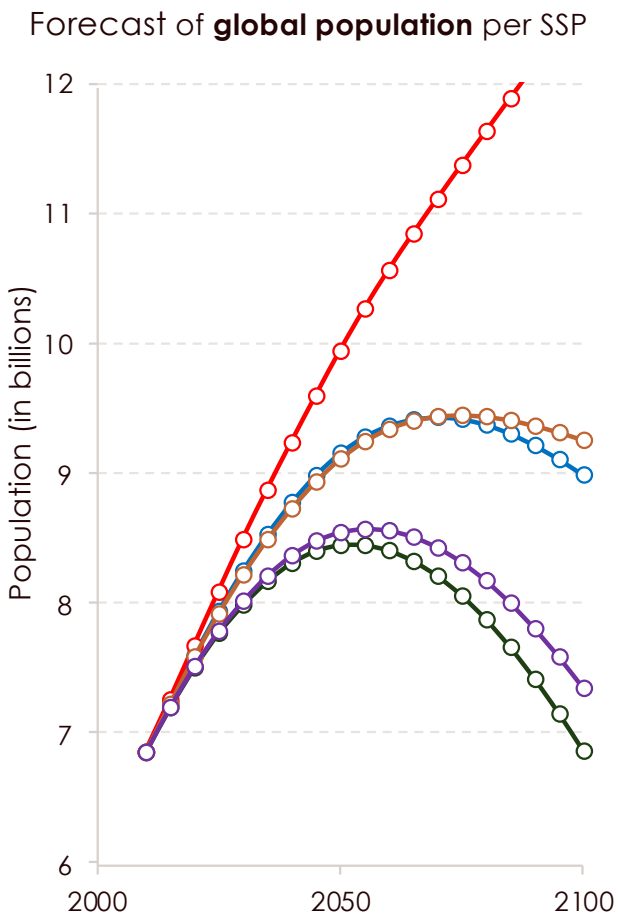


Forecasts require narratives for the future

Shared Socio-Economic Pathways (SSPs): scenarios that describe potential future global development trends in different dimensions, including:

