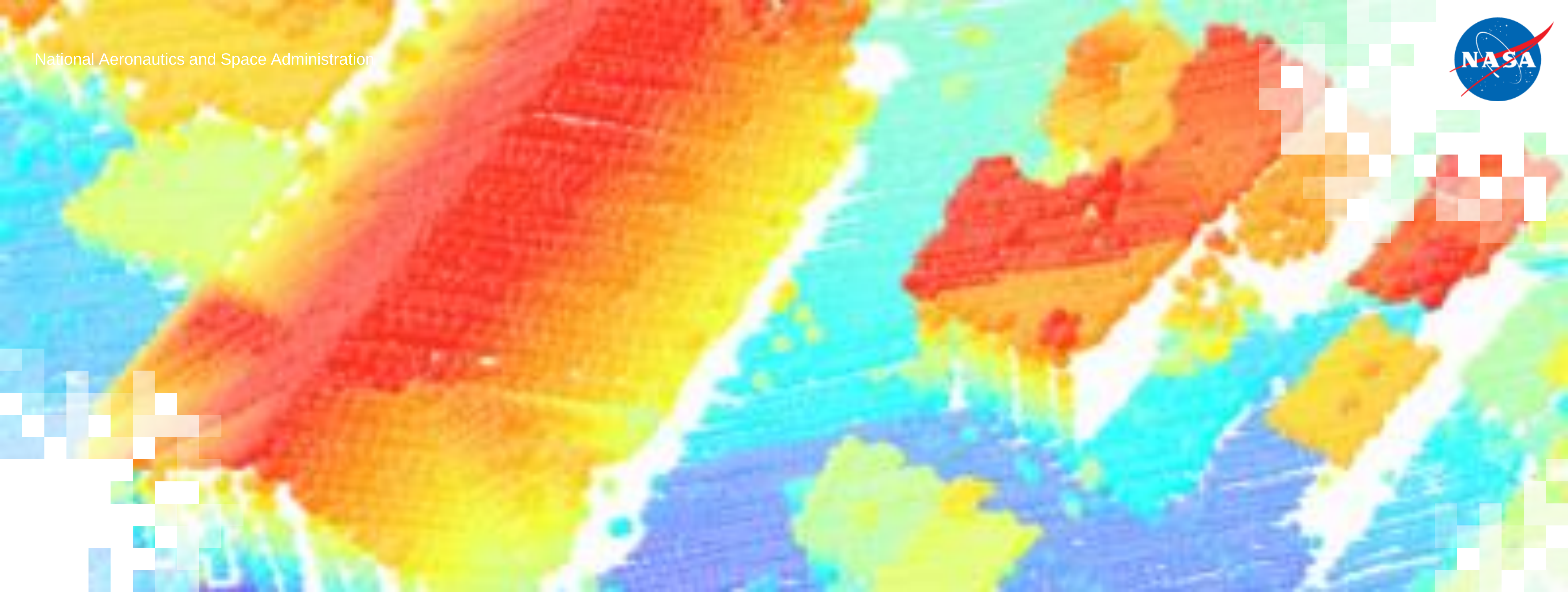
National Aeronautics and Space Administration

