



GLOBAL EXPOSURE MODELLING FOR MULTI-HAZARD RISK ASSESSMENT

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Daniela Gonzalez, Catarina Costa, Anirudh Rao, Daniel Gomez

27-29 November 2024

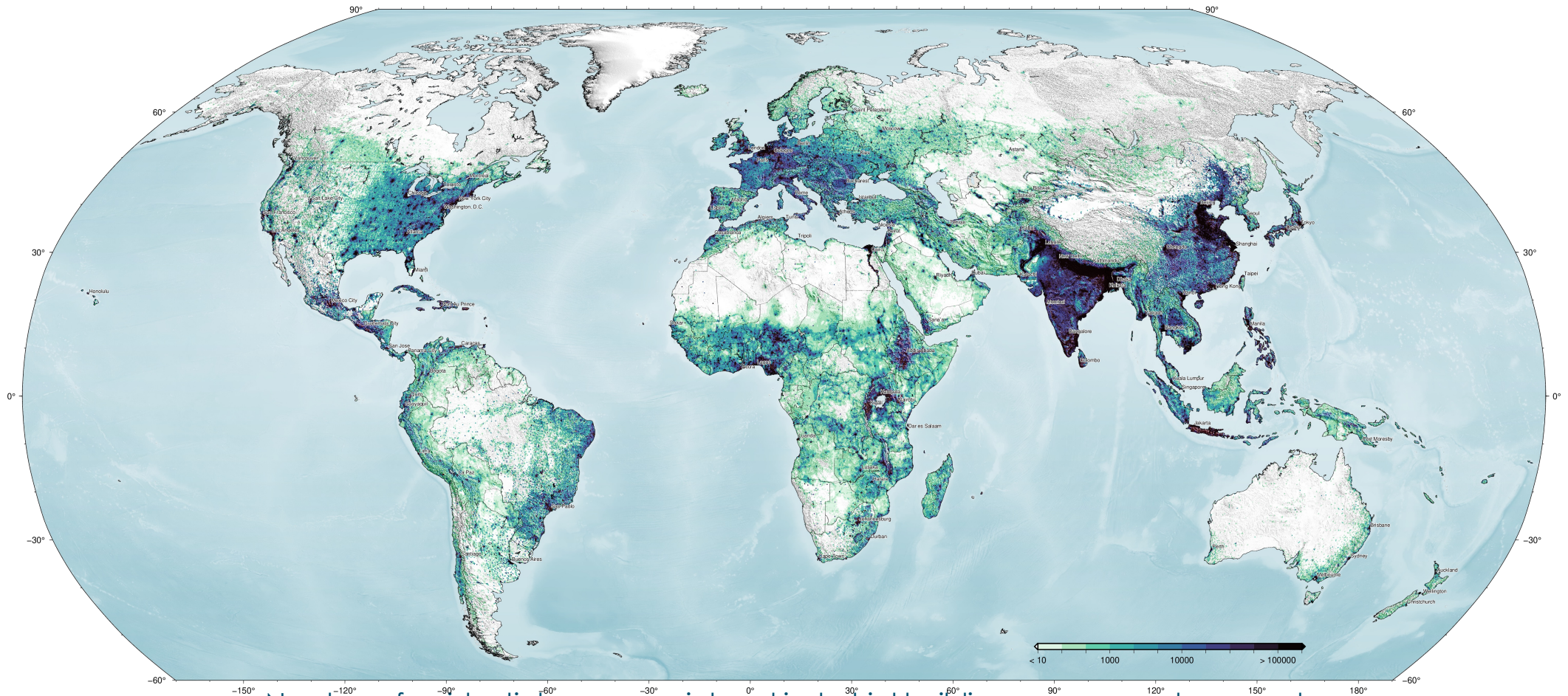
102nd Journées Luxembourgeoises de Géodynamique (JLG)

EFEHR Scientific Session 2024



working together to assess risk

The 2023 GEM's Global Exposure Model

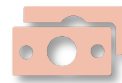


Number of residential, commercial and industrial buildings on an evenly spaced hexagon grid with a constant spatial resolution of 0.30x0.36 decimal degrees.

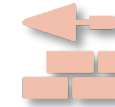
The 2023 GEM's Global Exposure Model



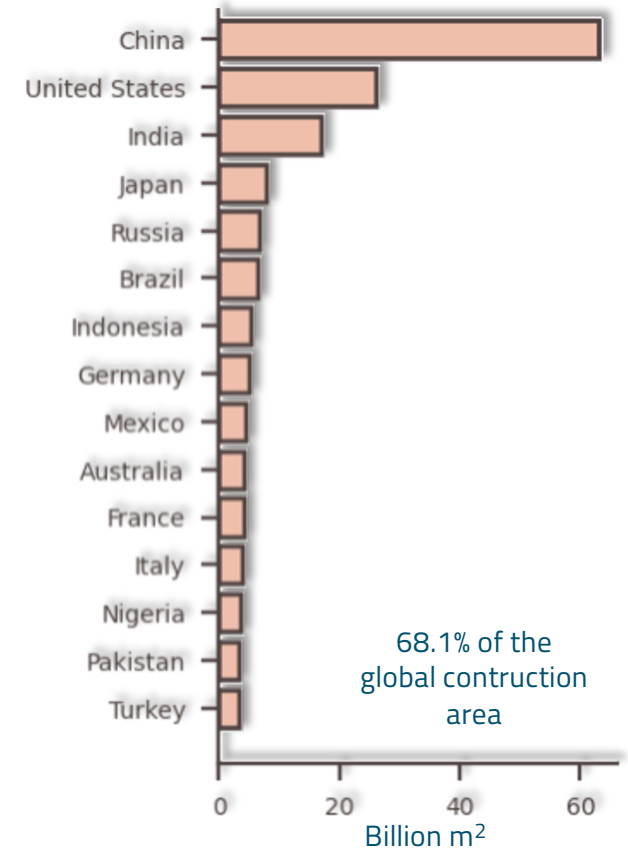
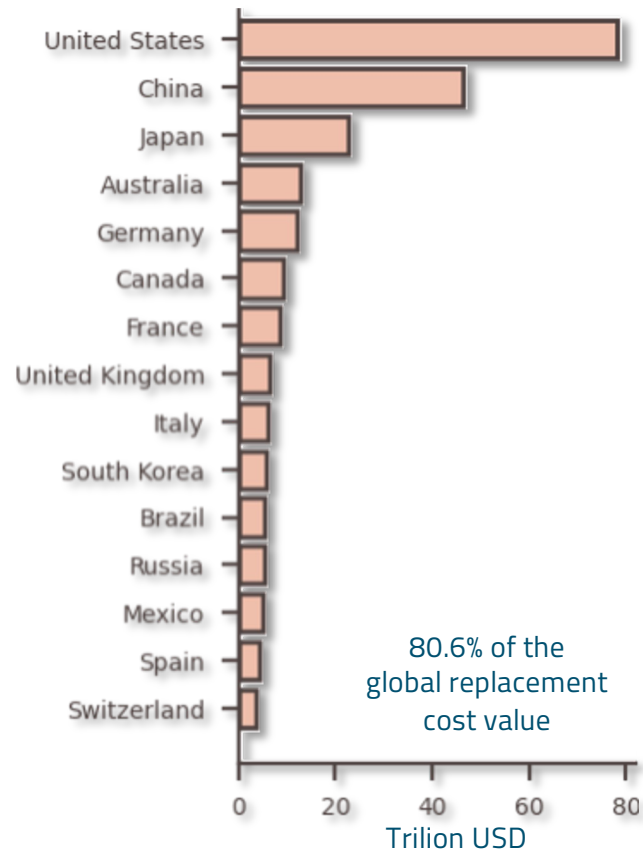
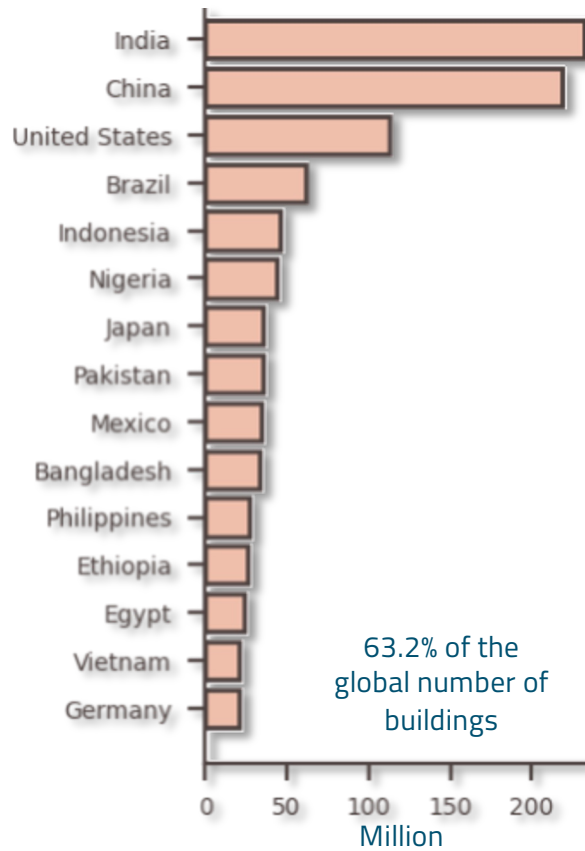
Number of buildings