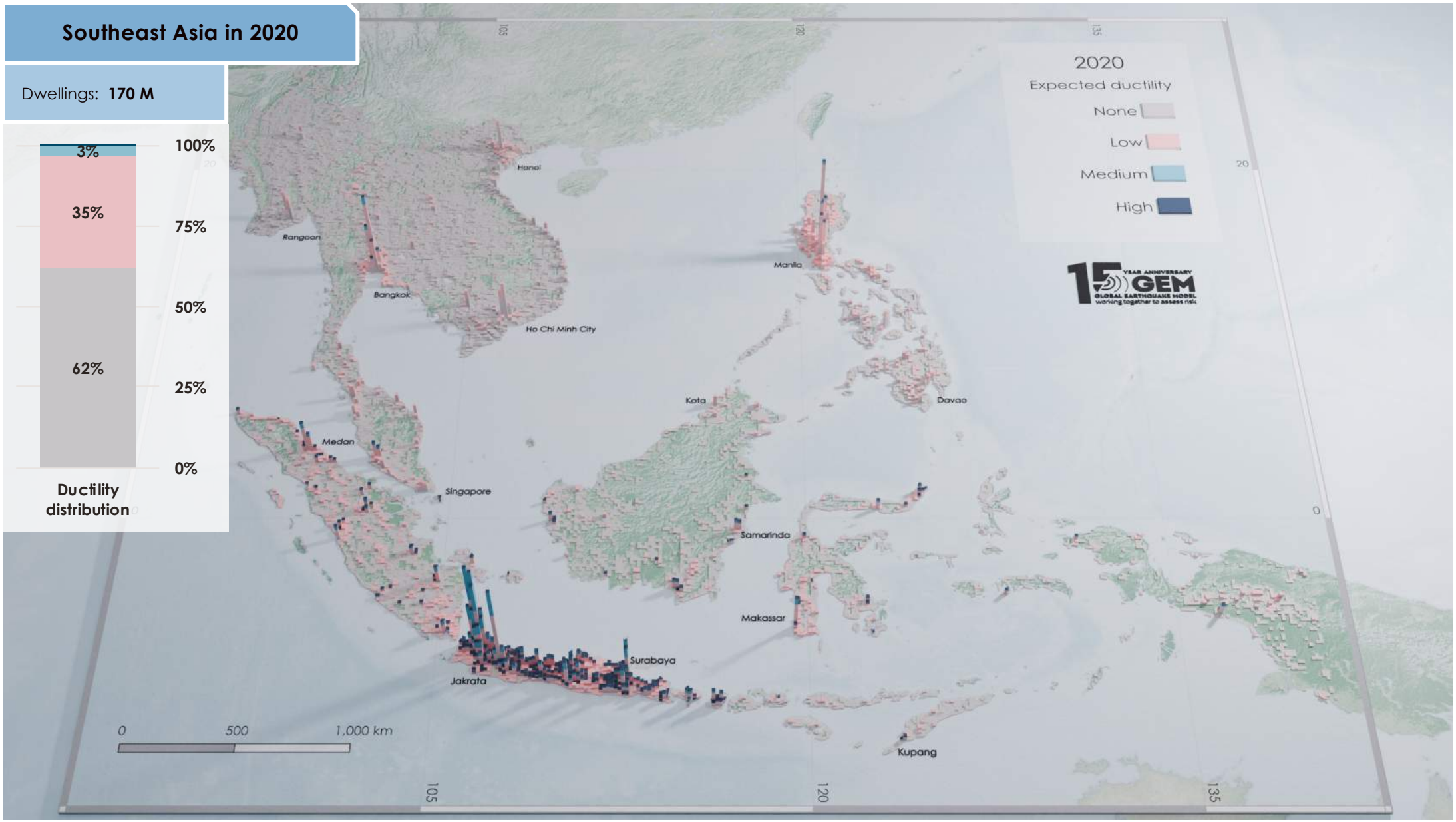
- Demographics
- Economics
- Urban





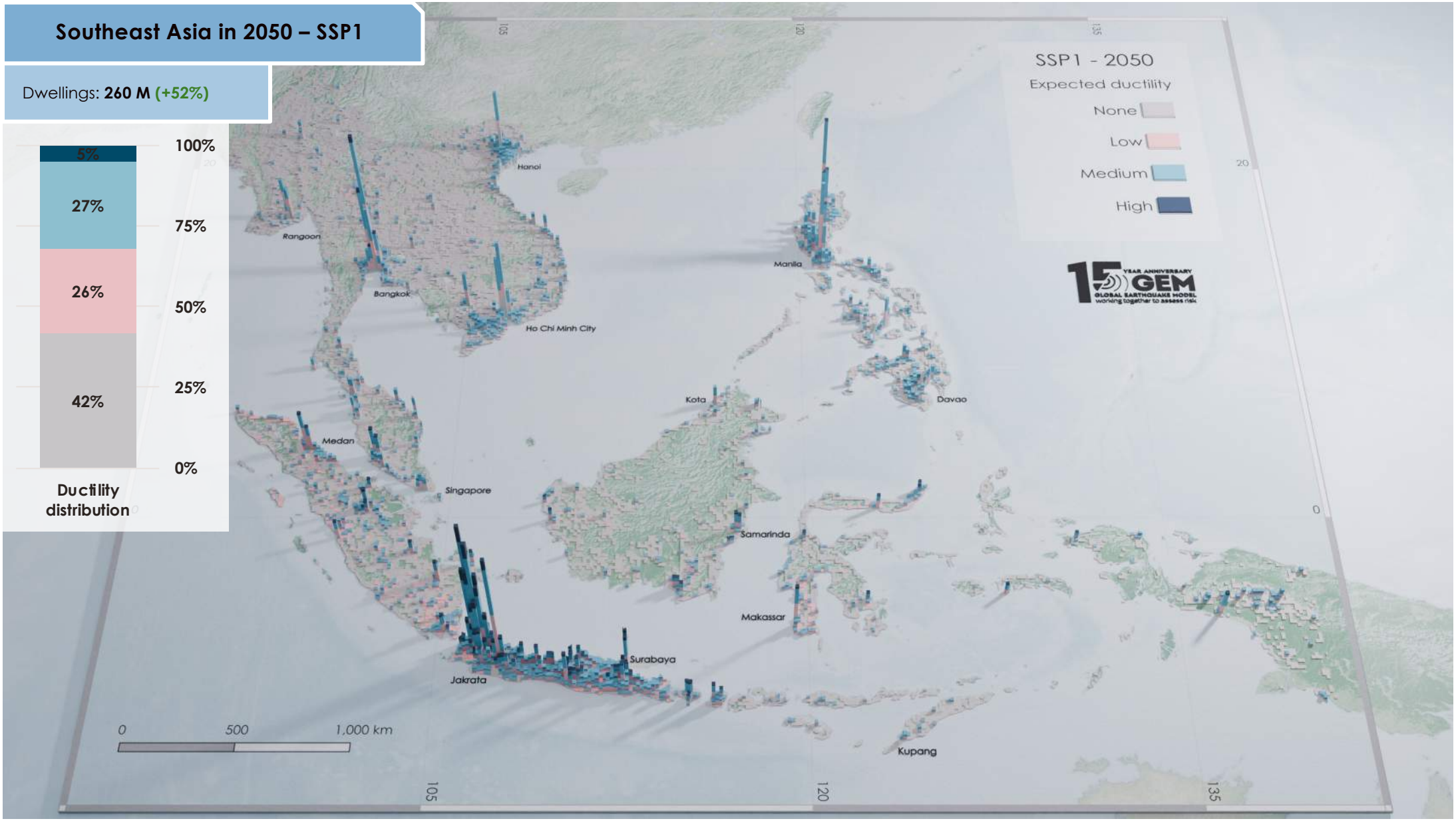
Relating the SSP narratives to future exposure development

	Narrative	Human action
SSP1	**Sustainability:** prioritizing environmental and social well-being, strong governance	• Sustainable demographics and construction, complemented with high economic and human development. Exposure projections have the lowest fertility growth rates, highest exposed value per capita, and strong adherence to the building codes.
SSP2	**Middle of the road (Business as usual)**: not too far from our historical behavior	• Projections have a moderate rate of growth in occupants and buildings, without significant variation in construction practices, building materials and seismic code compliance.
SSP3	**Regional rivalry (A rocky road):** competition, ineffective governance and a breakdown in global cooperation	• Construction grows faster to adjust to fast demographic growth, following practices of low sustainability. Building technology is unchanged and non-engineered construction increases.


Southeast Asia in 2020
Dwellings: 170 M
3%
35%
62%
100%
75%
50%
25%
0%
Ductility distribution
2020
Expected ductility
None
Low
Medium
High
15 YEAR ANNIVERSARY
GEM
GLOBAL EARTHQUAKE MODEL
working together to assess risk
Hanoi
Rangoon
Bangkok
Ho Chi Minh City
Manila
Kota
Davao
Medan
Singapore
Samarinda
Makassar
Surabaya
Jakrata
Kupang
0
500
1,000 km
105
120
135
20
0