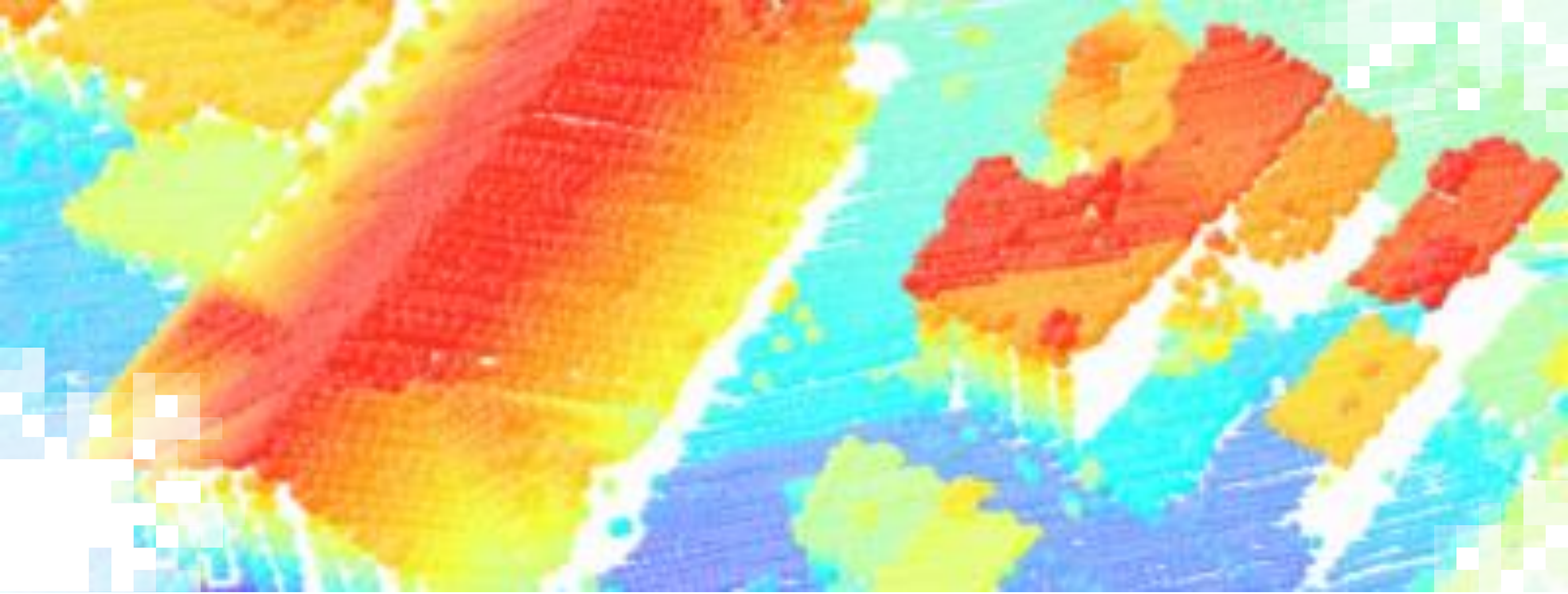


Transforming Earth Observation (EO) Data into Building Infrastructure Data Sets for Disaster Risk Modeling

Part 1: Development of Regional Exposure Data with Earth Observations

Charles Huyck (ImageCat), Georgiana Esquivias (ImageCat), & Michael Eguchi (ImageCat)

October 03, 2023



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

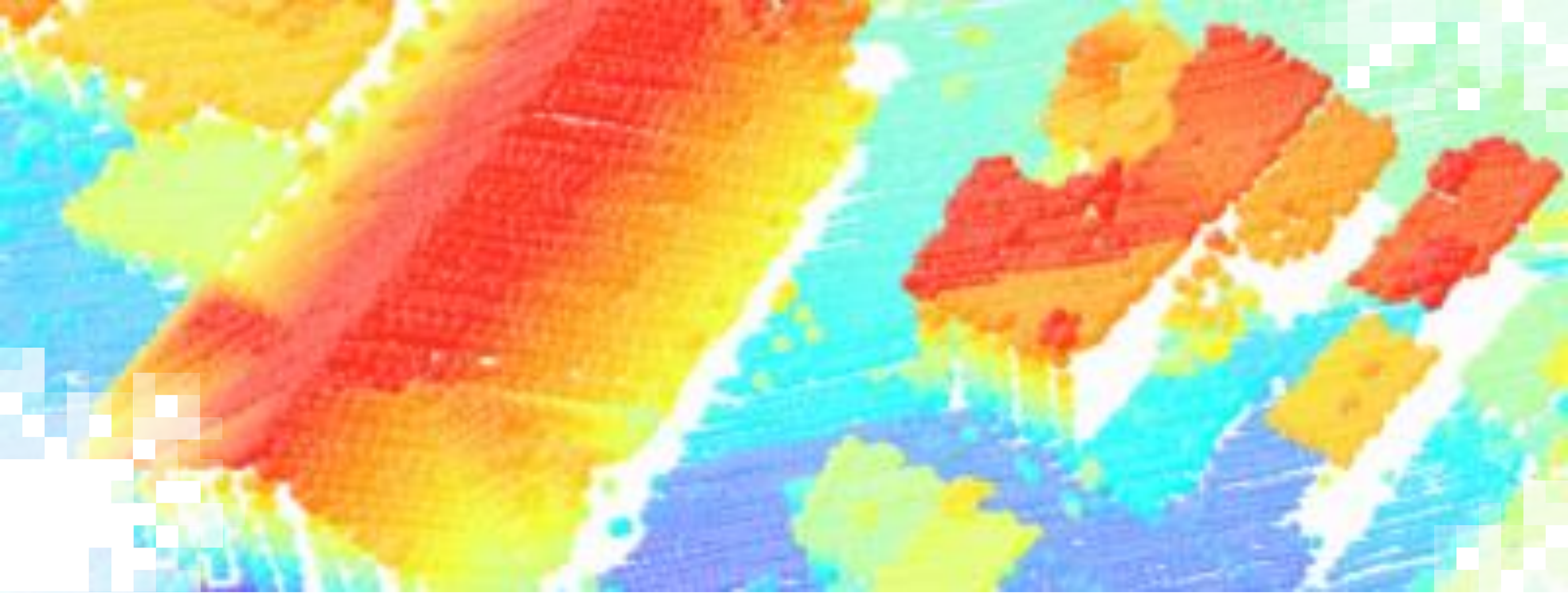
HEALTH & AIR QUALITY

WATER RESOURCES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.



Transforming Earth Observation (EO) Data into Building Infrastructure Data Sets for Disaster Risk Modeling

Overview

Why is Climate Risk Assessment Important?