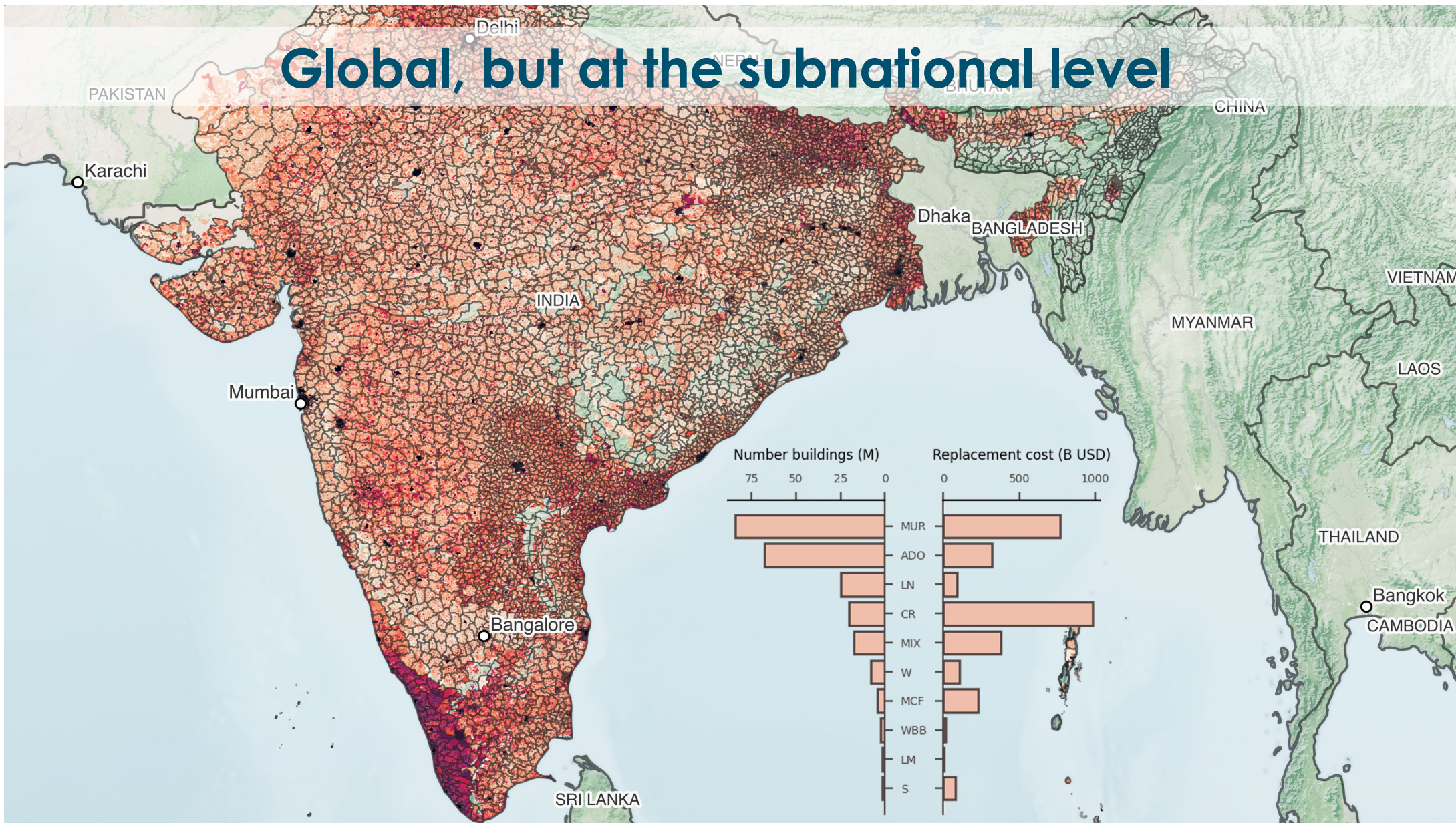
Replacement cost



Construction area

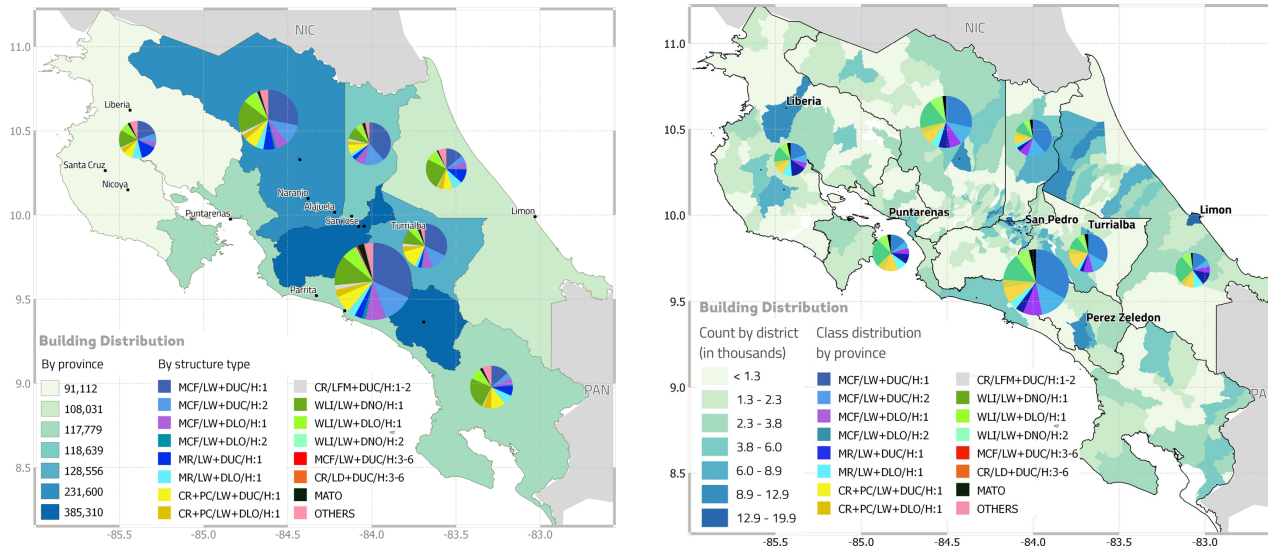


Global, but at the subnational level

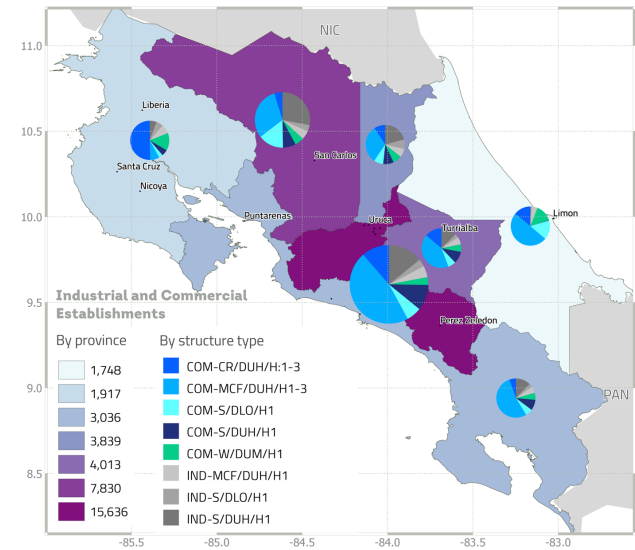


Exposure modelling within the GEM Foundation

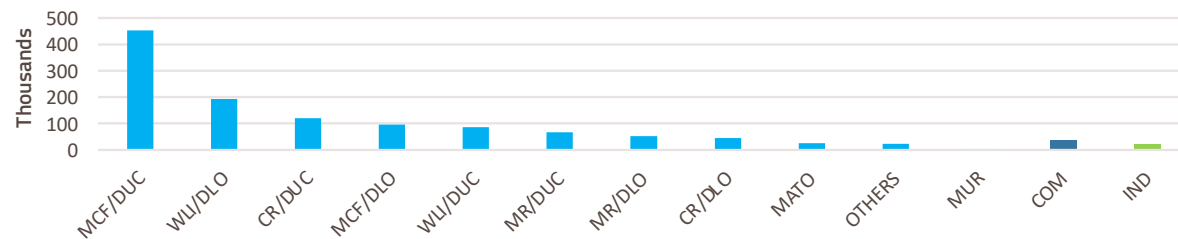
Residential building stock



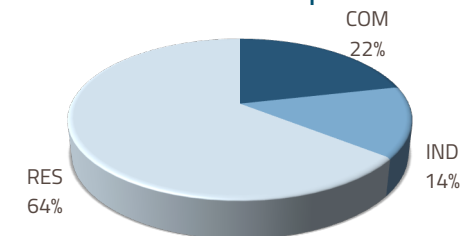
Non-residential building stock



Distribution of building classes



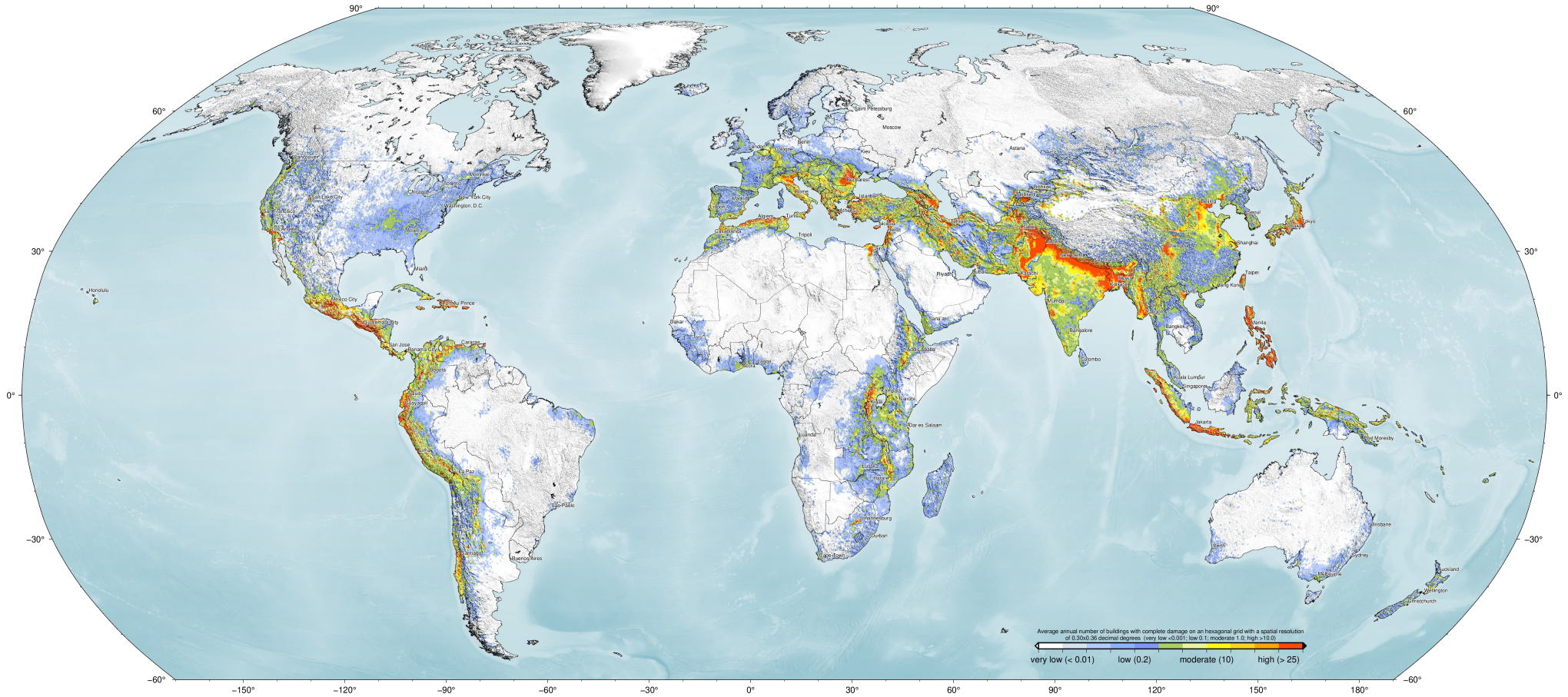
Distribution of capital stock





Some Recent Use Cases

Global Seismic Risk Assessment



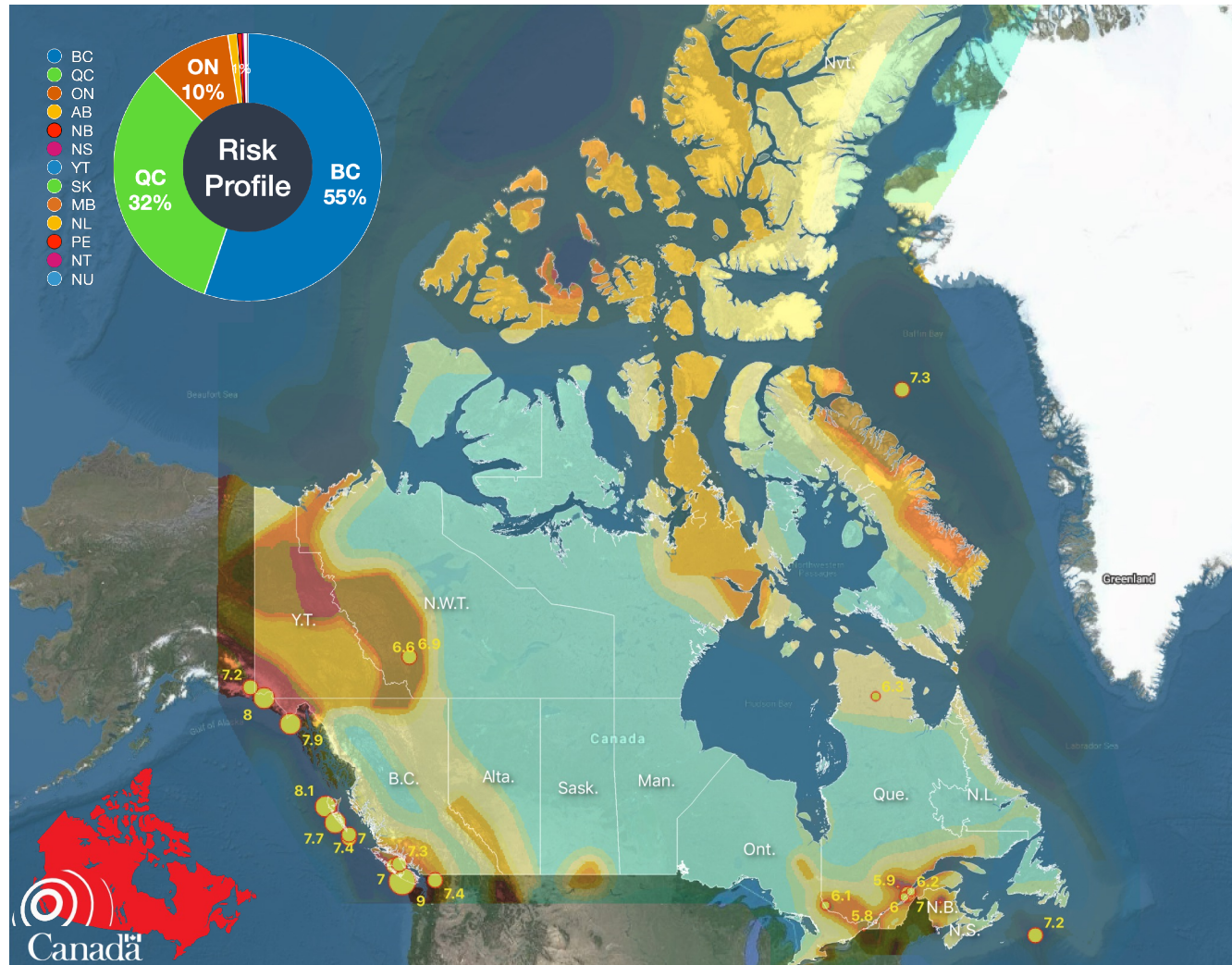
Average Annual Number of Buildings Destroyed on an evenly spaced hexagon grid with a constant spatial resolution of 0.30x0.36 decimal degrees.



Some Recent Use Cases

National Seismic Risk Model for Canada

- A new generation risk model
- Comprises updated hazard and new exposure information country-wide
- Developed with NRCanada



Some Recent Use Cases

Investment in Earthquake and Flood Risk Reduction in Türkiye

THE WORLD BANK
IBRD - IDA

Who We Are / News This page in: English | Türkçe

PRESS RELEASE | SEPTEMBER 27, 2022

\$512 million World Bank Loan to Expand Finance for Bolstering Homes, Infrastructure, and Resilience to Earthquakes, Flooding in Türkiye

WASHINGTON, September 27, 2022—The World Bank today approved \$512.2 million in financing to help Türkiye expand access to housing and infrastructure, improve climate and natural hazards, with the goal of supporting the country's economic development.

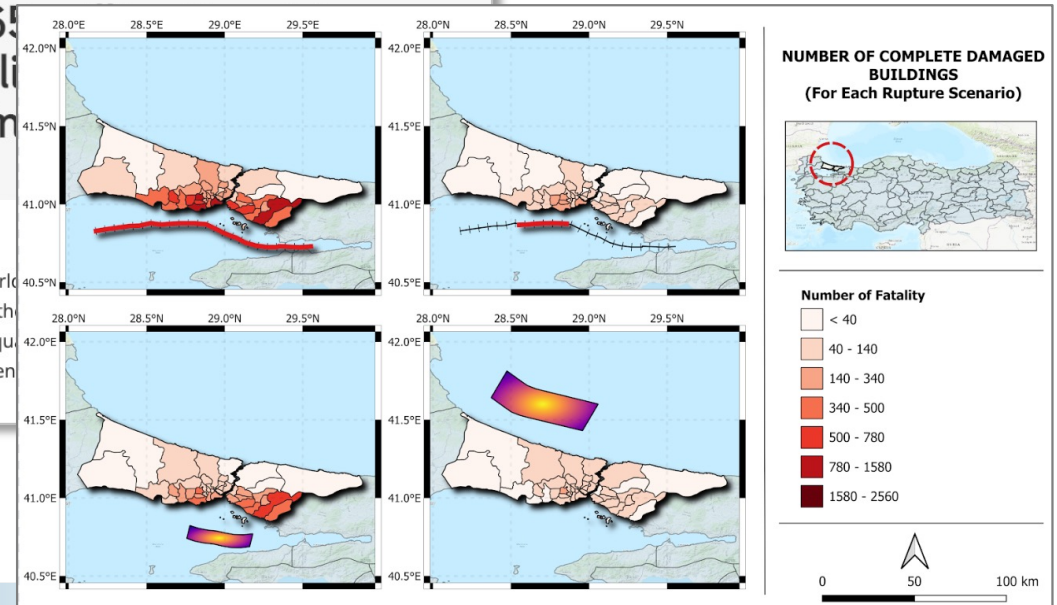
THE WORLD BANK
IBRD - IDA

Who We Are / News This page in: English | Türkçe

PRESS RELEASE | JUNE 9, 2021

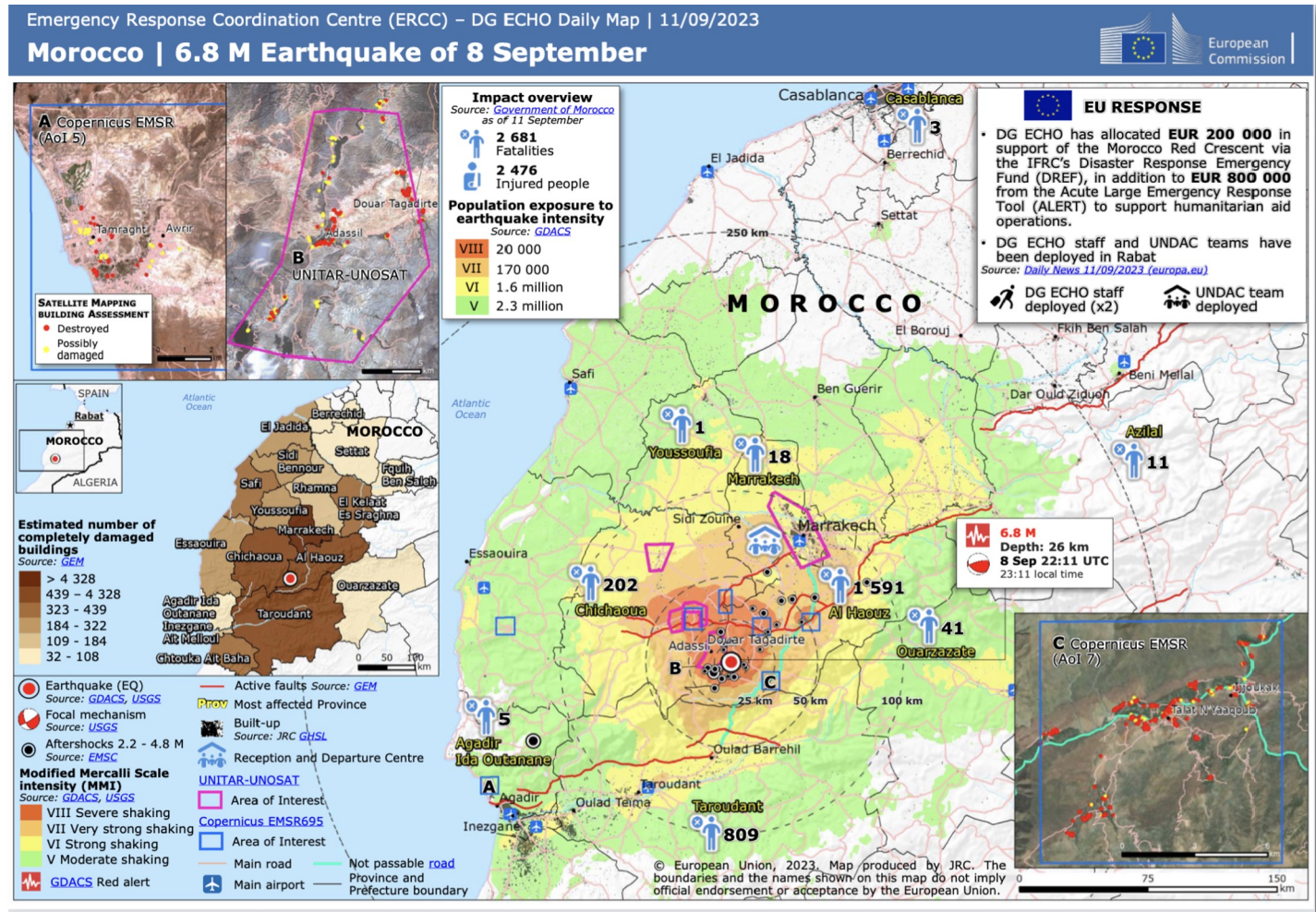
World Bank Provides \$265 million loan to Turkey to strengthen buildings against the dangers of earthquakes, improve energy efficiency of public buildings

WASHINGTON, June 9, 2021 – The World Bank today approved a \$265 million loan to Turkey to strengthen buildings against the dangers of earthquakes, improve energy efficiency of public buildings, and reduce carbon emissions.