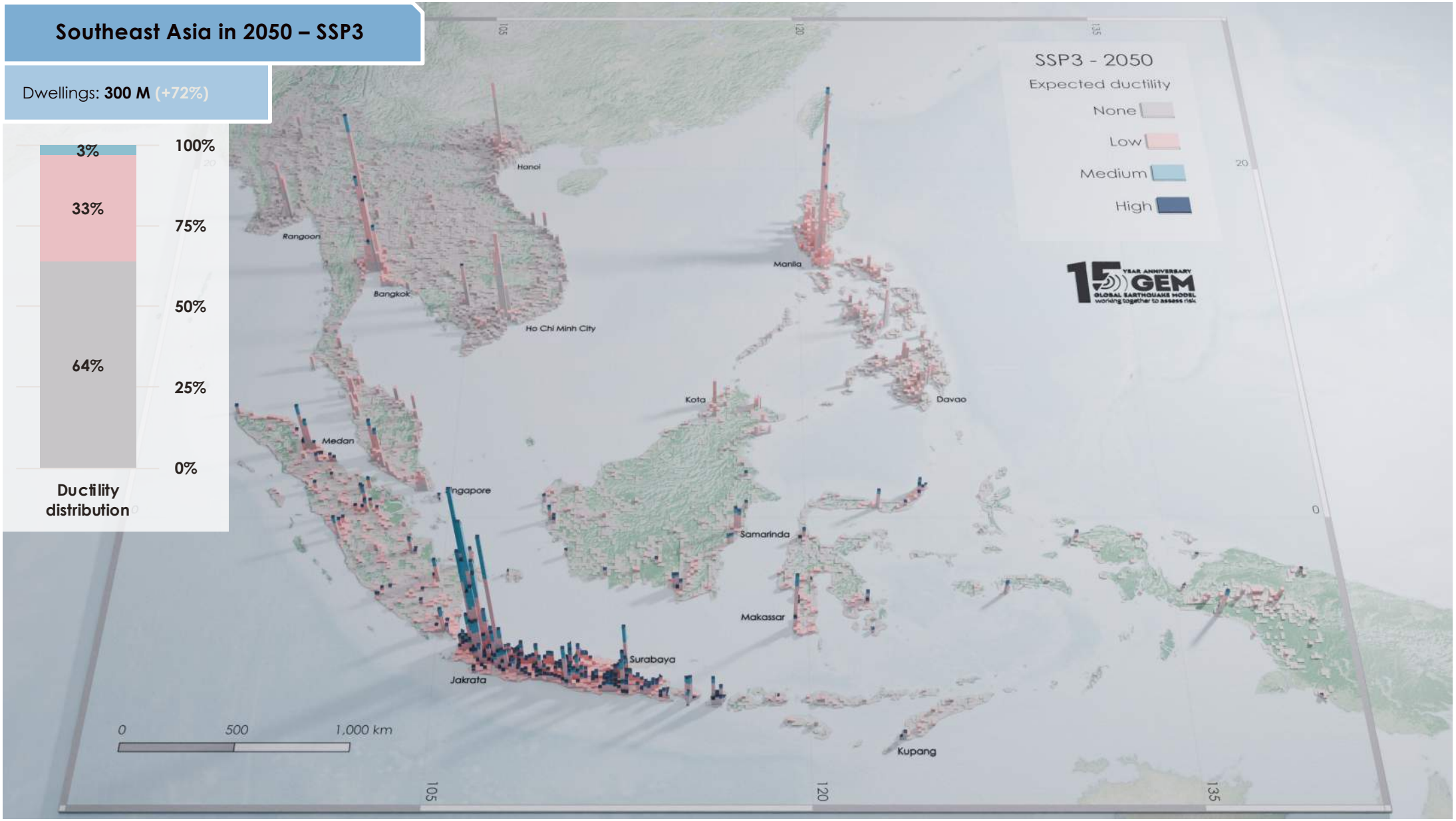
Southeast Asia in 2050 – SSP1

Dwellings: **260 M** **(+52%)**



Southeast Asia in 2050 – SSP3

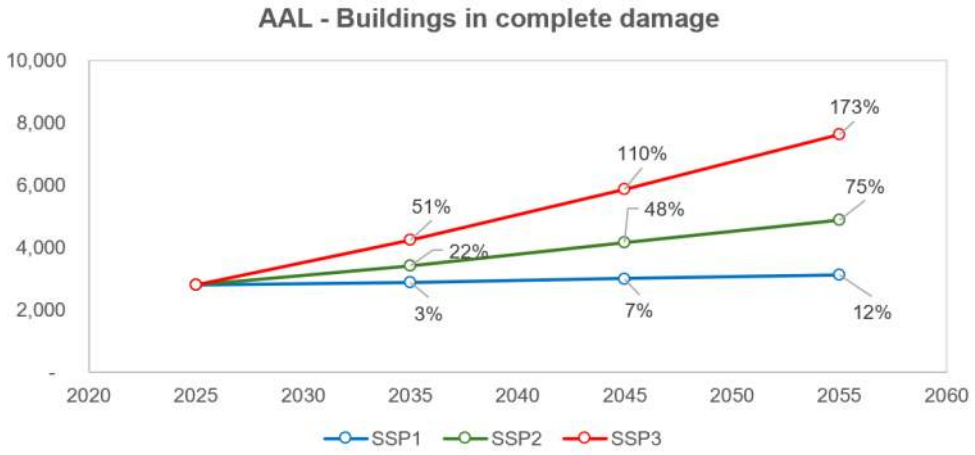
Dwellings: **300 M** (+72%)