- Even with drastic reduction in carbon emissions, short and medium-term impacts are inevitable
- Climate change impacts and risks are becoming increasingly complex and more difficult to manage (IPCC AR6, 2022).
- Climate change impacts on human infrastructure are not well understood and vary drastically by location
- Understanding community-specific risks to climate change is critical to evaluating adaptation strategies

"You can't stop the waves, but you can learn to surf." - Jon Kabat-Zinn

Credit: Scott Pena

Training Learning Objectives

By the end of this training, participants will be able to:

- Recognize what building vulnerability is and why it is important for risk modeling
- Identify the core elements of natural hazard risk modeling and asset loss estimation
- Identify fundamental approaches for developing building-exposure models using Earth Observation data and tools
- Apply a basic procedure to model built infrastructure exposure and vulnerability characteristics from Earth Observation data
- Evaluate building-specific exposure data sets to identify key components for fit, validity, consistency and rectify bias
- Evaluate the appropriate use of modeled building exposure data to a given community
- Apply strategies to identify and address equity and bias considerations
- Apply approaches to validate building data with imagery for regional datasets
- Document your exposure development process through metadata so that others can understand the process used, the limitations, and how to update if necessary

Prerequisites

- [Fundamentals of Remote Sensing]
- Basic understanding of disaster risk management

Review of Prior Knowledge

- Climate change science tells us about the regional climate
- Hazard specialists tell us about the hazards (flooding, drought, hail, tornados)
- GIS and EO give us what is what is where (exposure)
- Engineers tell us about the susceptivity to damage (vulnerability)
- Together- these give us risk (likelihood of impact)

- GIS is critical!
  - GIS provides the digital glue between disciplines
  - Evaluating new sensors, technologies, and datasets (e.g., OSM, Lidar, drones)
  - Understanding and communicating key GIS concepts and limitations
  - Fusing, harmonizing, and assessing quality of multi-modal base data

Training Outline

Part 1

Development of Regional Exposure Data with EO

October 03, 2023

10:00-12:00 EDT (UTC-4)

Part 2

Development of Site-Specific Exposure Data with EO

October 05, 2023

10:00-12:00 EDT (UTC-4)

Part 3

Assessing Utility and Communicating Uncertainty

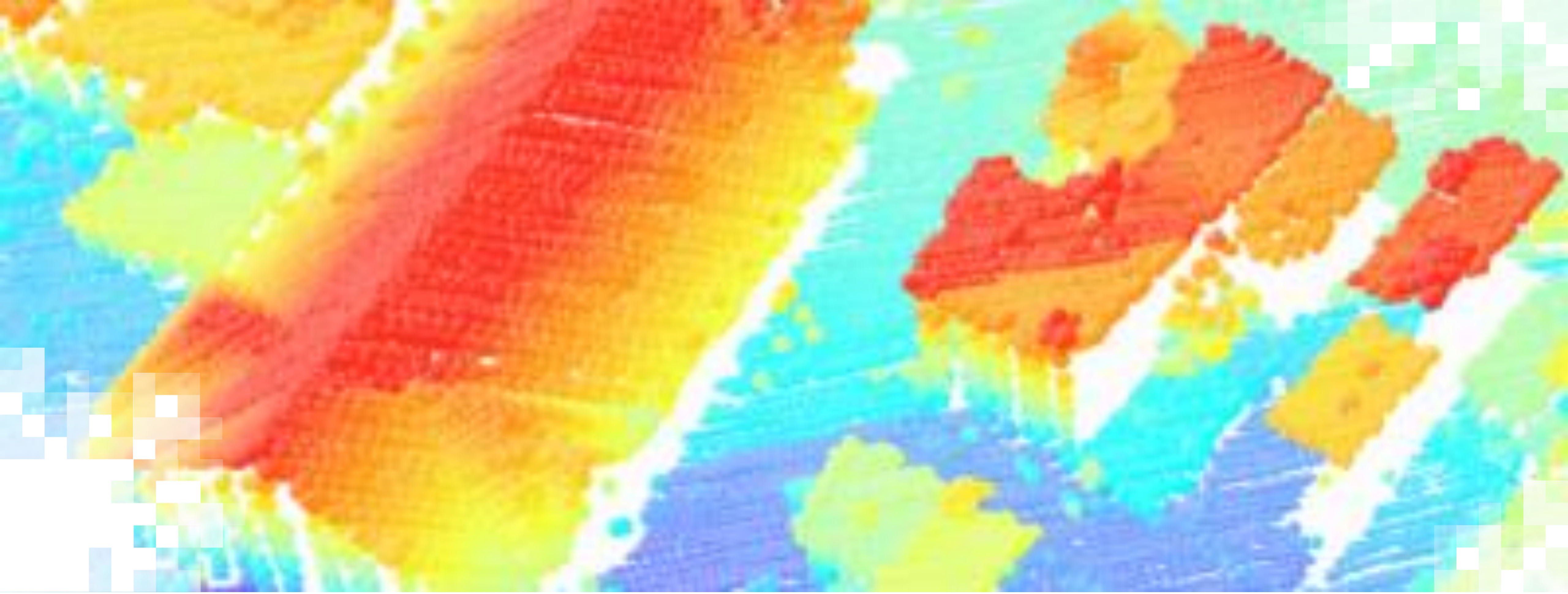
October 10, 2023

10:00-12:00 EDT (UTC-4)

Homework

Opens October 10 – Due October 24 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment before the given due date.