Some Recent Use Cases

Rapid multi-hazard impact assessment for DGECHO, the JRC and the World Food Programme



Some Recent Use Cases

Expansion of the Earthquake Risk CAT Bond in Latin America to Floods



CASE STUDY

Super-sized Catastrophe Bond for Earthquake Risk in Latin America

OVERVIEW

The World Bank helped the countries of the Pacific Alliance—Colombia, Chile, Mexico, and Peru—insure themselves against earthquake risk.

Understanding the significant financial implications that earthquakes can have for a country's economy, the finance ministers of the four countries set the ambitious goal of working together to address this risk, increase countries' resilience to natural disasters, and expand their disaster financing options—all without increasing sovereign debt.



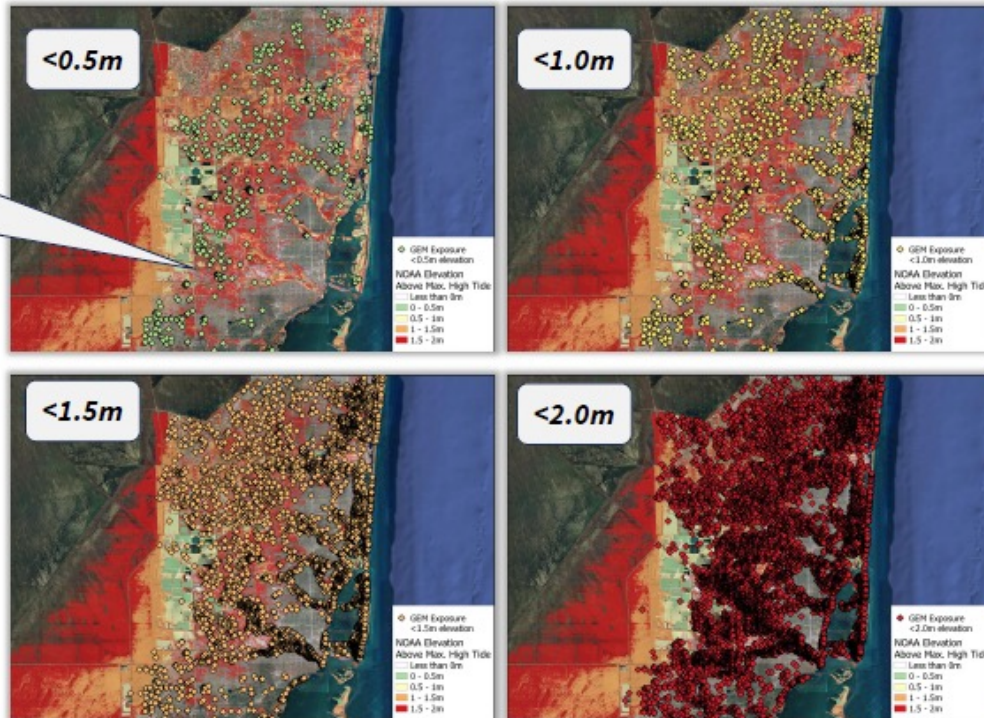
Earthquake recovery. Photo credit: Thinkstock.

Some Recent Use Cases

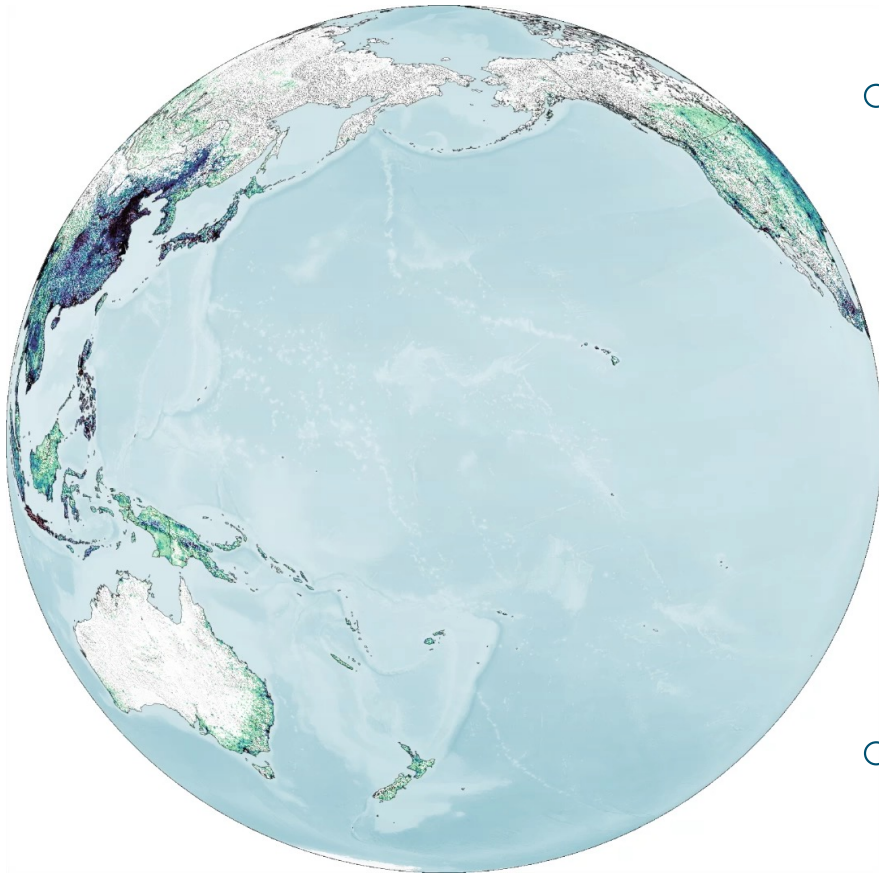
Assessment of the impact of tsunamis in coastal areas

2. Financial Impact of Chronic SLR

Per location inundated,
GEM exposure provides:
'lon'
'lat'
'value-residents'
'value-structural'
'value-nonstructural'



Main Ingredients of an Exposure Model



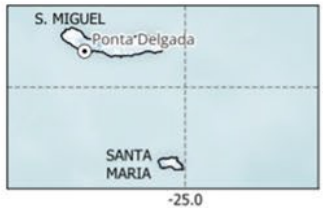
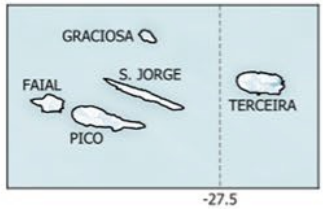
- Number of buildings
- Average areas
- Construction costs
- Vulnerability classes
- Location of buildings



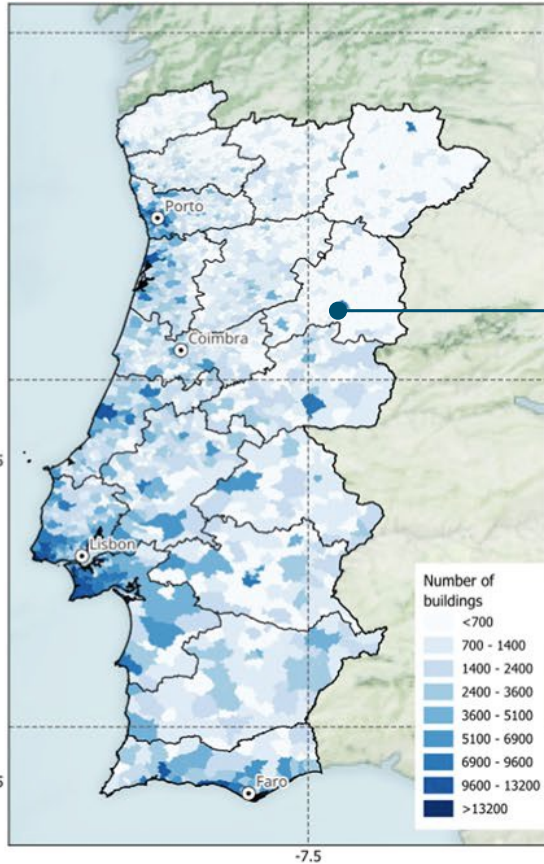
Estimating Number of Buildings

Leveraging housing census information and socio-economic data

Azores islands



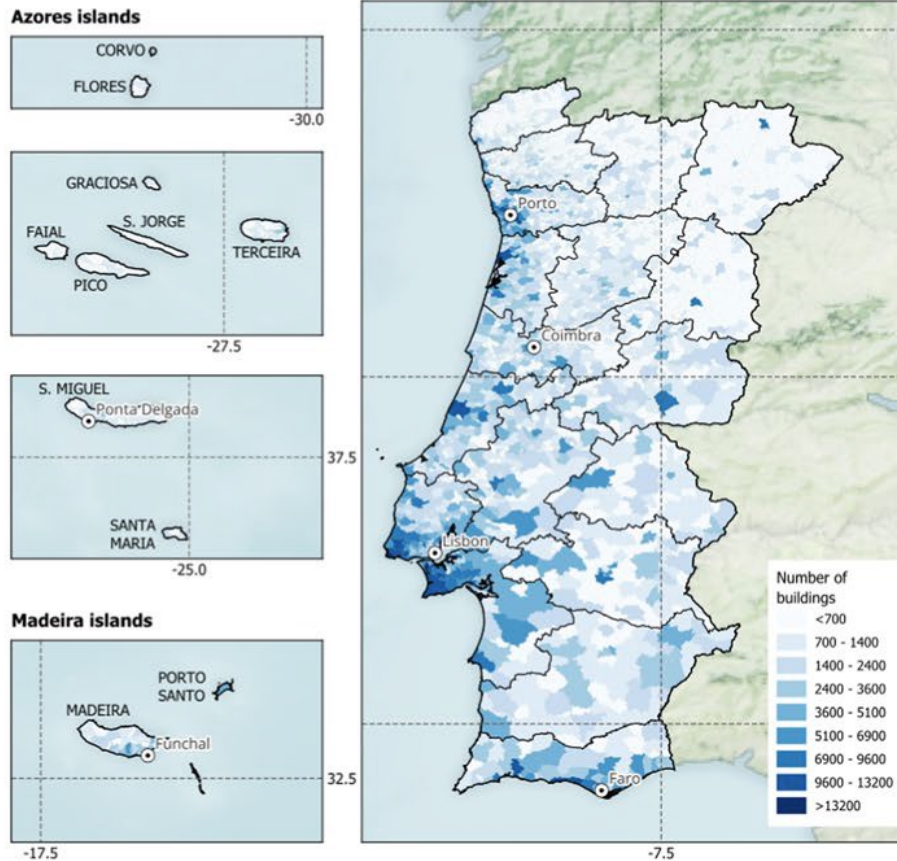
Madeira islands



- Number of buildings or dwellings
- Construction material
- Type of roof
- Height (number of floors)
- Age of construction
- Type of floor
- Material of the walls
- Type of building

Estimating Number of Buildings

Leveraging housing census information and socio-economic data



Advantages

- Covers entire countries
- May provide information about vulnerability attributes
- May be correlated with socio-economic variables

Disadvantages

- Does not provide building-by-building information
- Sometimes only provides information about material of the walls or type of dwelling

Estimating Number of Buildings

Volunteered Geographic Information (VGI) such as OpenStreetMap (OSM)



- Number of building footprints
- In some cases:
 - Type of use
 - Number of floors

Estimating Number of Buildings

Volunteered Geographic Information (VGI) such as OpenStreetMap (OSM)



Advantages

- Information at the building level
- Covers building area

Disadvantages

- Heavily incomplete in many parts of the world
- Covers assets that are not buildings

Estimating Number of Buildings

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

Inacurate building footprints



Missing footprints

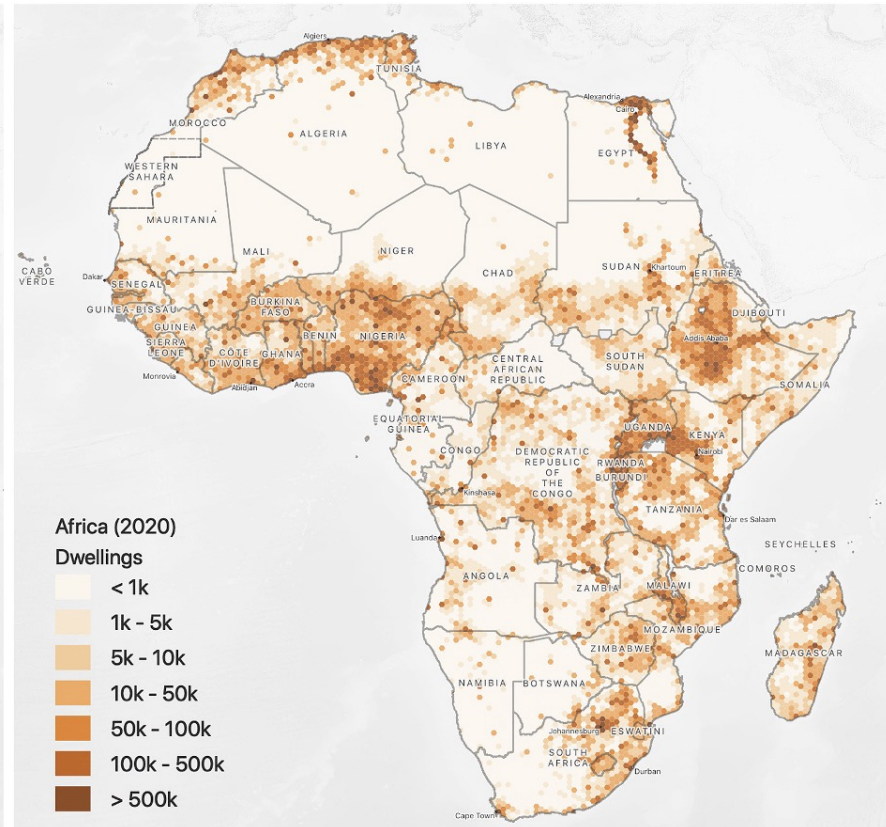
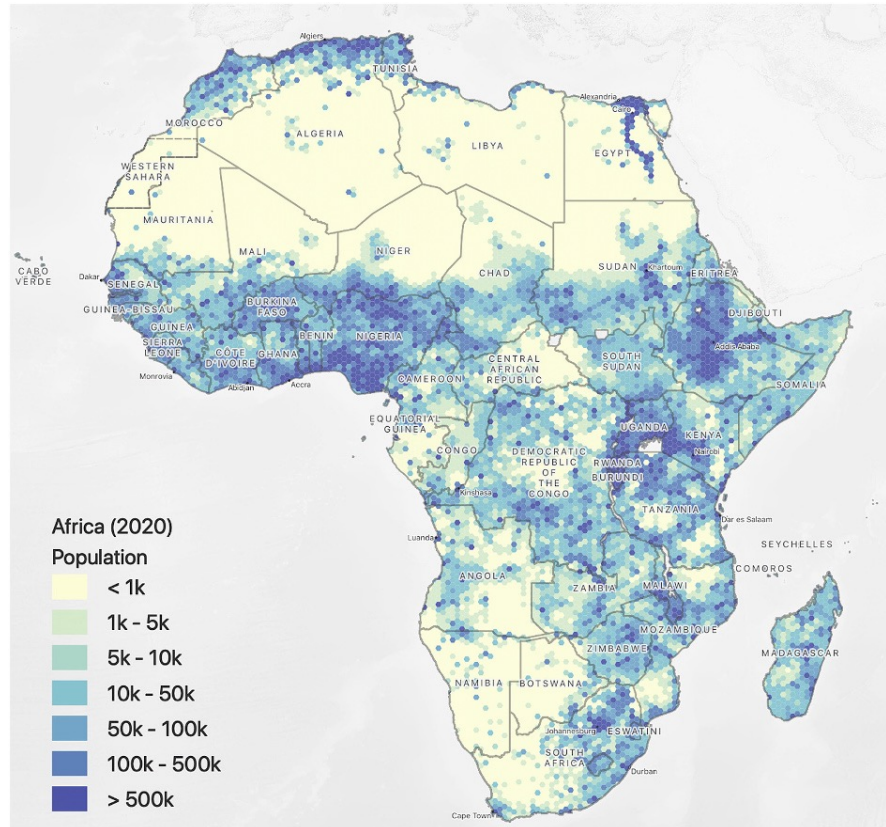