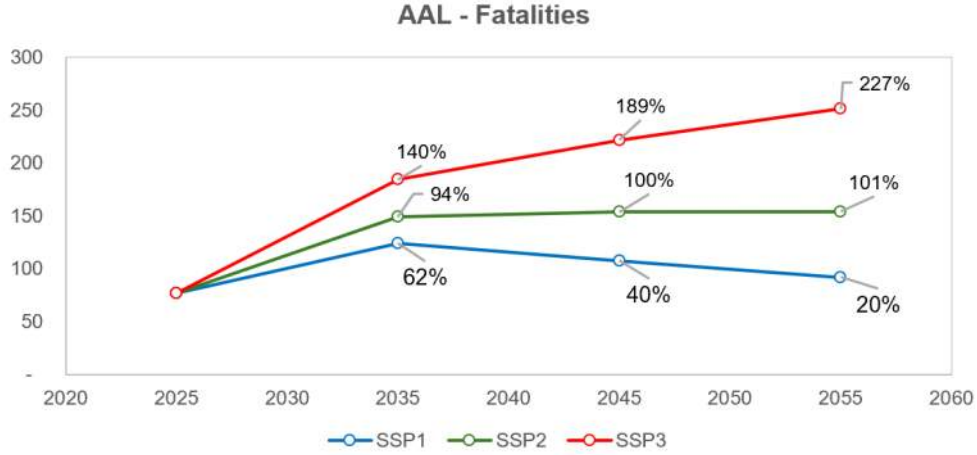


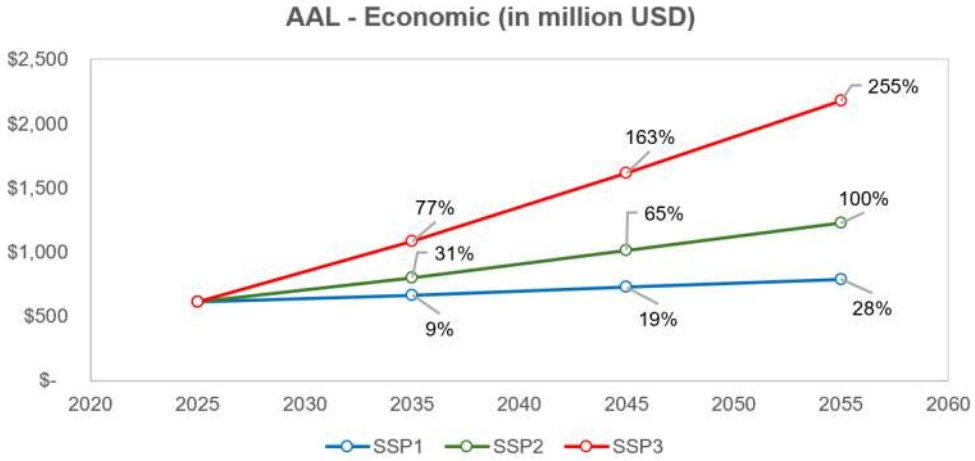
future risk and the carbon cost of earthquakes

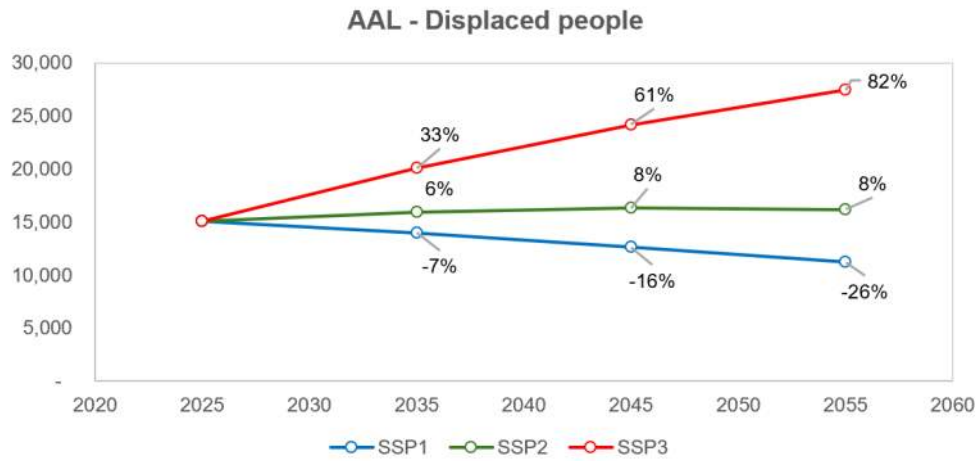
Forecasting various seismic risk metrics

El Salvador – each SSP relates to different assumptions on the enforcement of design codes



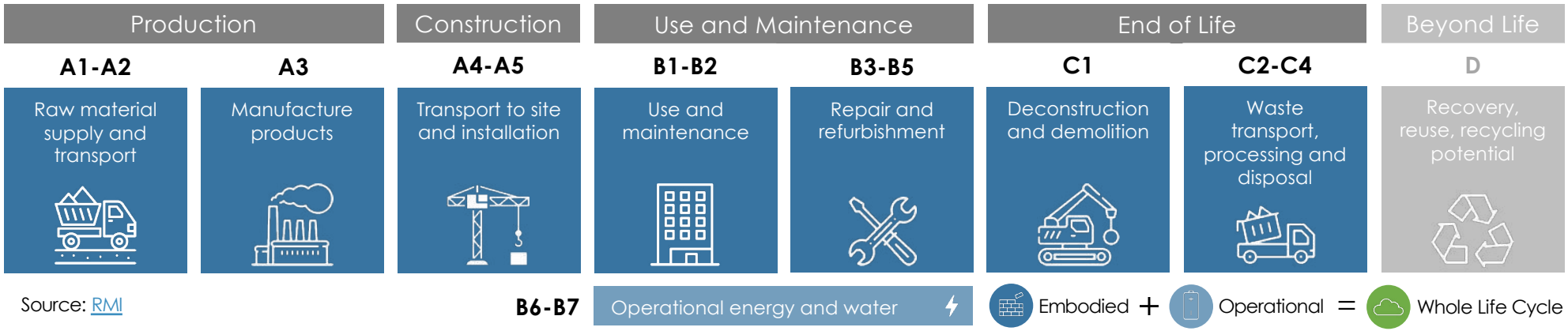






A new risk metric - embodied carbon

Embodied carbon represents the carbon dioxide equivalent emissions (**CO_2e**) that go into producing and transporting vital materials such as concrete, steel and glass throughout the entire lifecycle of a project:



Database of embodied carbon factors

Modules **A1-A3**		Quantity [unit/m^2]	×		Cradle to gate carbon [CO_2e/unit]				
Modules **A4/C2**		Mass [ton/m^2]	×		Distance to factory [km]	×		Transport factor [CO_2e/ton/km]	
Module **A5**		Mass [ton/m^2]	×		Gravity [m/s^2]	×		Half building height [m]	×	Diesel factor [CO_2e/MJ]
Module **C1**		C1 factor [CO_2e/m^2]							
Modules **C3-C4**		Mass [ton/m^2] (to landfill)	×		C3-C4 factor [CO_2e/ton]				

EC3 | Environdec | EPD Hub | EPDItaly (ICMQ)