Transforming Earth Observation (EO) Data into Building Infrastructure Data Sets for Disaster Risk Modeling

Part 1: Development of Regional Exposure Data with Earth Observations

Part 1 Objectives

By the end of Part 1, participants will be able to:

- Recognize what building vulnerability is and why it is important for risk modeling
- Identify the core elements of natural hazard risk modeling and asset loss estimation
- Identify fundamental approaches for developing building-exposure models using Earth Observation data and tools

How to Ask Questions

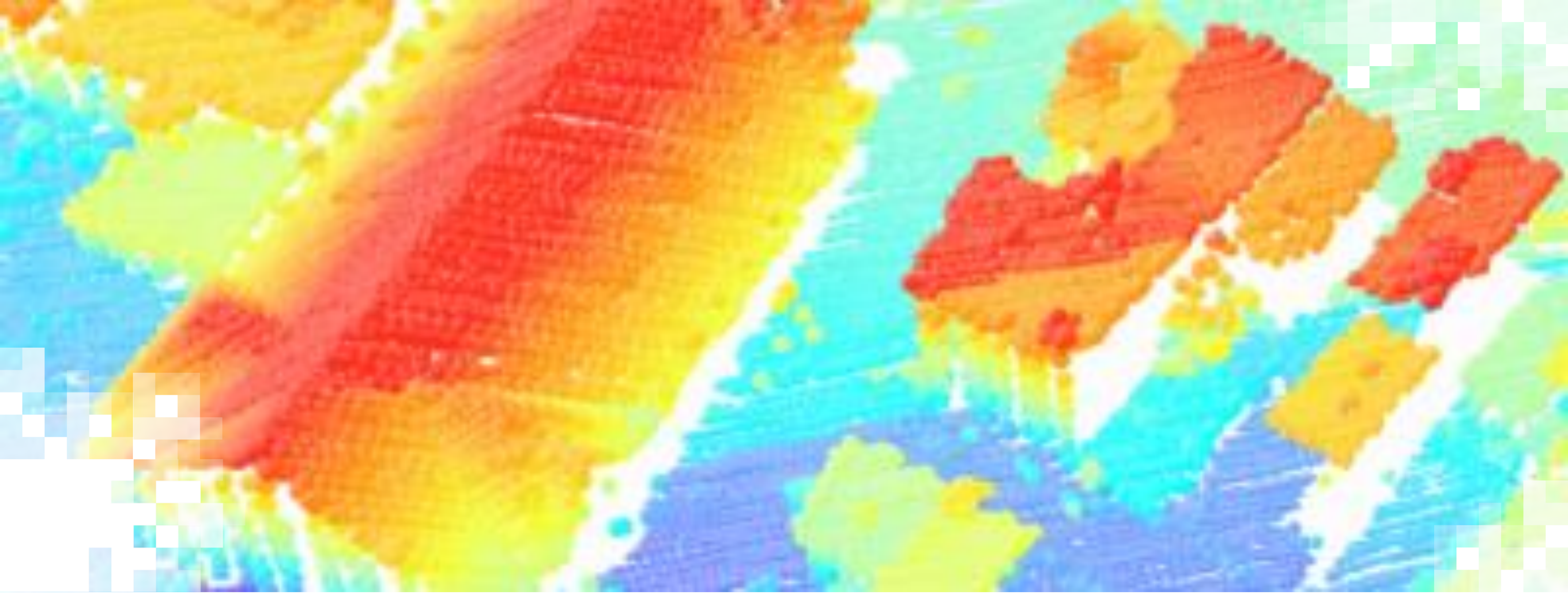
- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 1 – Trainers