Estimating Number of Buildings

Population datasets and household sizes

From population

To dwellings and buildings



Estimating Average Areas

Surveys from National Statistical Offices and NGOs

Housing Types		Plot Size (M ²)	Floor Area (M ²)	Occupants (People)	Monthly rent (USD)	Value (USD)	Water	Sanitation	Tenure
Formal	Apartment Kabul	n/a	90	4	250	65,000	Piped water or own well	Septic tank or composting toilet	Owner with title deeds/ Owner with other documents (sales transaction) / renter
	Apartment Large Size	n/a	150	8-9	250-350	100,000			
	Apartment Medium Size	n/a	80	5-7	150-250	80,000			
	Apartment Small Size	n/a	50	4-6	100	40,000-65,000			
	Average	n/a	90	6	200	80,000			
	Dwelling Kabul	300	170	9	600	250,000			
	Dwelling Large Size	300-450	200	10-12	300	150,000			
	Dwelling Medium Size	200-300	150	10-12	250	100,000			
	Dwelling Small Size	200	100	8-9	200	50,000			
	Average	300	150	9	250	100,000			
Informal	Planned Kabul	400	200	7	180	50,000	Piped water or own well	Septic tank or dry pit latrine	Sales transaction/ Inheritance / municipal notebook
	Planned Large Size	500	200	8-15	200	60,000			
	Planned Medium Size	400	150		150	45,000			
	Planned Small Size	300	100		100	30,000			
	Average	400	150	11	150	45,000			
	Spontaneous Kabul	180	120	9	160	-	Shared well/ public taps/ water tanker	Dry pit latrine	No documentation / municipal notebook
	Spontaneous Large Size	250-600	100-200	10-15	60	20,000			
	Spontaneous Medium Size	150	80	7-9	50	15,000			
	Spontaneous Small Size	80-100	50-70	5-6	40	7,000			
	Average	150	80	9	50	12,000			

[Source: 'State of Afghan Cities 2017' p. 88].

SOURCE: SOAC FIELD SURVEY

Estimating Average Areas

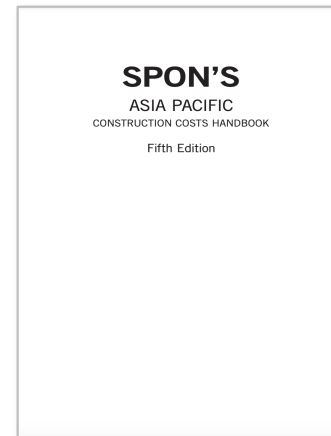
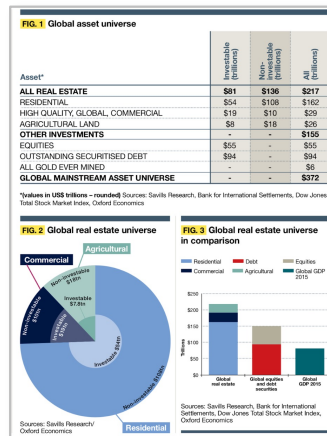
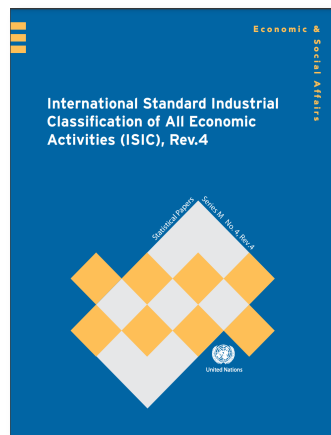
Combine cadastral datasets (building footprints) with land use layers



Residential
Commercial
Industrial

Estimating Construction costs

Combine cadastral datasets (building footprints) with land use layers

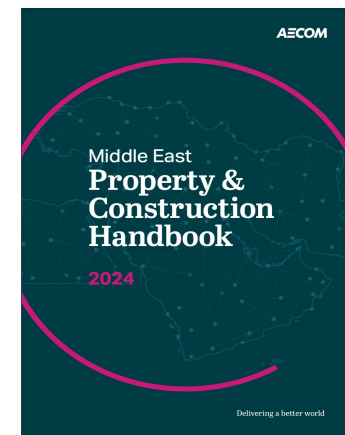
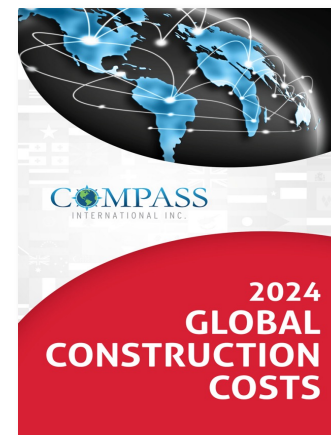
The International Code Council is pleased to provide the following Building Valuation Data (BVD) for its members. The data will be updated on a quarterly basis, with the next update in August 2018. ICC strongly encourages that all architects and other interested parties contact our code update department for more information.

The BVD data provides the average construction cost per square foot, which can be used in determining permit fees for a jurisdiction. Permit fees are calculated as a percentage (10% of the 2018 International Building Code (IBC) average building value) plus a fixed fee. The permit fee is a Permit Fee Multiplier, which is based on the total construction value when the jurisdiction for the permit fee. The Square Foot Construction Cost table presents factors that affect relative value of one construction classification category group in relation to the most common classification category group in that jurisdiction. Classification categories are listed in greater detail than in the permit fee table.

ICC has developed this data to aid jurisdictions in determining permit fees. It is important to note that while the BVD table lists the average construction cost per square foot, the permit fee table does not rely on the permit fee table to determine the cost of construction. Therefore, the permit fee table is not intended to be used as an average cost because the data only reflects average costs and is not representative of specific construction.

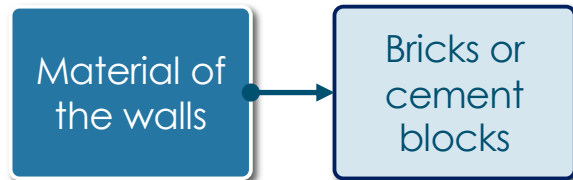
This degree of precision is sufficient for the intended purpose, which is to help jurisdictions determine permit fees. The BVD table provides construction cost information that is dependent on the location of a building that does not rely on the permit fee table to determine the cost of construction. Therefore, the permit fee table is not intended to be used as an average cost because the data only reflects average costs and is not representative of specific construction.

The following building valuation data represents average construction cost per square foot (C/SF) for the 2018 International Building Code (IBC) data is shared as an aid to the building official in determining the permit fee relative to construction. Again, it should be noted that when using this data, these are average costs based on typical construction methods for each category group. The BVD table is not intended to be used as a cost estimator for individual projects. The BVD table includes: foundation work, structural and nonstructural