Whole life carbon assessment for the built environment — RICS

Total replacement embodied carbon - building type and occupancy

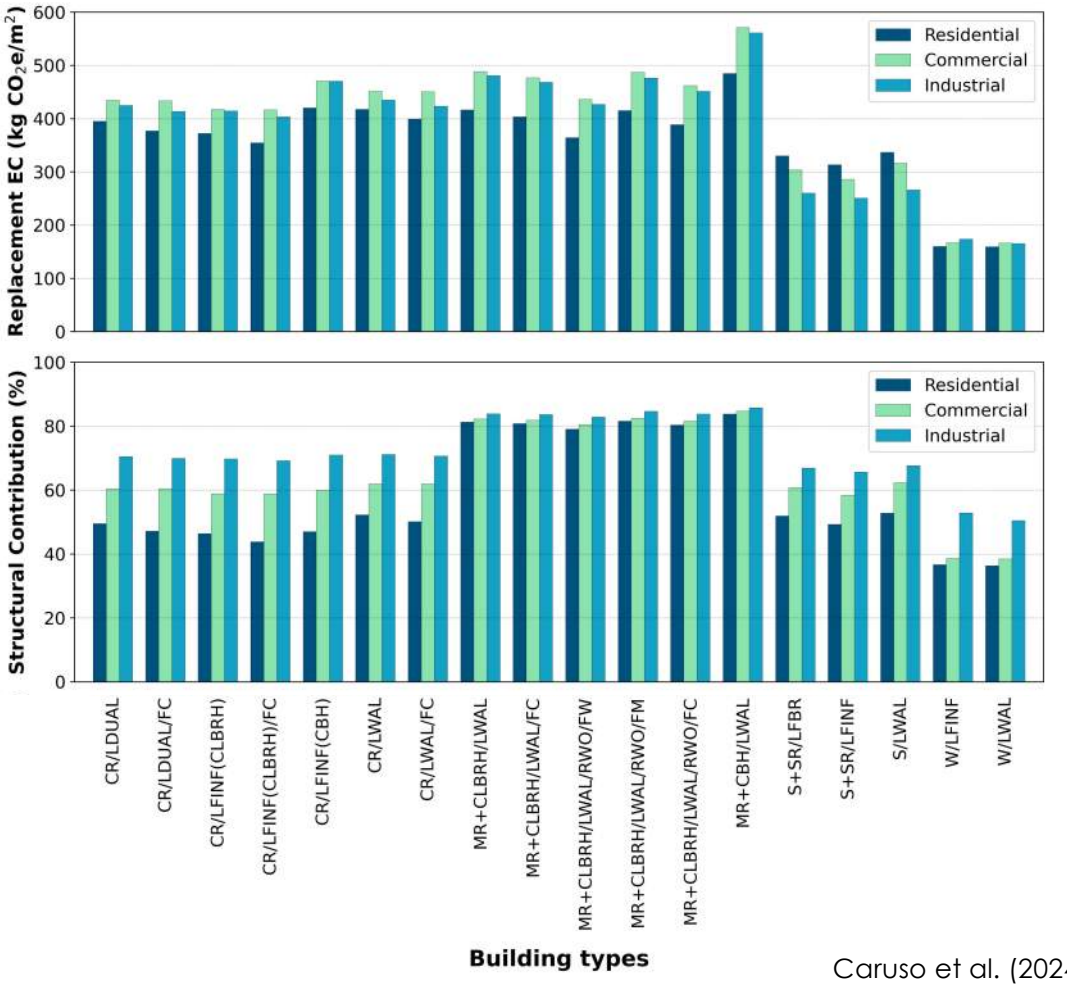
Embodied Carbon Factors (A1-A5, C1-C4) per unit of component [kg CO_2e/unit]

×

Quantity of components [unit/m^2]

×

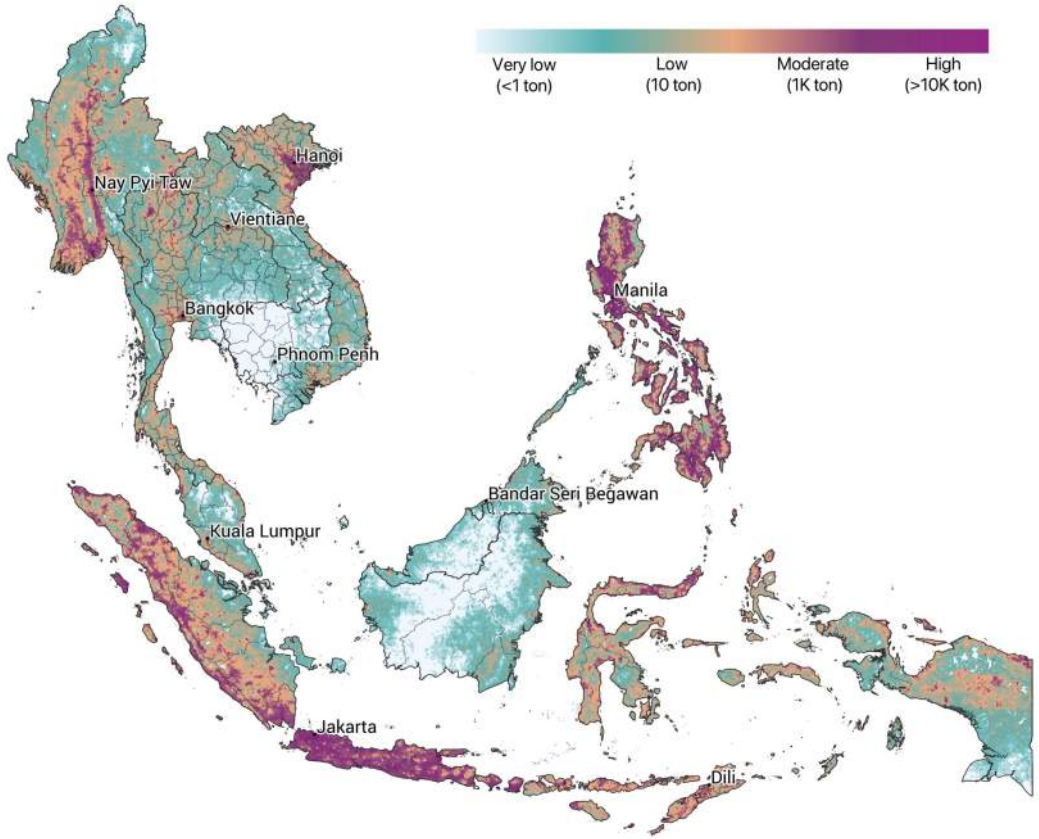
Built Area (exposure models) [m^2]