Charles Huyck
Executive Vice President
ImageCat

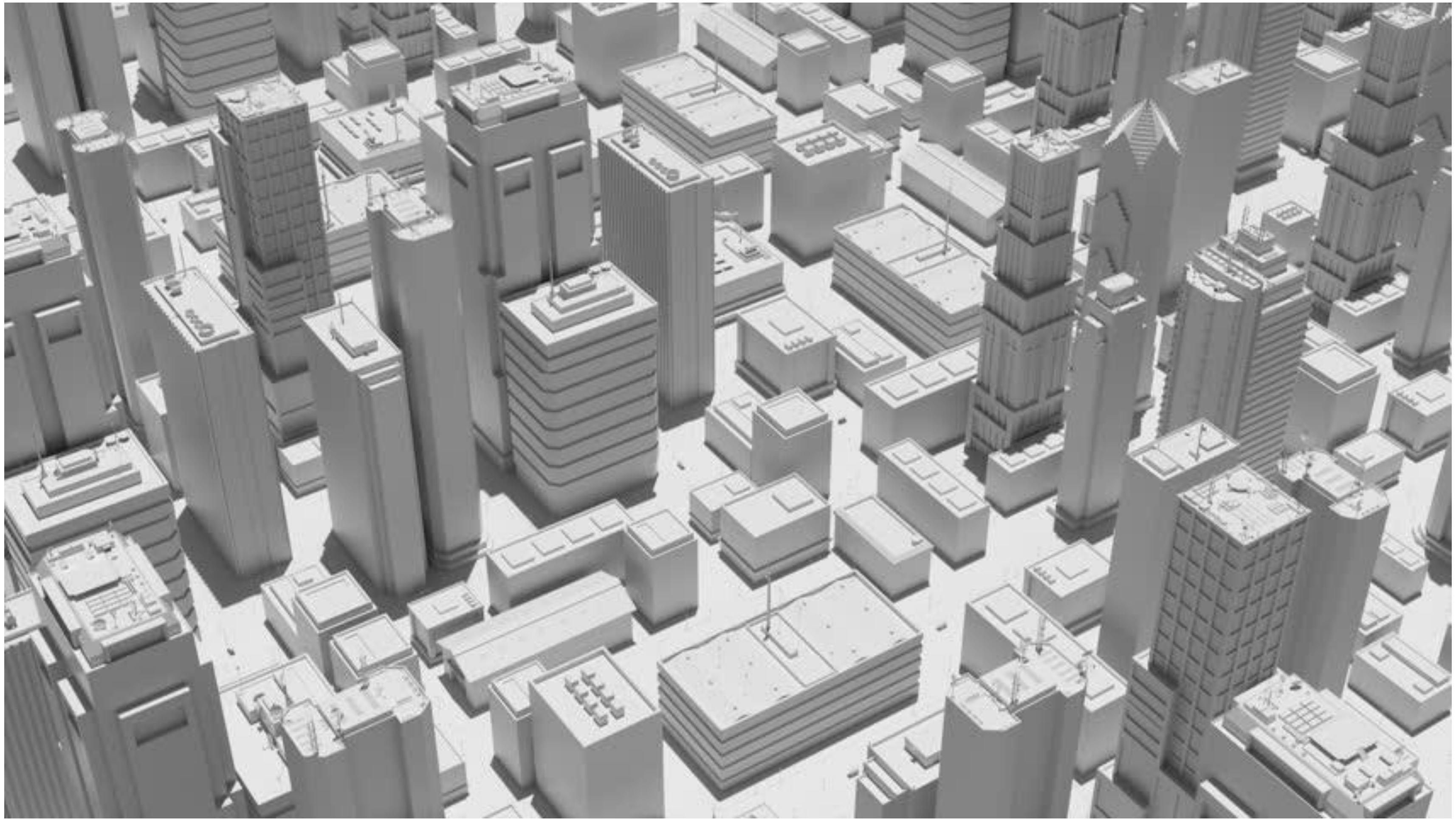
Georgiana Esquivias
Senior Project Analyst
ImageCat

Michael Eguchi
Project Engineer
ImageCat

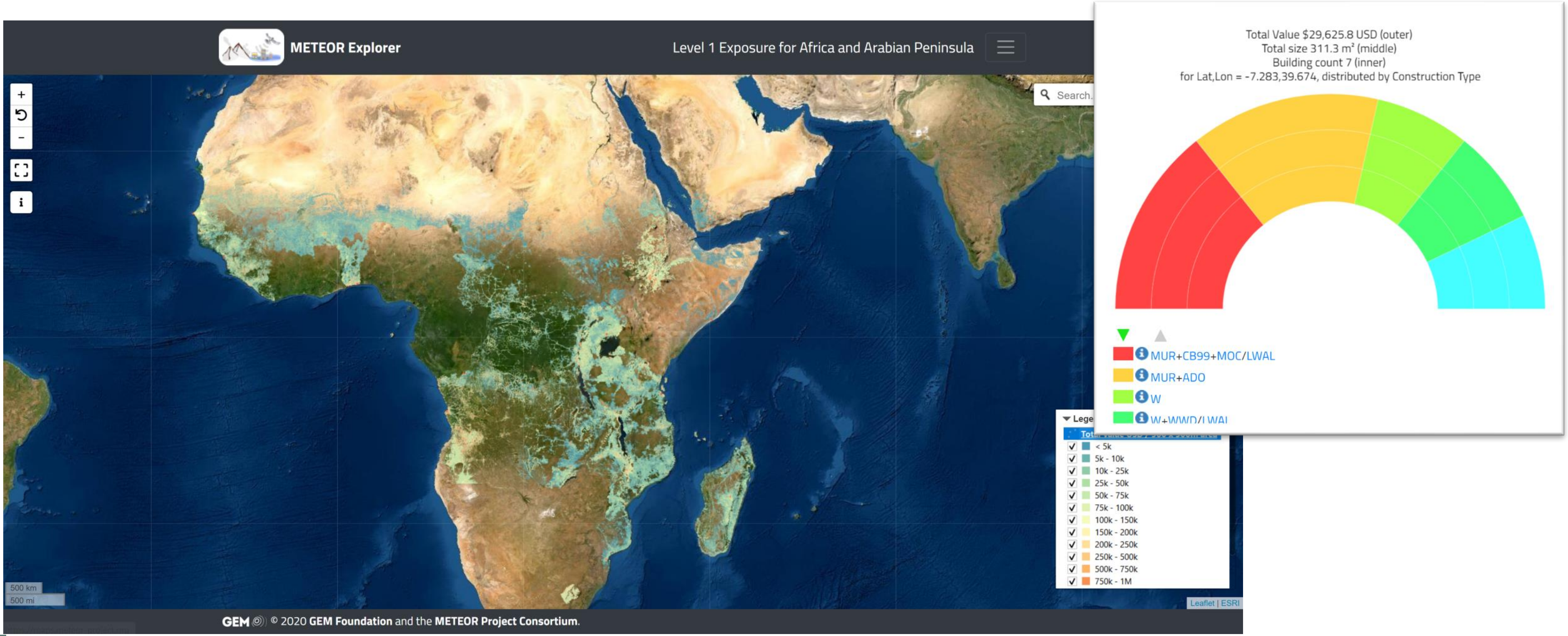


What is Exposure Data and How is it Used in the Loss Estimation Process?