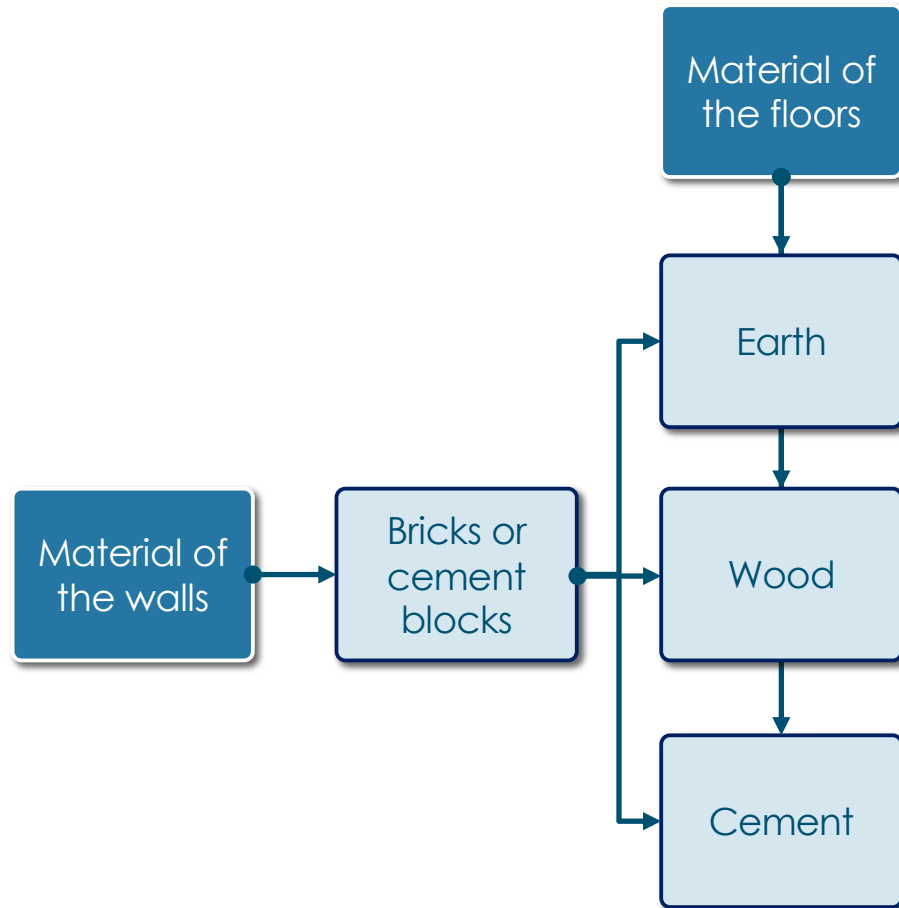
Defining Vulnerability Classes

Defining mapping schemes to convert building attributes to vulnerability classes



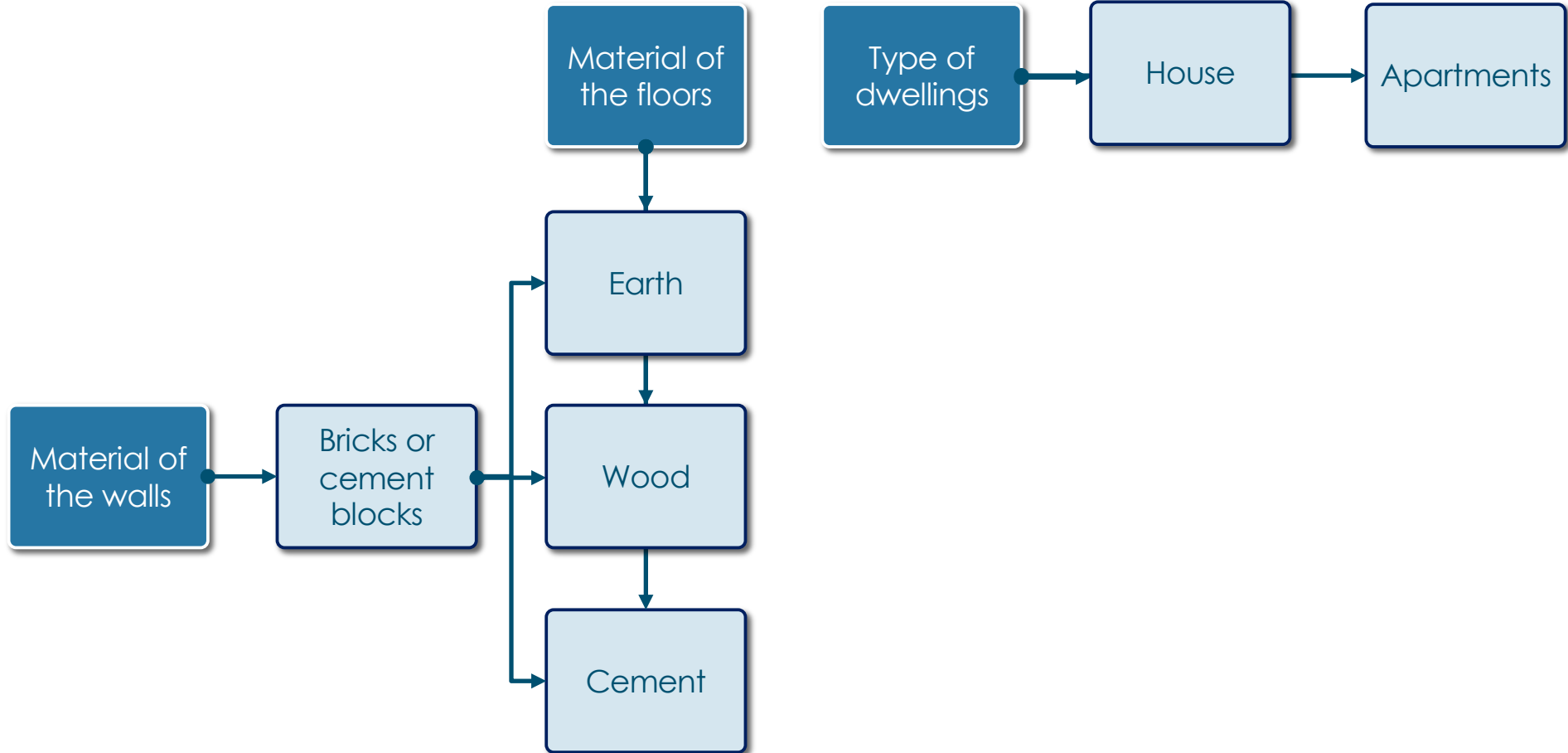
Defining Vulnerability Classes

Defining mapping schemes to convert building attributes to vulnerability classes



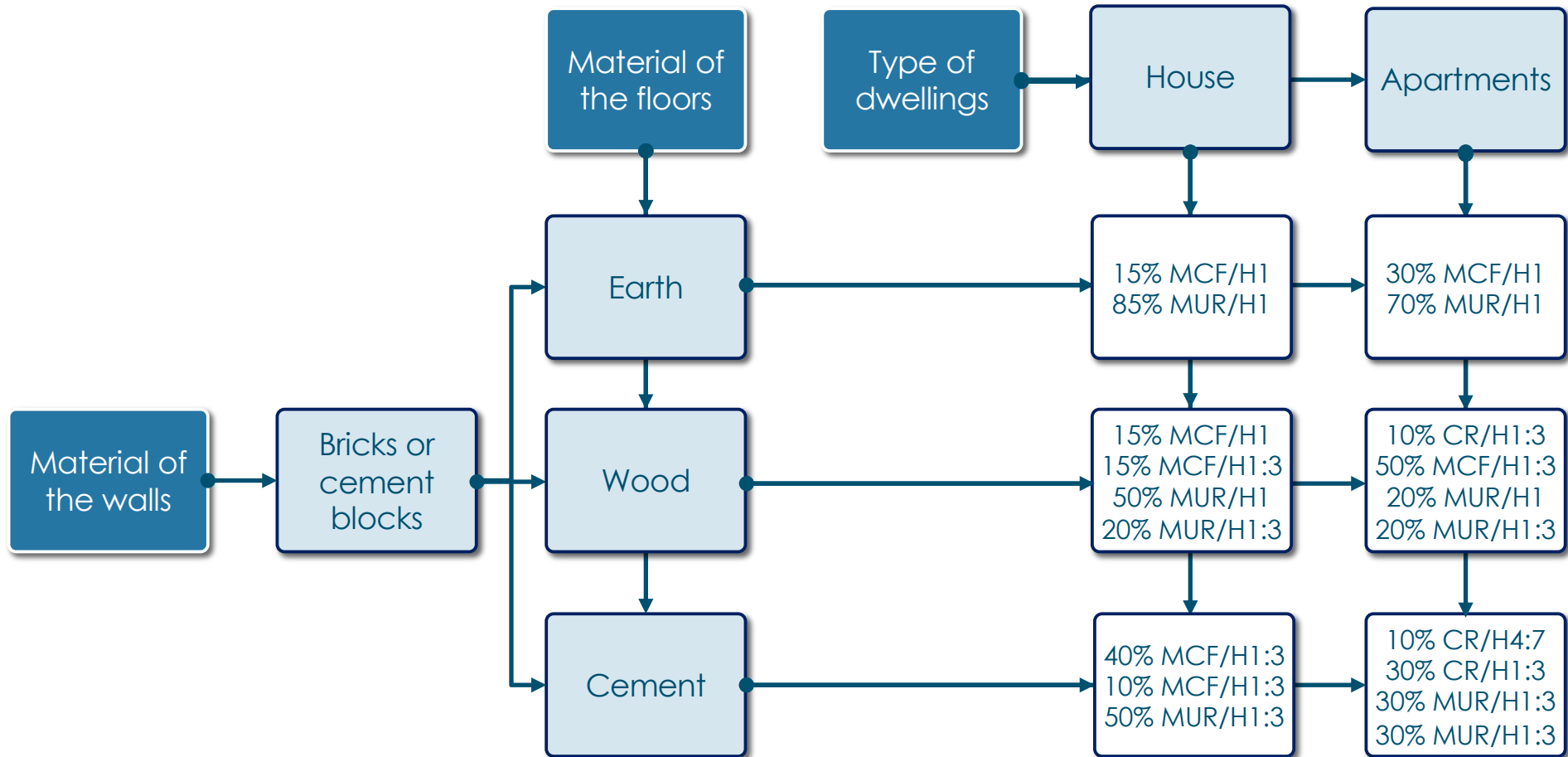
Defining Vulnerability Classes

Defining mapping schemes to convert building attributes to vulnerability classes



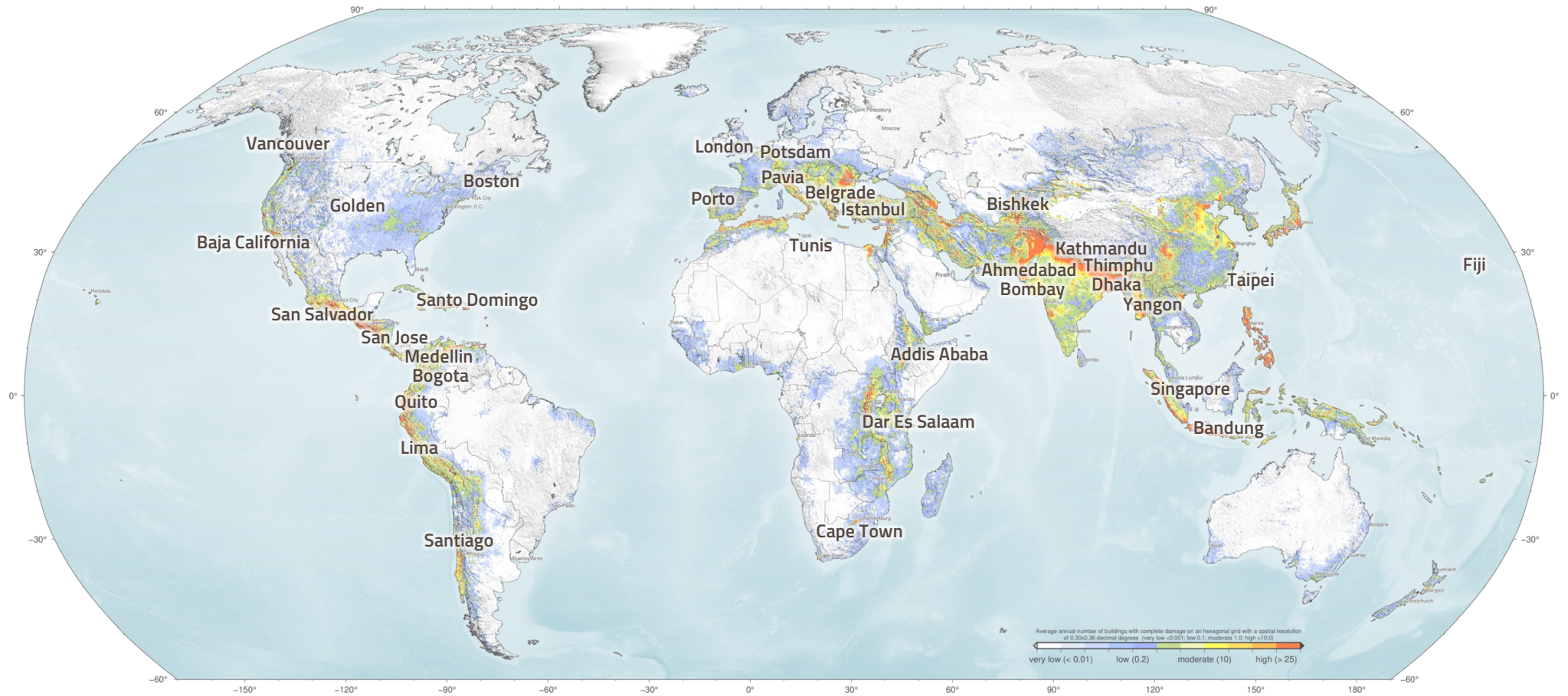
Defining Vulnerability Classes

Defining mapping schemes to convert building attributes to vulnerability classes



Defining Vulnerability Classes

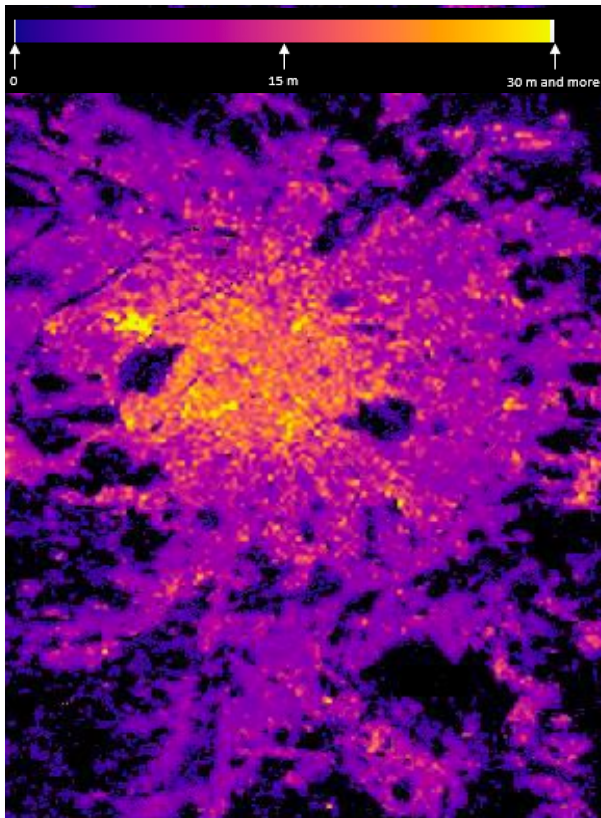
Working with local experts to develop and improve mapping schemes



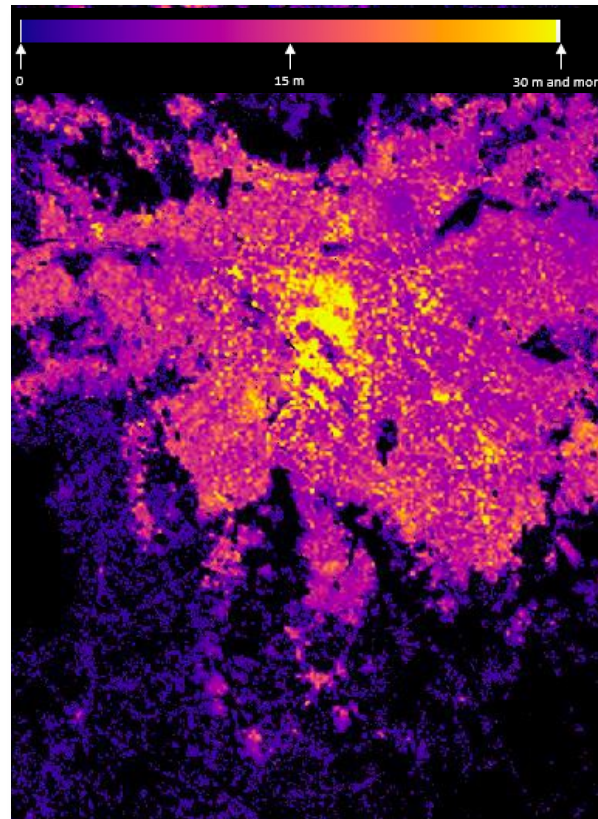
Defining Vulnerability Classes

Incorporation of building height from satellite imagery

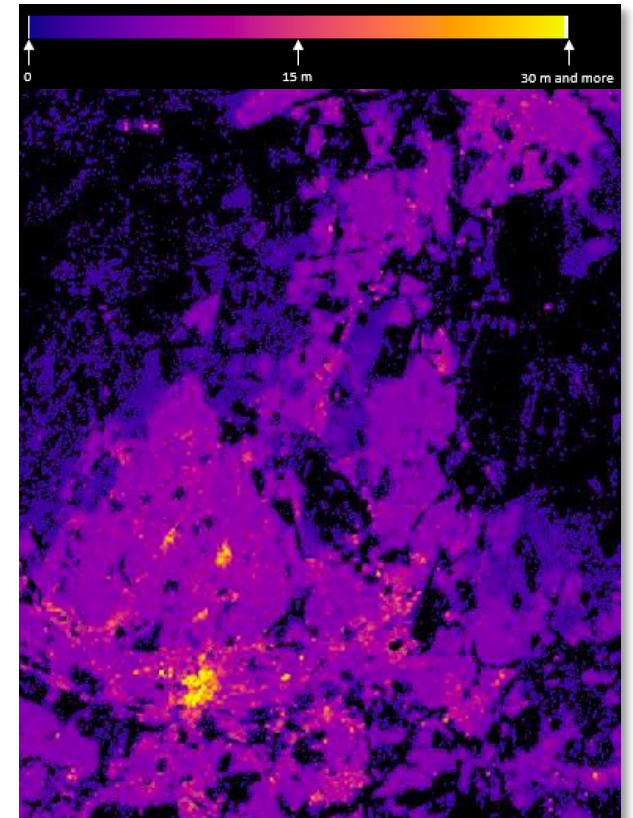
Paris, France



Sao Paulo, Brasil



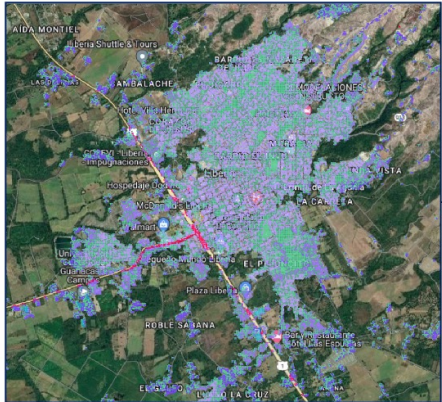
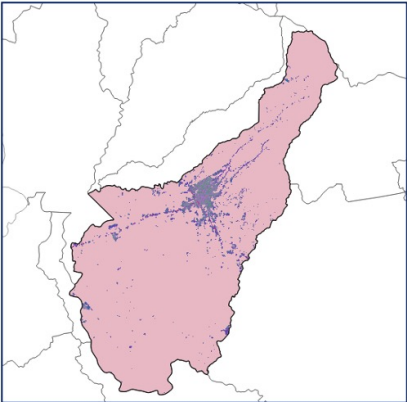
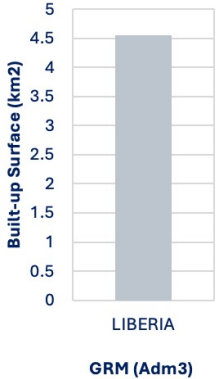
Johannesburg, South Africa



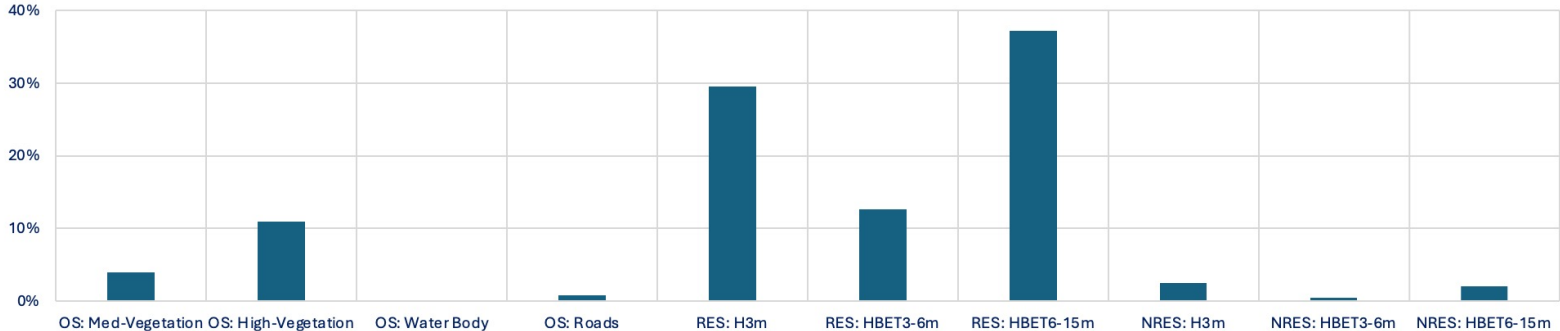
Defining Vulnerability Classes

Incorporation of building height from satellite imagery

Liberia Built-up Surface 2020

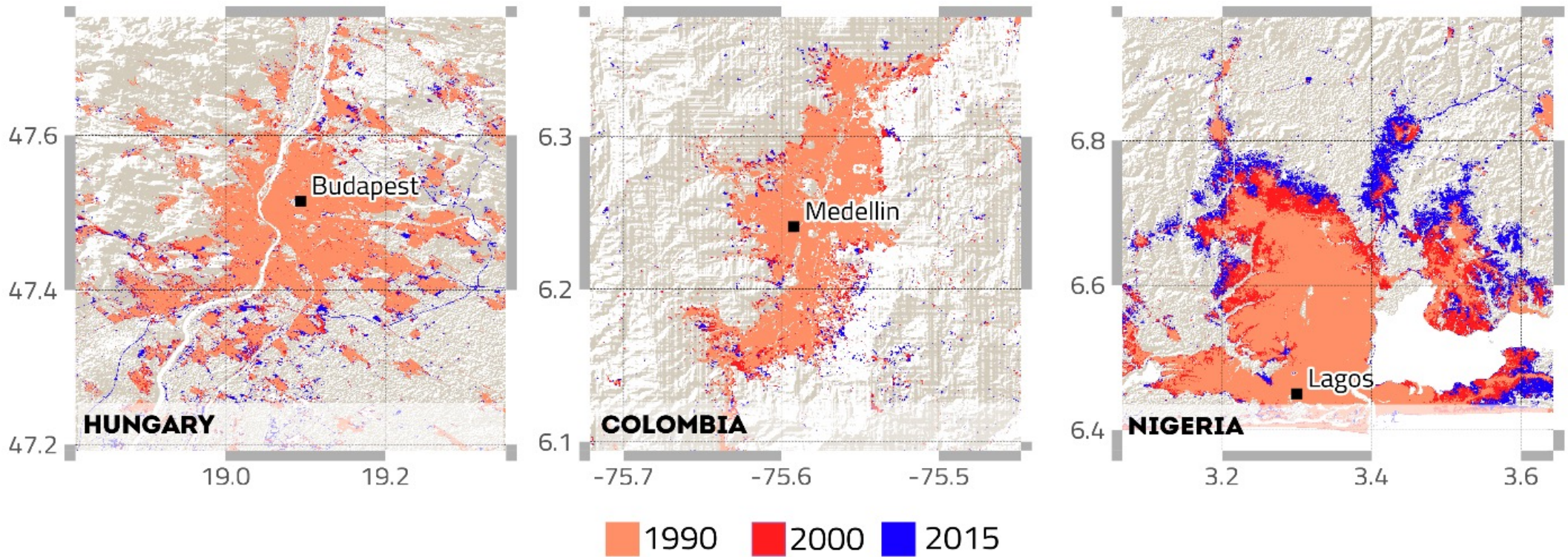


Liberia Morphological Settlement Zone – Cell Distribution (Res10x10)