Caruso et al. (2024)

Average Annual Embodied Carbon (AAEC) due to earthquakes in 2025

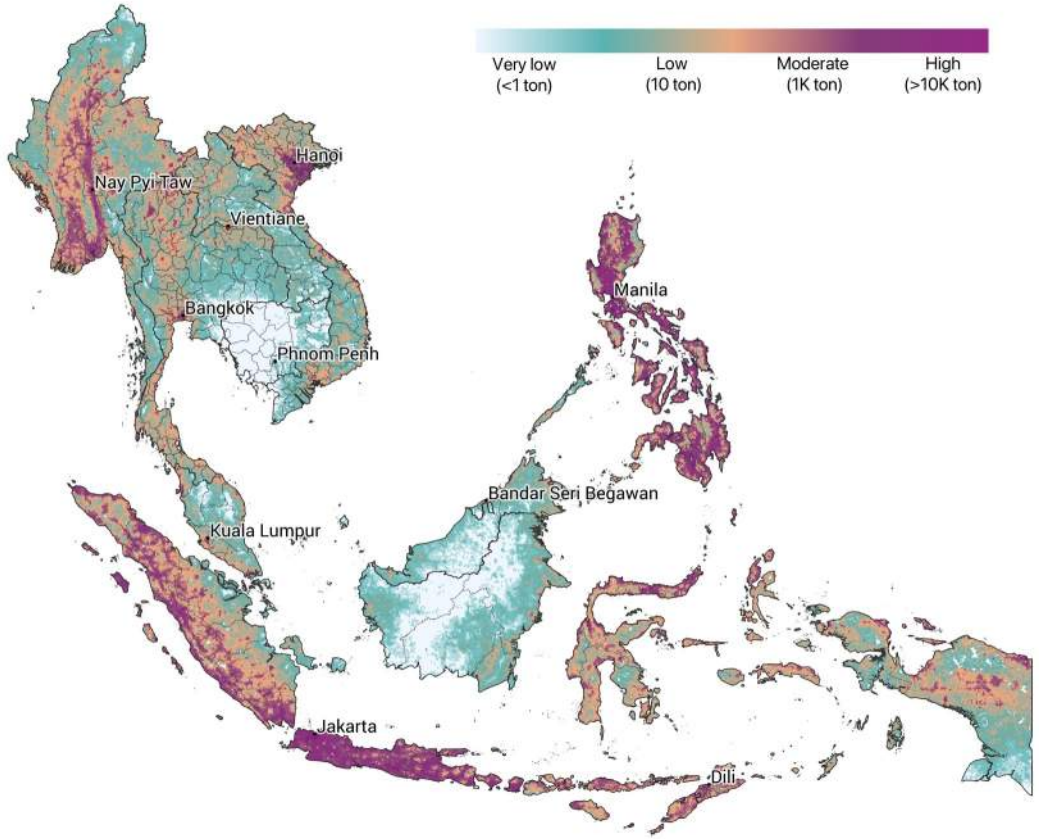
Average annual earthquake risk in **Southeast Asia** in 2025 terms of **embodied carbon**



Global Assessment Report (2025)

Forecasted AAEC due to earthquakes in 2050 under SSP3

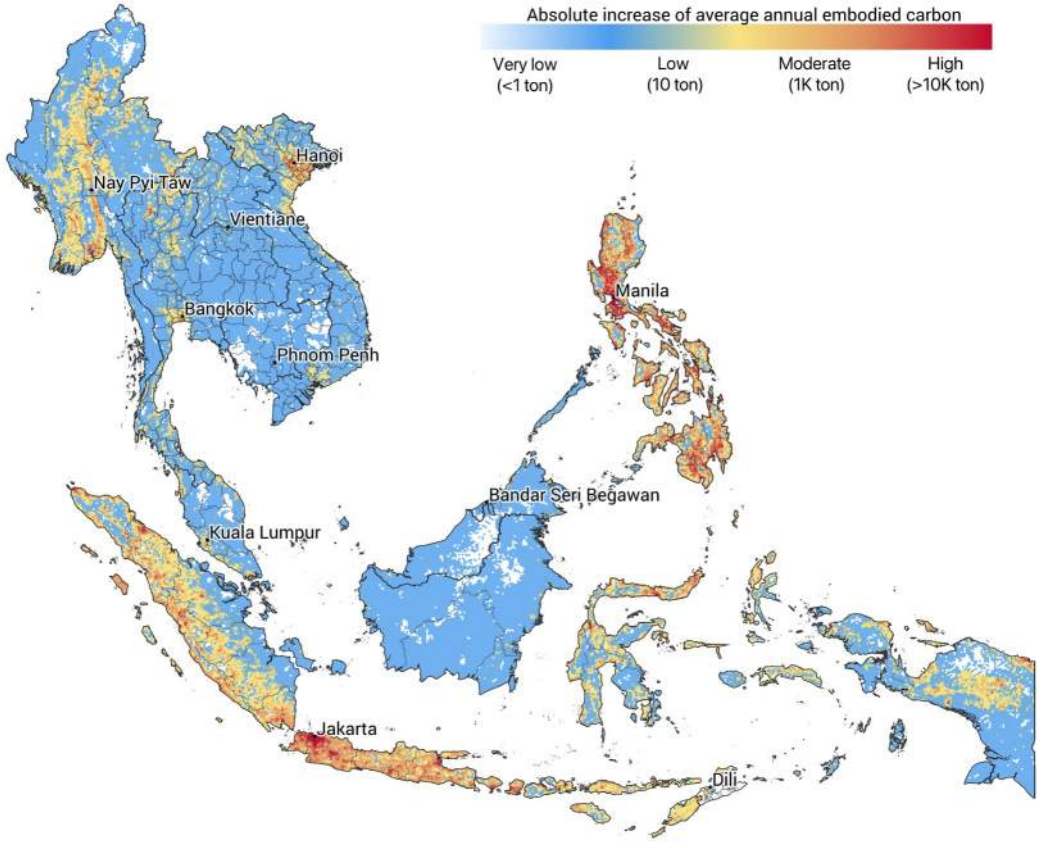
Average annual earthquake risk in **Southeast Asia** in 2050 terms of **embodied carbon**