What is Exposure Data?



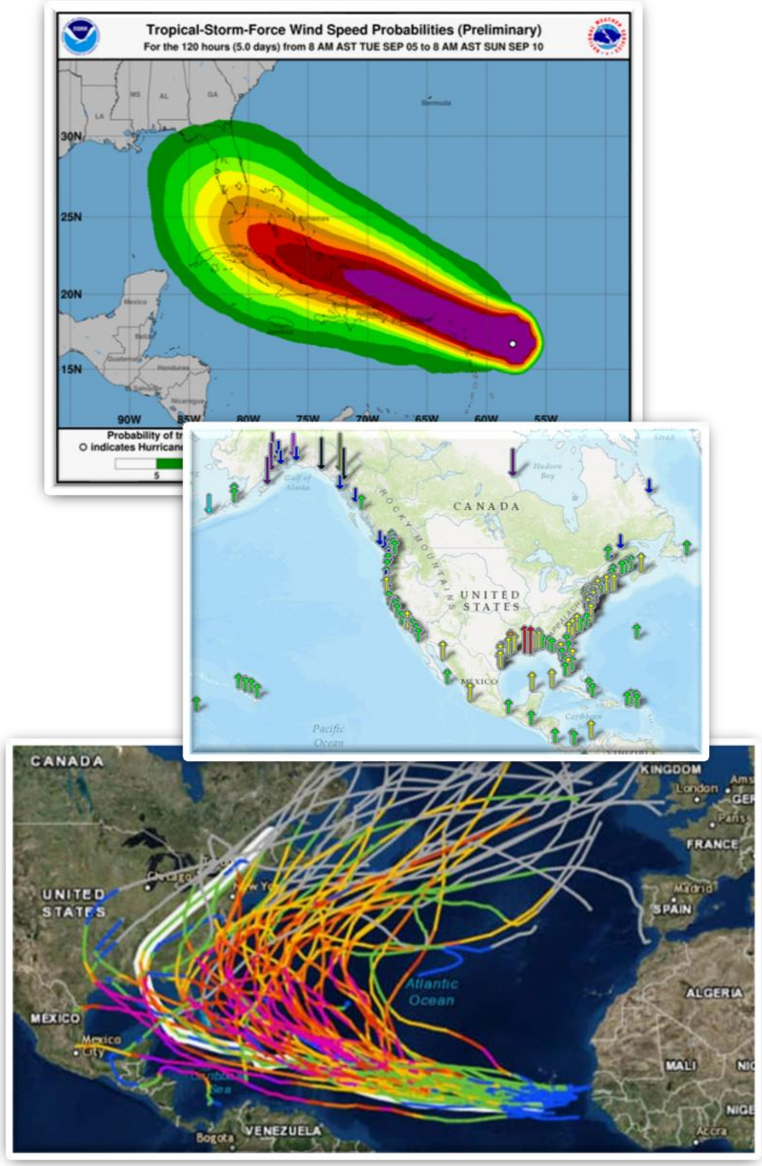
Risk Assessment: Exposure



Loss Estimation and Risk Modeling for Disaster Risk Reduction (DRR)

SUSTAINABLE DEVELOPMENT GOALS

- **Before an event –** What might happen if…?
- **During an event –** Where is this going? What should we do?
- **After an event –** What just happened? Should we ask international help? Where is the most damage? Where are people without food and shelter?
- **On average –** Where should we build stronger, higher, or farther away? Where should we retrofit, acquire property, or replace facilities? What should be insured? (Insurers – how much should that cost?)