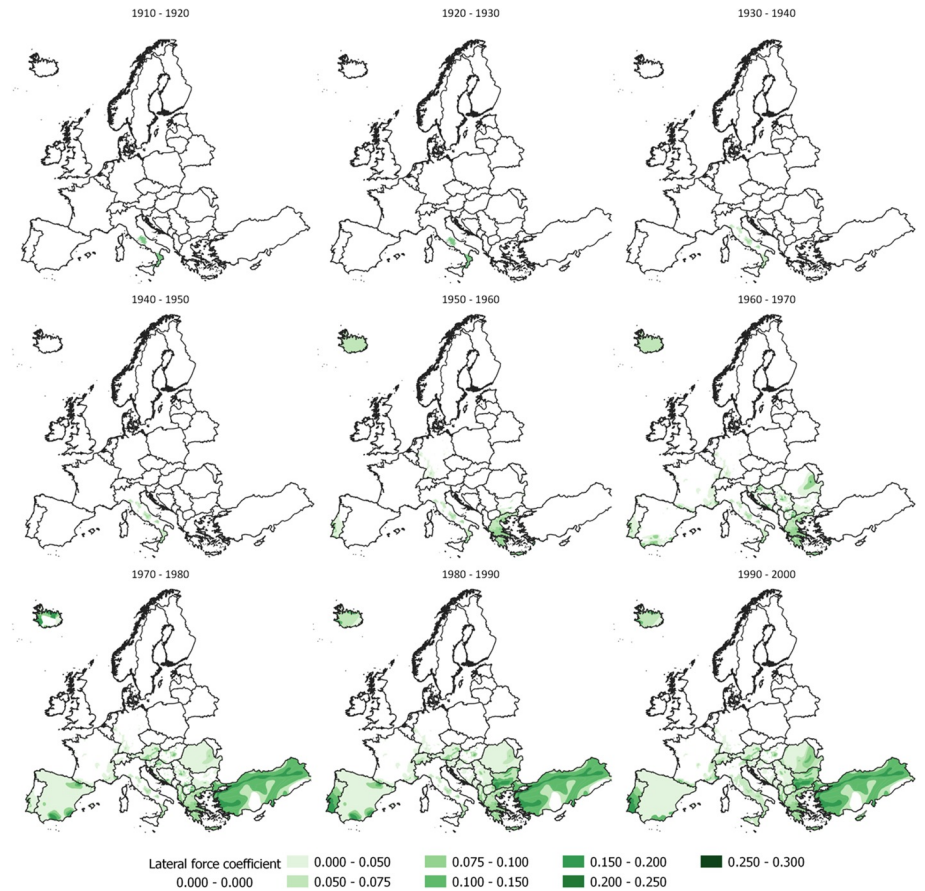
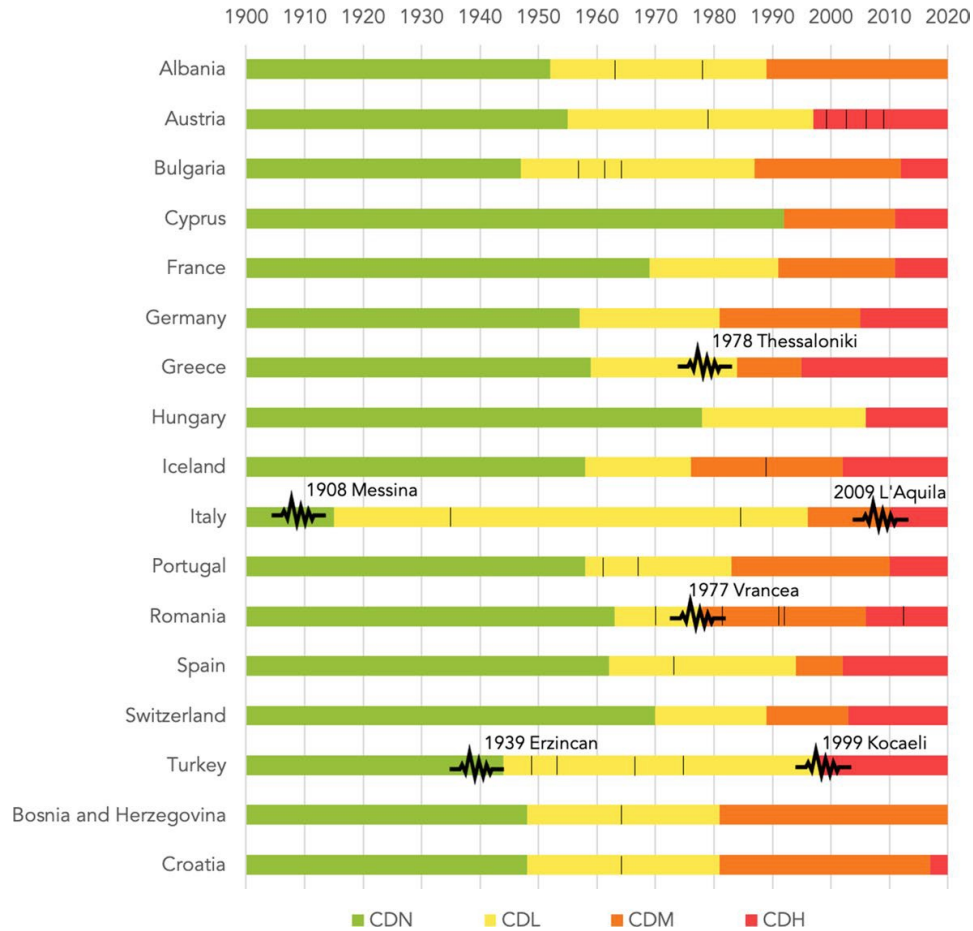
Defining Vulnerability Classes

Incorporation of satellite imagery to assign building age (or epoch of construction)



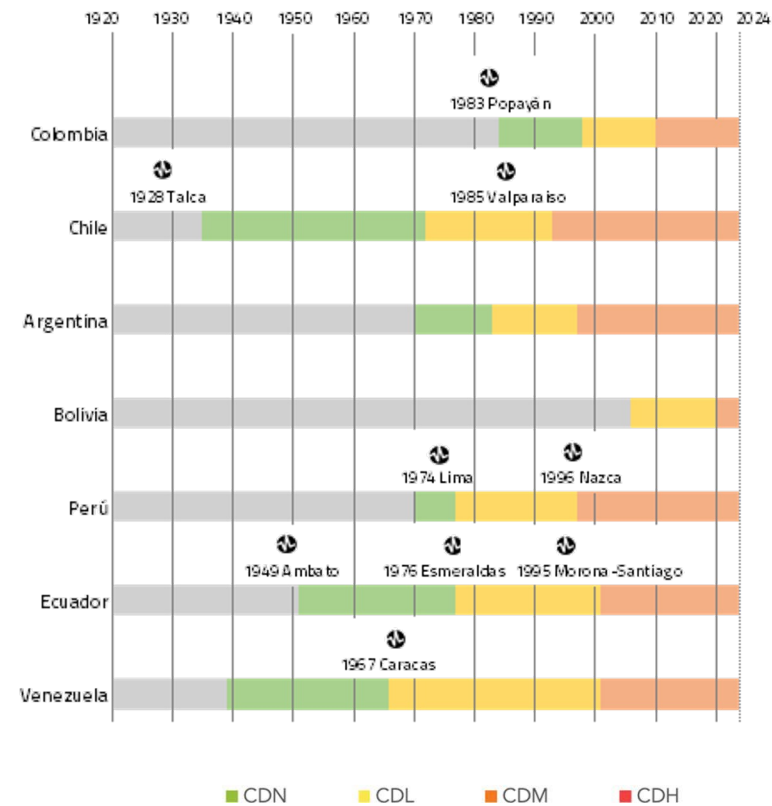
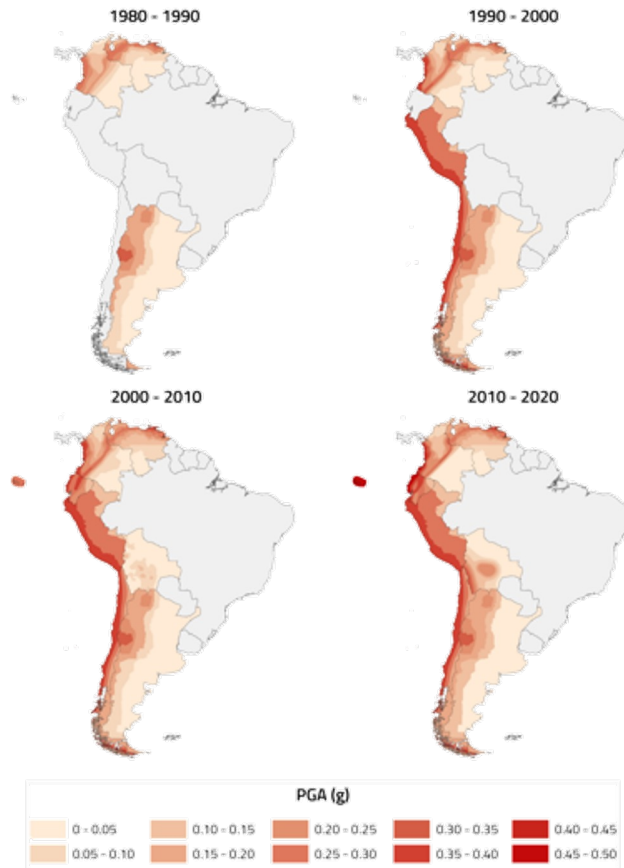
Incorporating Design Regulations

Considering the year of design regulation and the associate seismic zonation



Incorporating Design Regulations

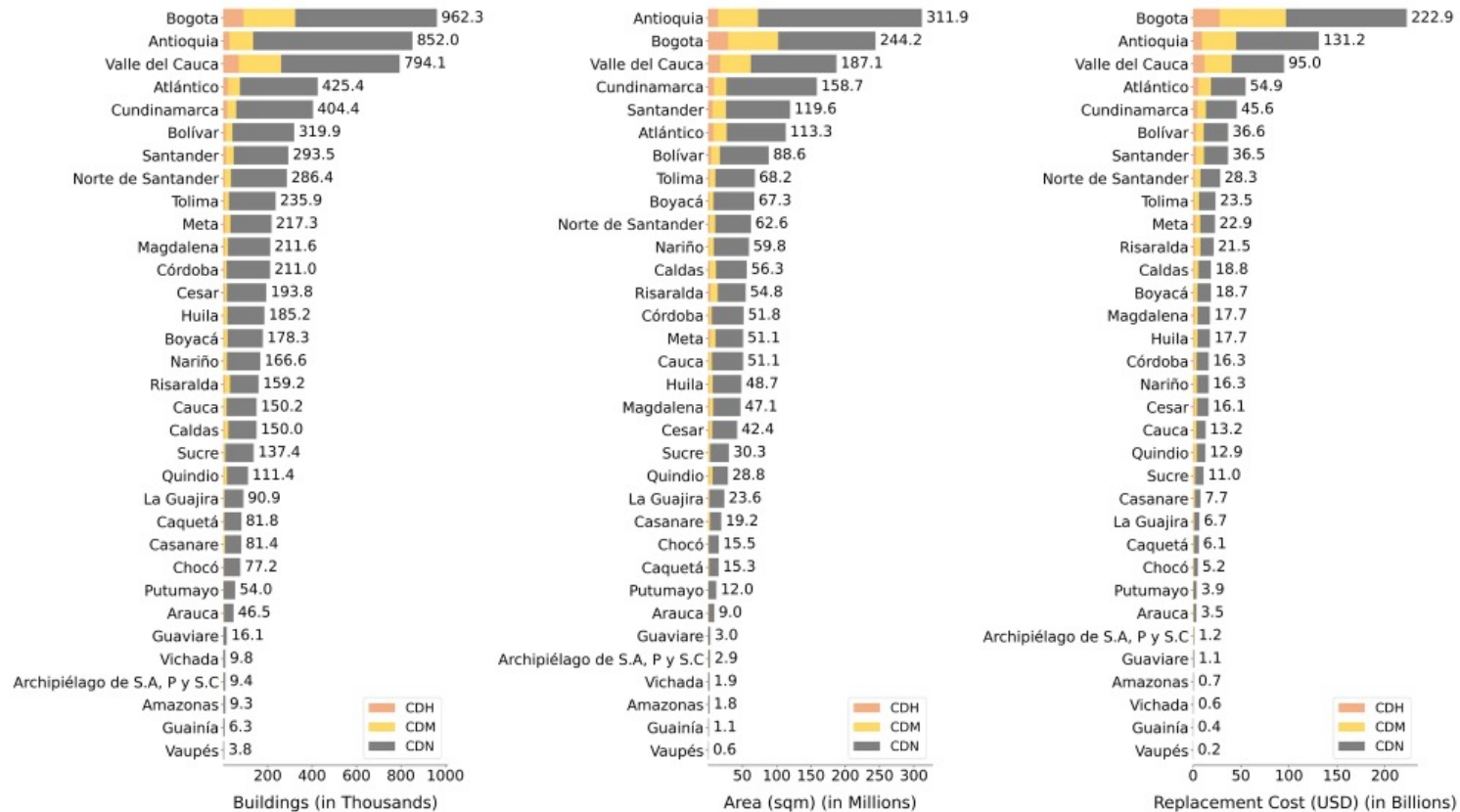
Considering the year of design regulation and the associate seismic zonation