Global Assessment Report (2025)

Forecasted AAEC due to earthquakes in 2050 under SSP3

Increase in average annual earthquake risk in **Southeast Asia** in terms of **embodied carbon**

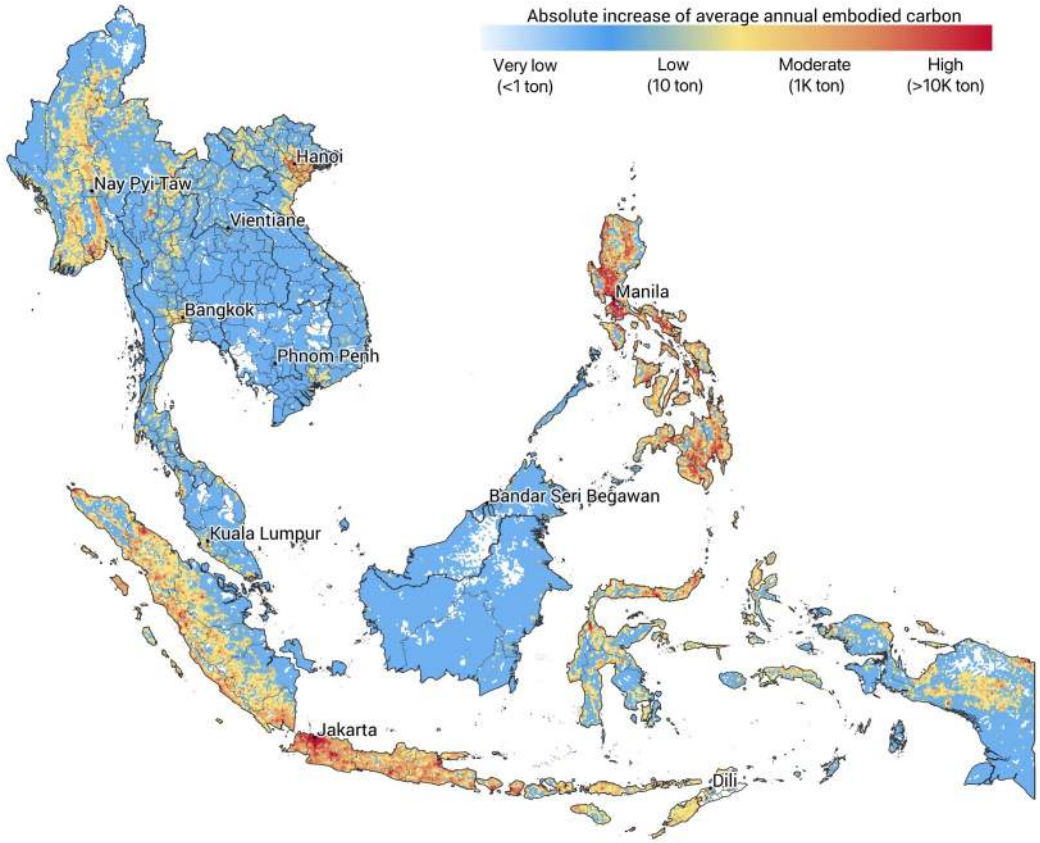


Reaching up to 10 million tonnes of CO_2 equivalent by 2050 in the whole region

Global Assessment Report (2025)

Forecasted AAEC due to earthquakes in 2050 under SSP3

Increase in average annual earthquake risk in **Southeast Asia** in terms of **embodied carbon**



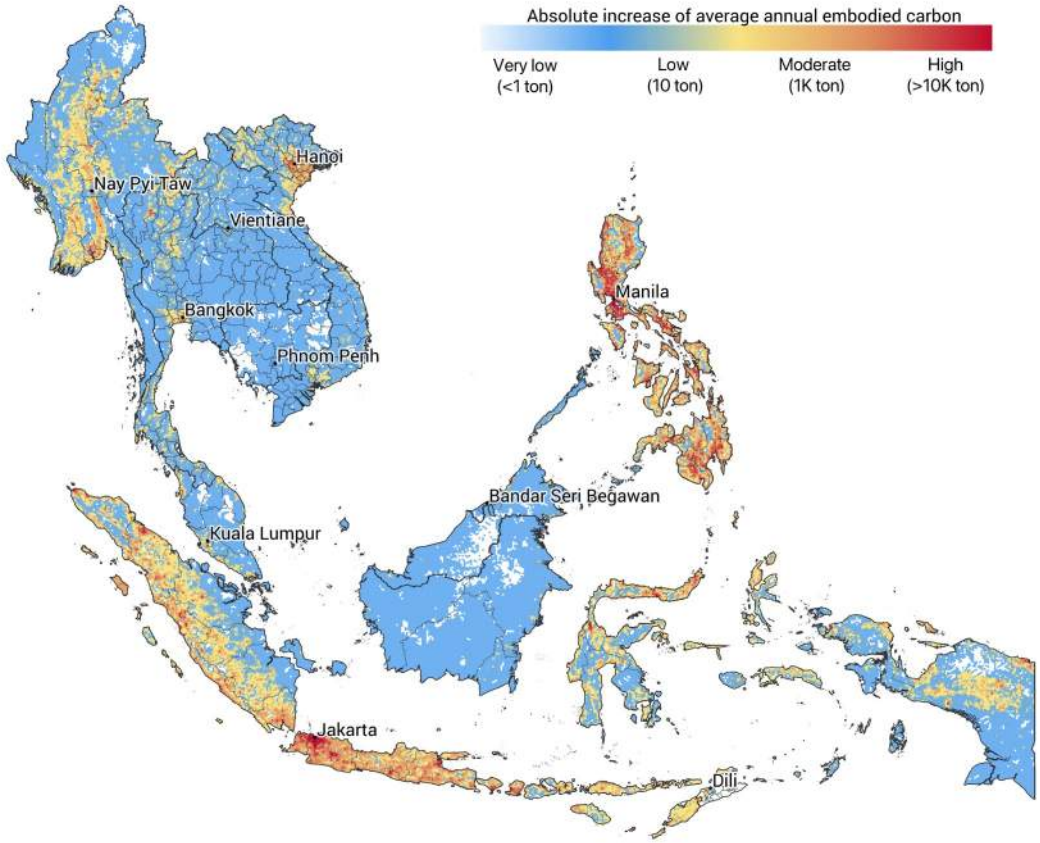
When we build or 'build back better' we should also consider the embodied carbon of materials and construction practices