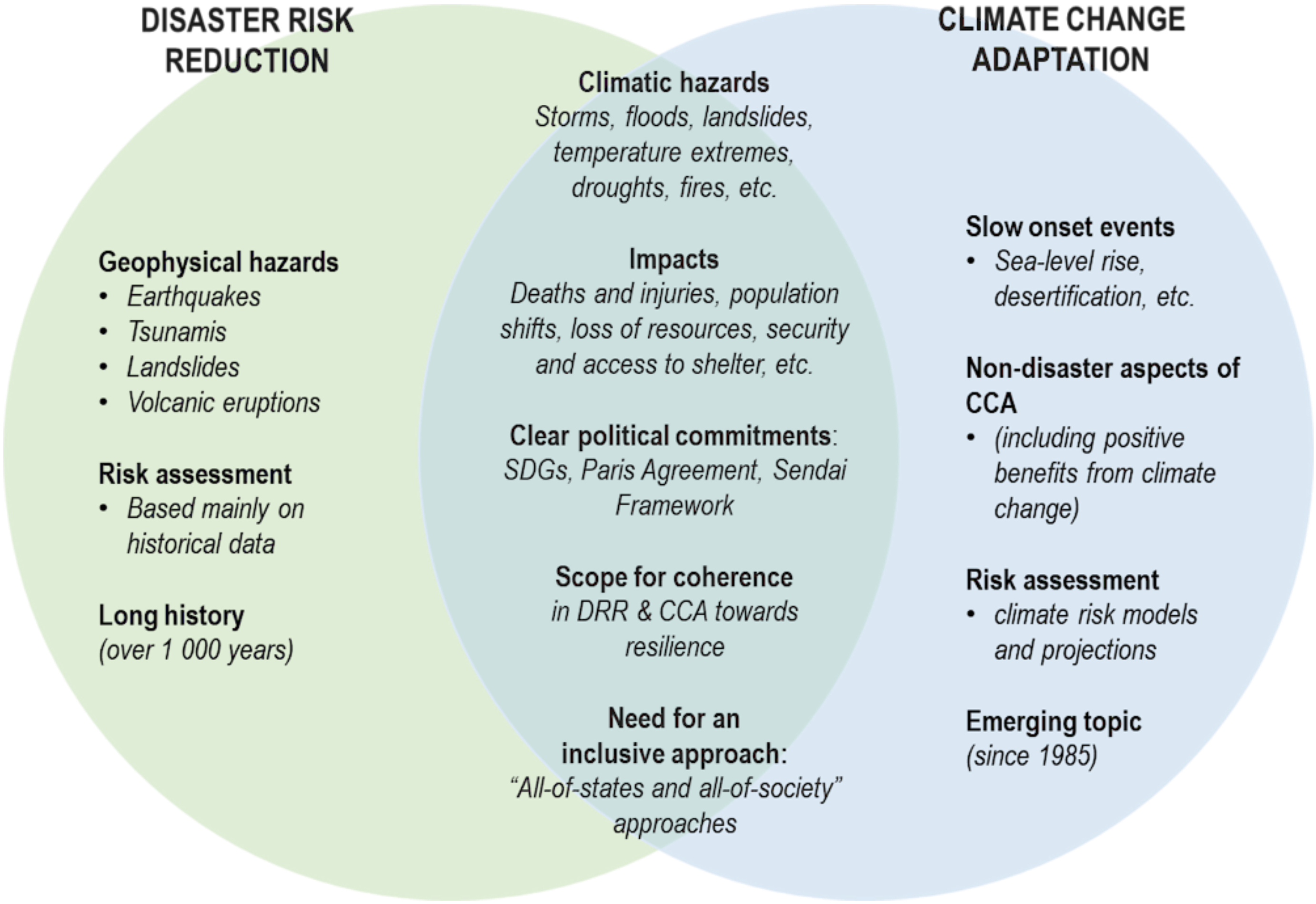
1 NO POVERTY

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

17 PARTNERSHIPS FOR THE GOALS

Terms and Meanings in CCA and DRR: Commonalities and Differences



[CCA and DRR, OECD]

DRR & CCA – Different terminology

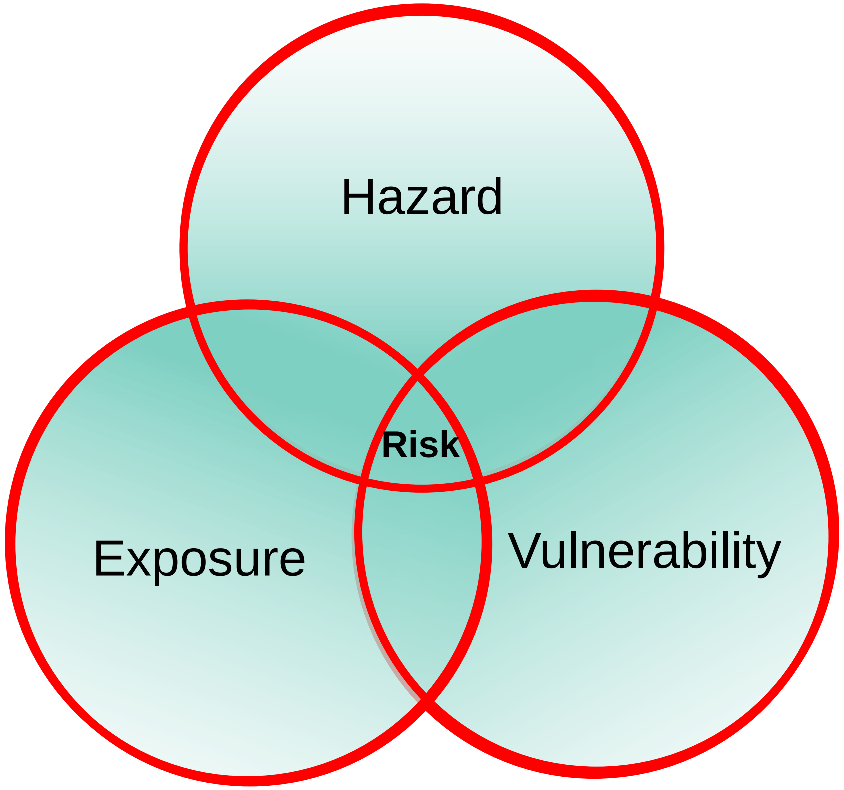
- **Disaster Risk Reduction (DRR):** Concept and practice of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters. DRR is aimed at preventing new and reducing existing disaster risk, which contributes to strengthening resilience and therefore to the achievement of sustainable development (UNDRR).
- **Mitigation**: The lessening or minimizing of the adverse impacts of a hazardous event. Mitigation measures include engineering techniques and hazard-resistant construction as well as improved environmental and social policies and public awareness.
- **Vulnerability**: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