Incorporating Design Regulations

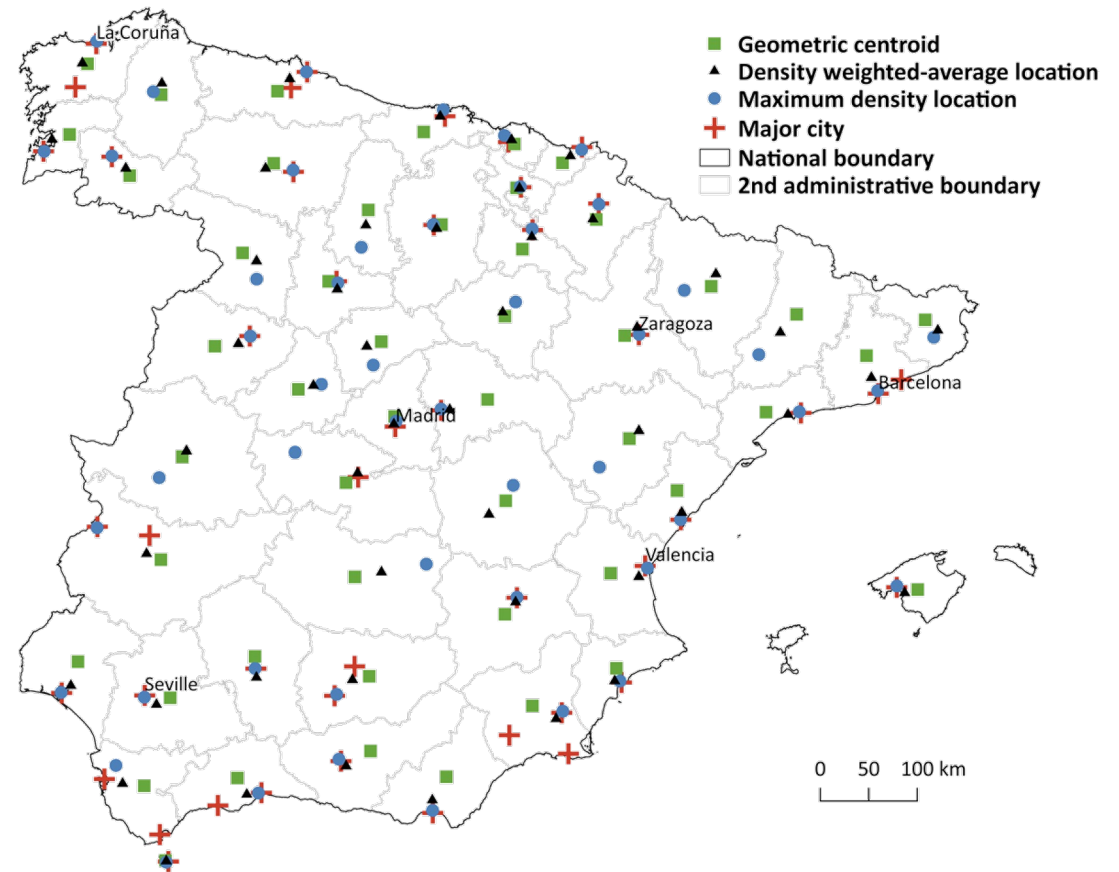
Distribution of buildings, area and replacement cost across different code levels for Colombia

Estimated fractions by code level per region



Location of Buildings

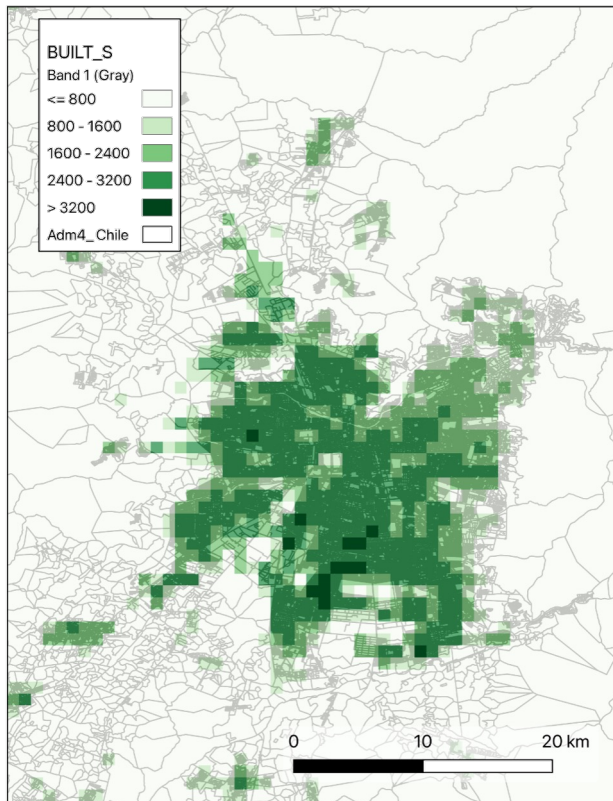
The current exposure model for Spain is at the first administrative level. Either the data is aggregated at a given site, or spatially disaggregated using auxiliary datasets. For the latter approach, different techniques and datasets can be pursued to minimized the uncertainty and bias.



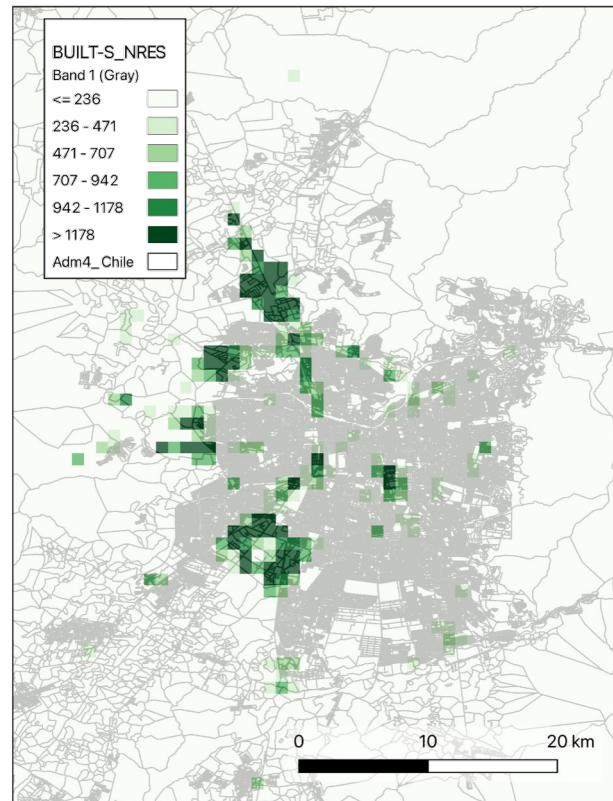
Location of Buildings

Incorporation of national data and vulnerability improvements due to projects

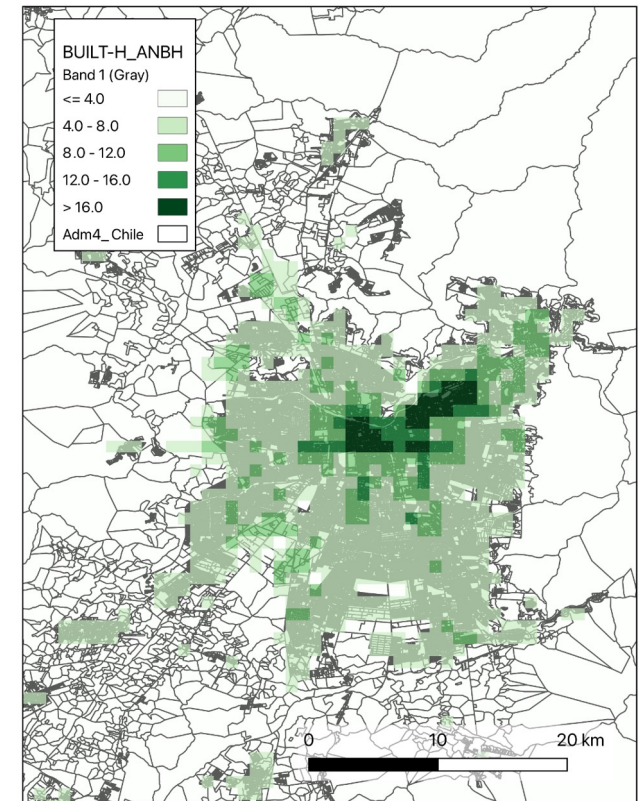
Built-up Surface



Built-up Surface (Non-residential)



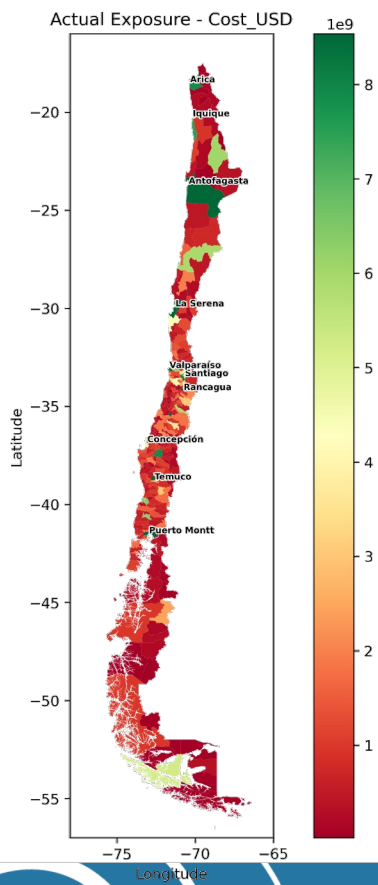
Building Height



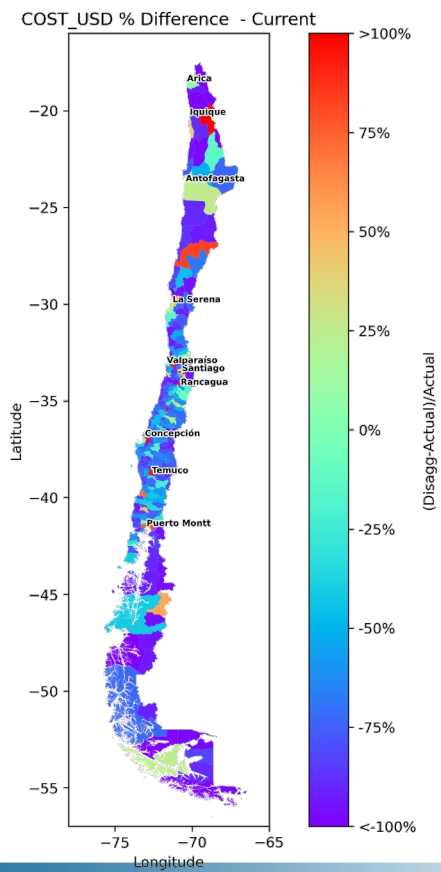
Location of Buildings

Application of different spatial disaggregation approaches (example for Chile)

Actual



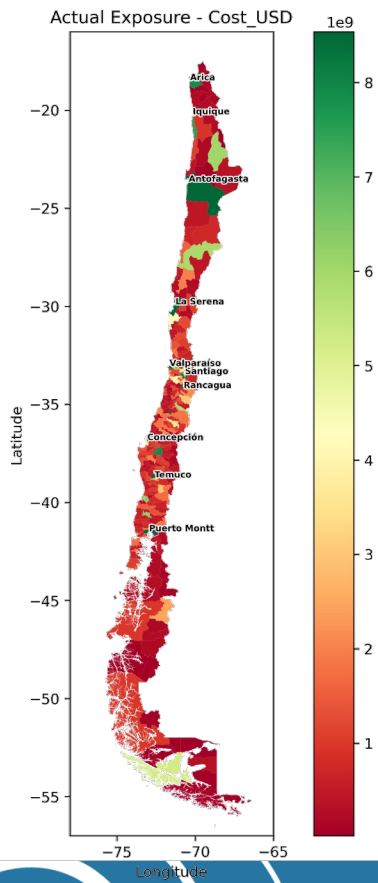
Using population



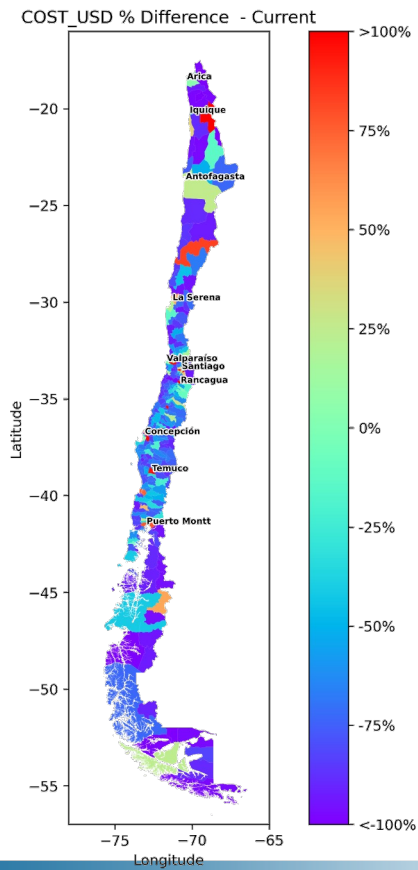
Location of Buildings

Application of different spatial disaggregation approaches (example for Chile)