Otherwise, by 2050 we can expect to **double** the **average annual embodied carbon** in Southeast Asia due to earthquake damage

Global Assessment Report (2025)

Forecasted AAEC due to earthquakes in 2050 under SSP3

Increase in average annual earthquake risk in **Southeast Asia** in terms of **embodied carbon**



Otherwise, by 2050 we can expect to **double** the **average annual embodied carbon** in Southeast Asia due to earthquake damage

=

✈️ **22K flights Paris-New York** with 200 passengers or

⚡ **Electricity use** in Slovenia in 2021 (~17.5 TWh) or

🌊 **13 km²** of Arctic summer sea ice melted

each year!

The next global seismic risk model (v2026)

Buildings lost

Today, 2050

CO_2e Embodied carbon

Area lost

Today, 2050

Fatalities

Today, 2050

Exposure to liquefaction

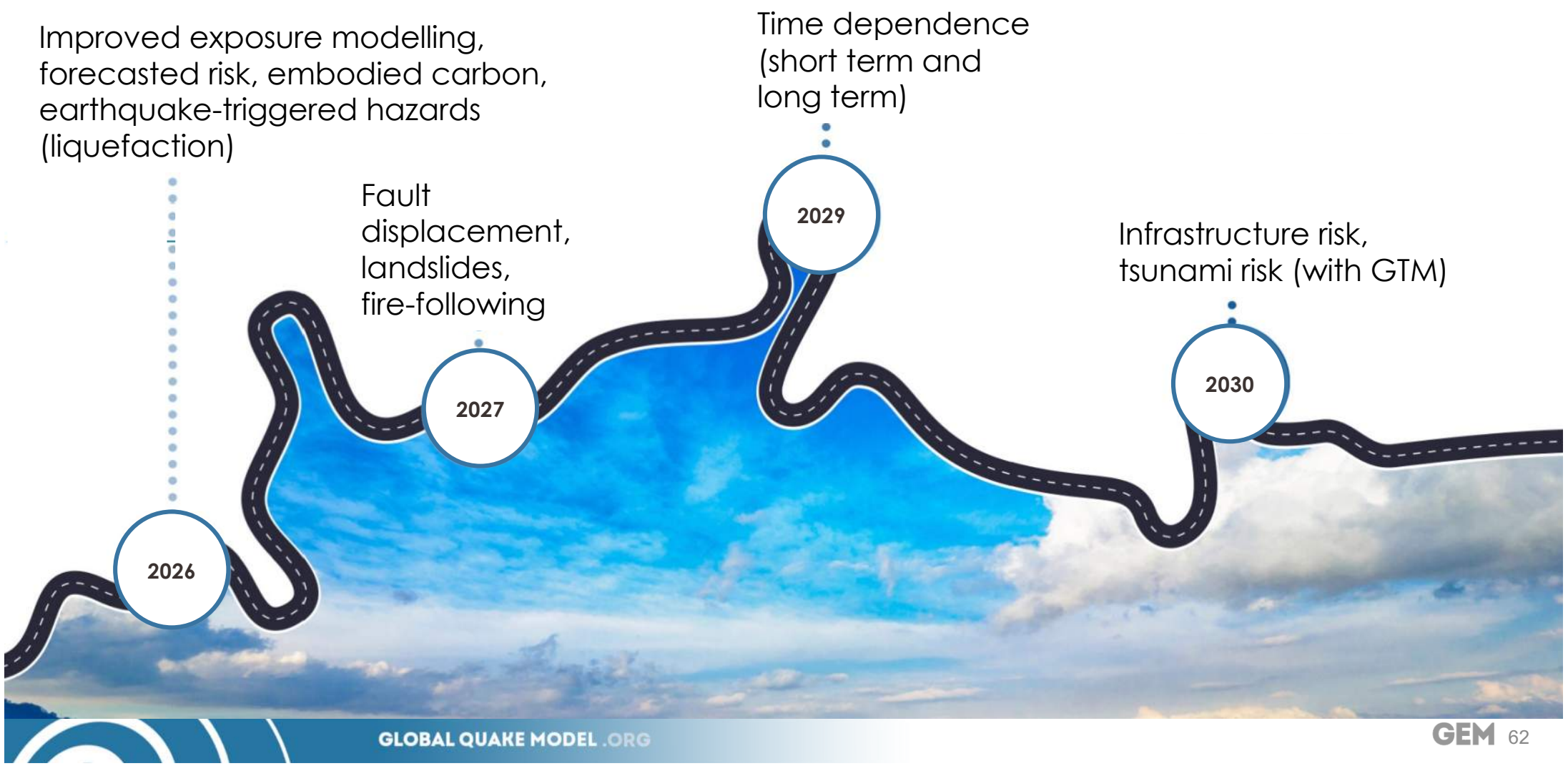
Displaced

Today, 2050

Economic loss

Today, 2050

Improved seismic risk modelling by 2030



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Thank you!

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