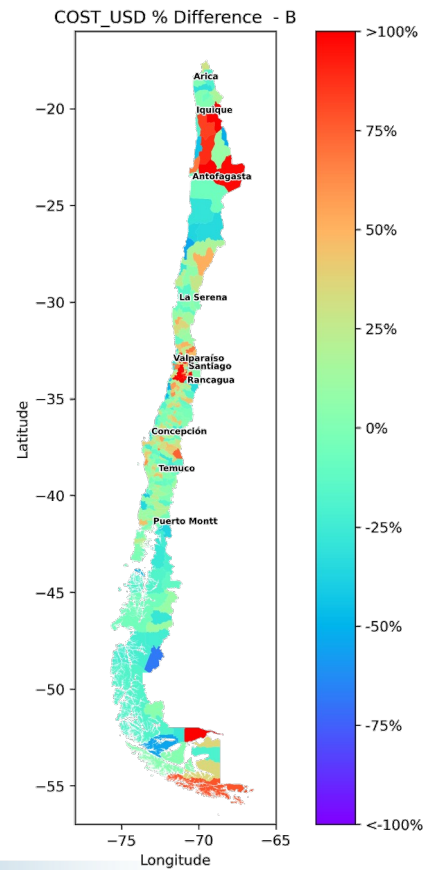
Actual



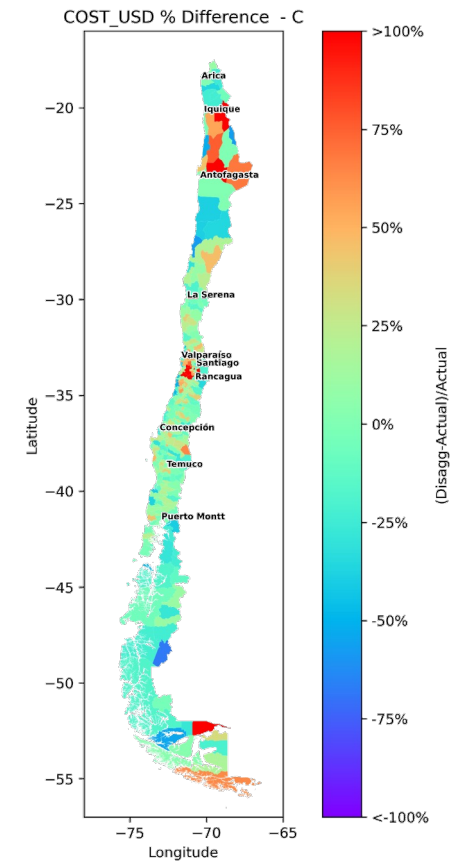
Using population



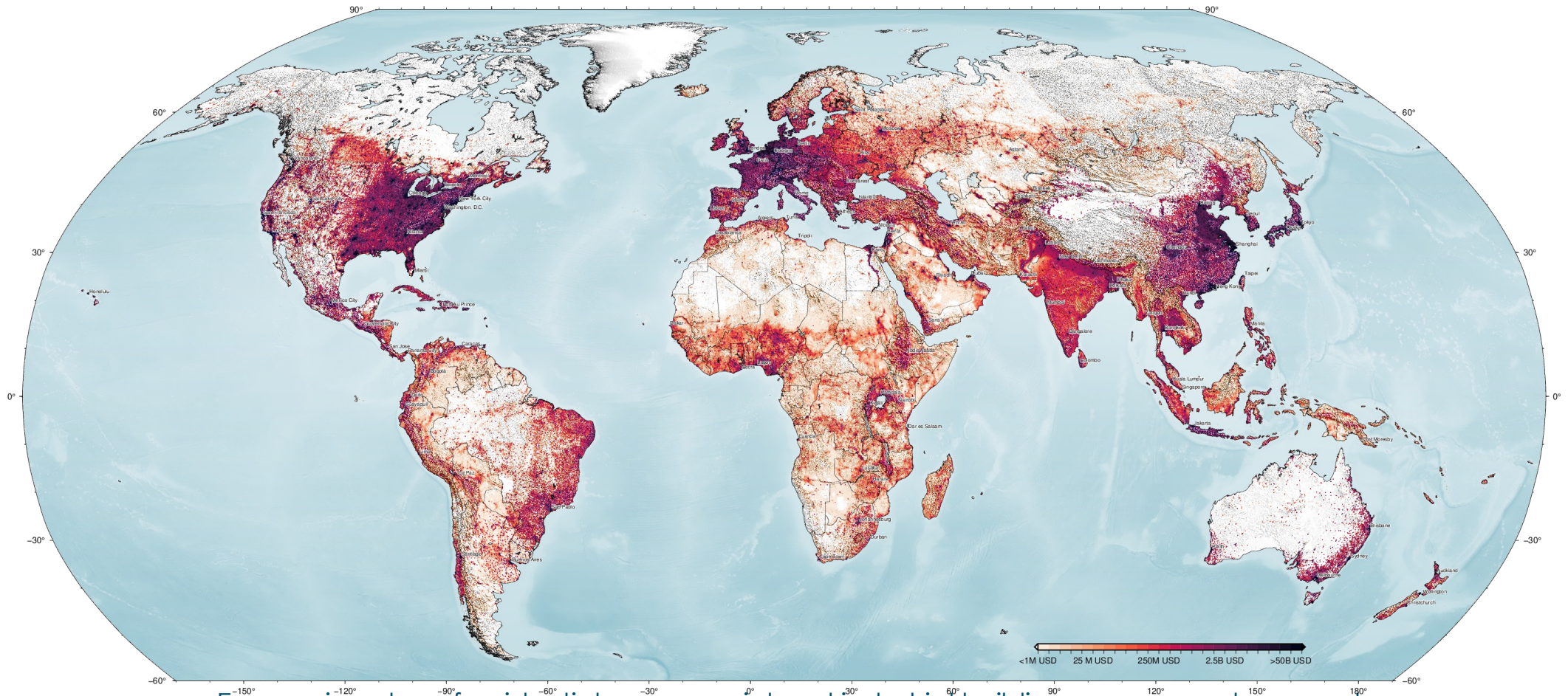
Using built up area



Using built up area and building height



GEM's Global Exposure Model



Economic value of residential, commercial and industrial buildings on an evenly spaced hexagon grid with a constant spatial resolution of 0.30×0.36 decimal degrees.

Some Future Developments



Exposure Modelling with ML/AI



Exposure Modelling with ML/AI



Exposure Modelling with ML/AI



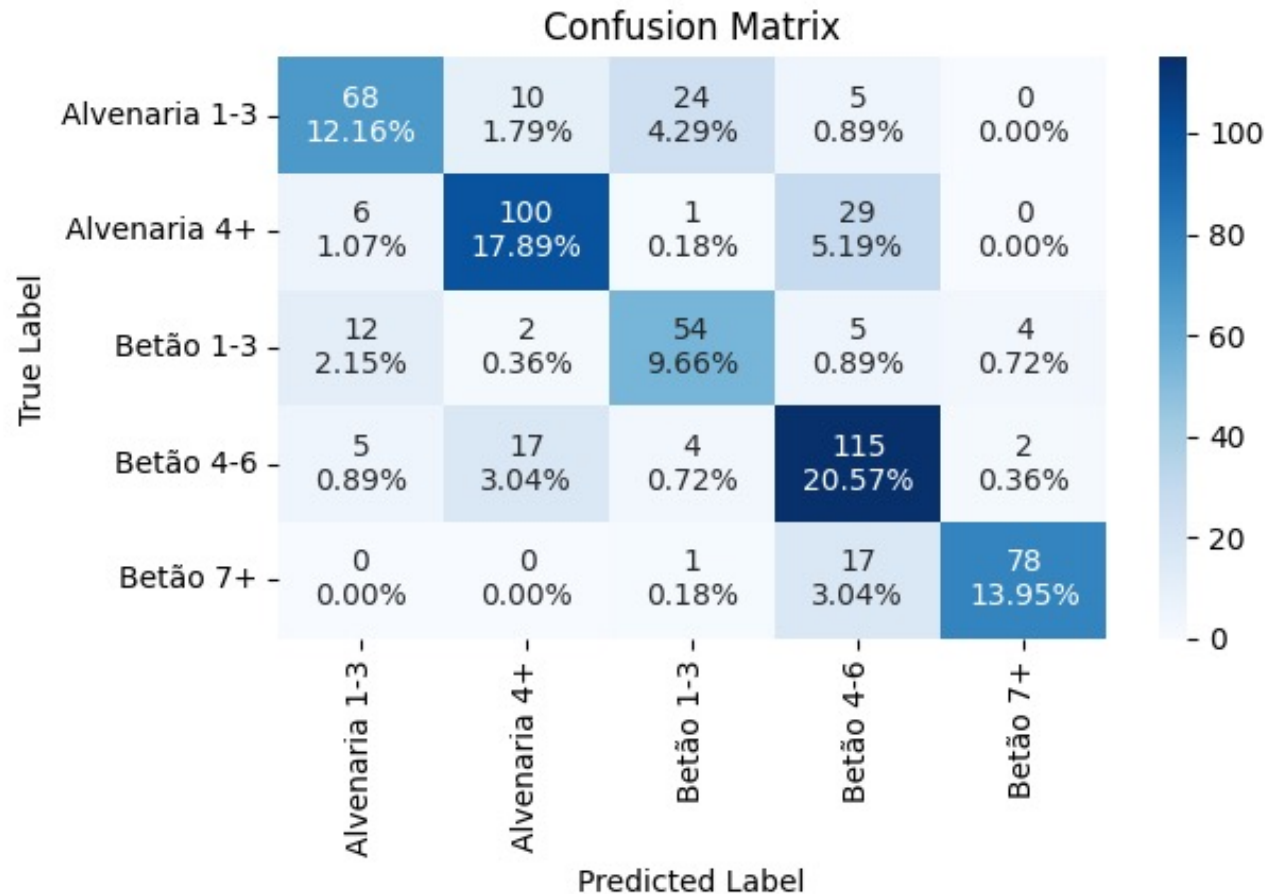
- Material of construction
- Number of storeys
- Epoch of construction
- Structural system
- Irregularities
- Type of roof
- Number of windows
- Number of doors
- Number of balconies
- Presence of basement

Exposure Modelling with ML/AI



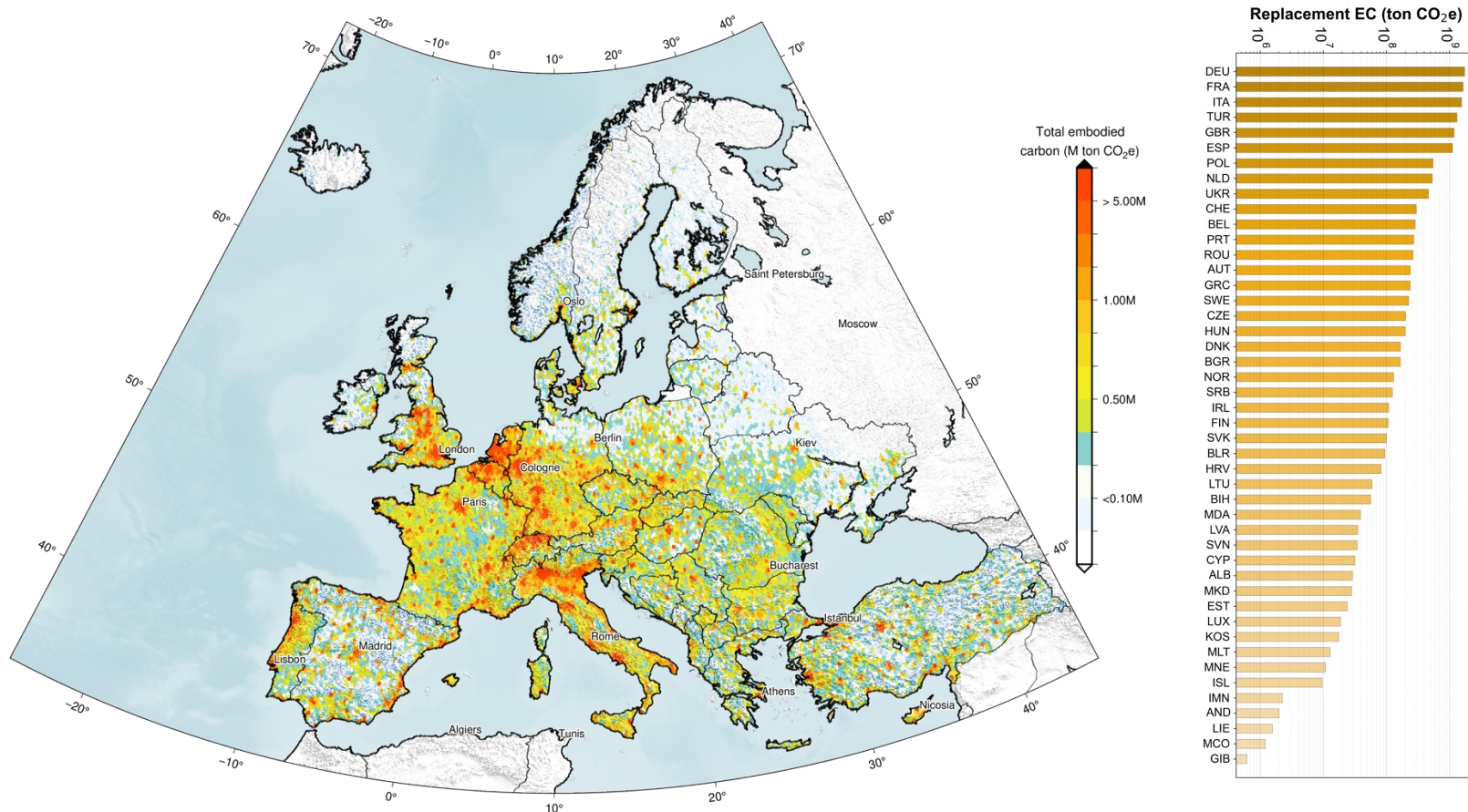
Exposure Modelling with ML/AI

The algorithm predicted the building class in more than **86%** of the cases



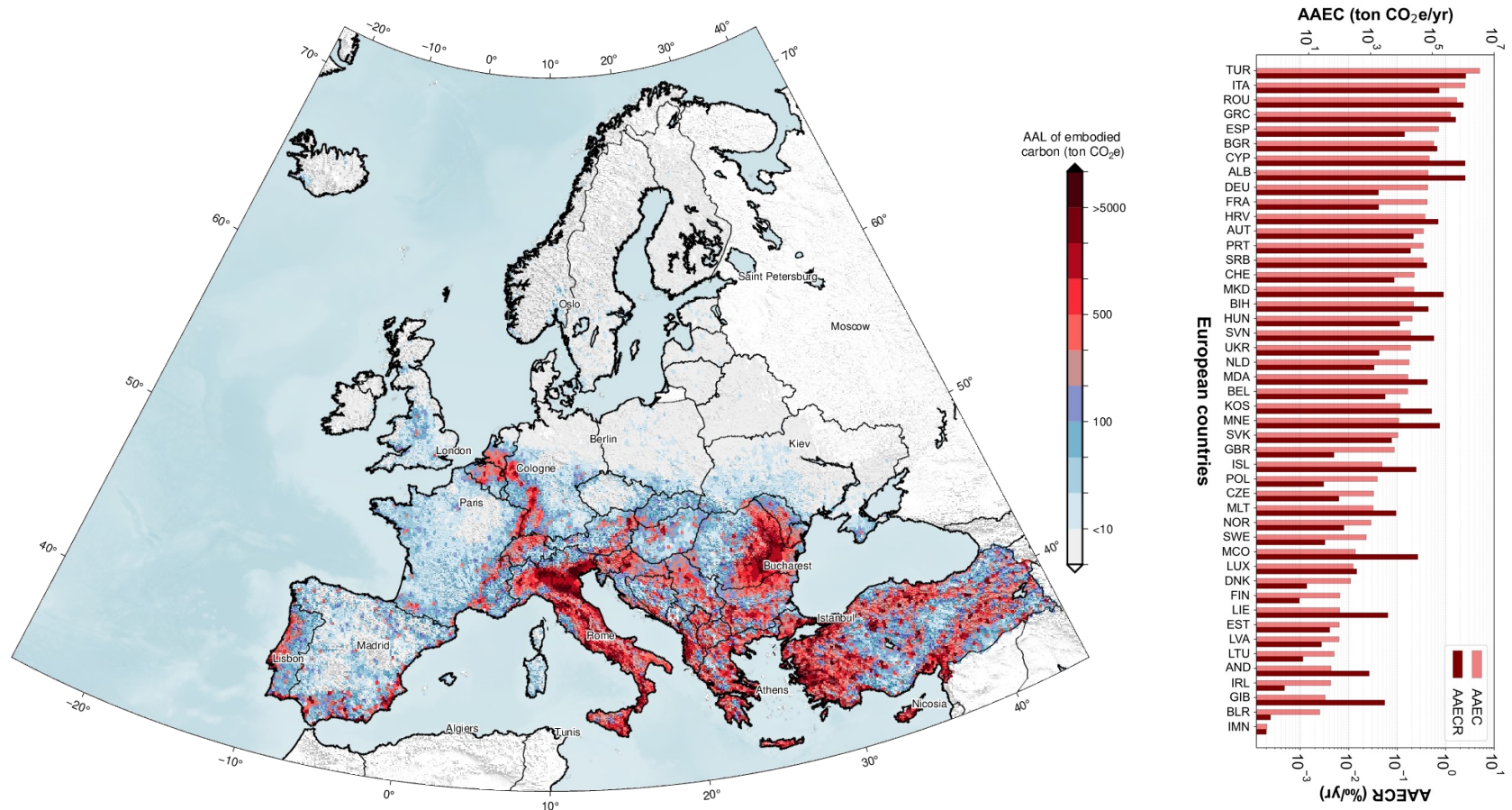
Incorporating Sustainability in Exposure Modelling

Estimation of the embodied carbon in the building stock in Europe



Incorporating Sustainability in Exposure Modelling

Estimation of the embodied carbon in the building stock in Europe



FINAL REMARKS

- Exposure models are fundamental for several multi-hazard risk analysis and to support the development of risk reduction measures.
- Several challenges still remain in the estimation of the number of buildings, their location, costs and vulnerability classes.
- It is fundamental to ensure that the same exposure model is used for the assessment of impact due to different hazards, to avoid unnecessary bias.
- New technologies such as machine learning and existing datasets can support the development of exposure models, or the enhancement of current datasets.

Thank you and thanks to all the co-authors

Vitor Silva
vitor.silva@globalquakemodel.org



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