- **Climate Change Adaptation (CCA):** Human-driven adjustments in ecological, social or economic systems or policy processes, in response to actual or expected climate stimuli and their effects or impacts (UNFCCC).
- **Mitigation**: In climate change policy, "mitigation" is defined differently, and is the term used for the reduction of greenhouse gas emissions that are the source of climate change.
- **Vulnerability**: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

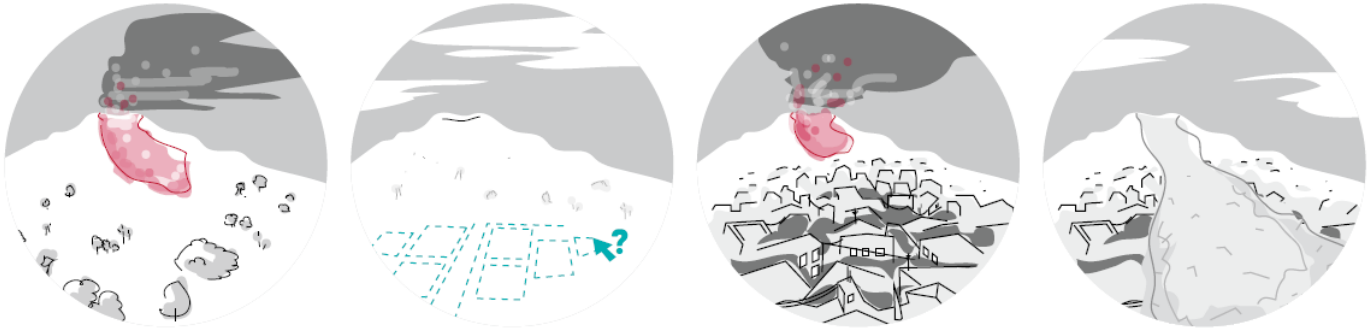
UNDRR Terminology

UNFCCC Glossary

Risk… Confluence of Hazard, Vulnerability, and Exposure



Risk and the context of hazard, exposure and vulnerability



There is no such thing as a **natural disaster**, only **natural hazards**

We make **choices** as to where we inhabit, how we build and what research we do

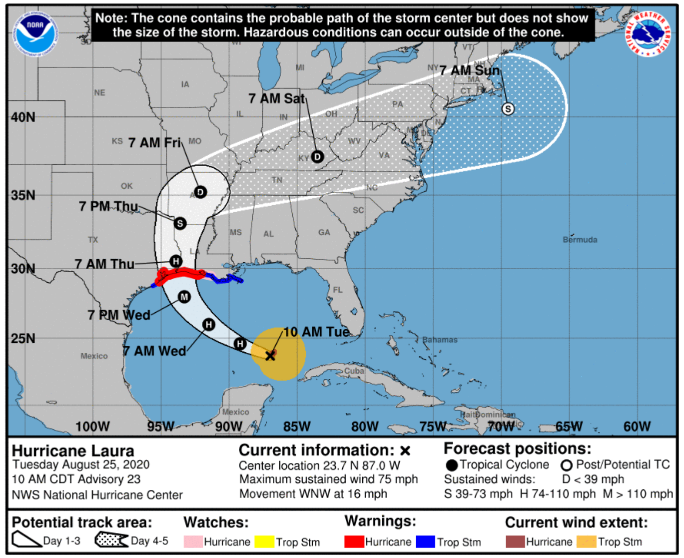
Risk is the combination of **hazard**, **exposure** and **vulnerability**

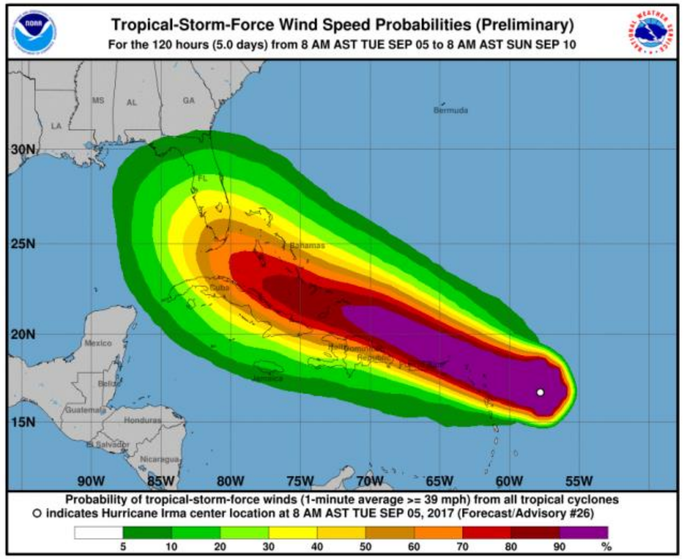
Death, **loss** and **damage** is the function of the context of hazard, exposure and vulnerability

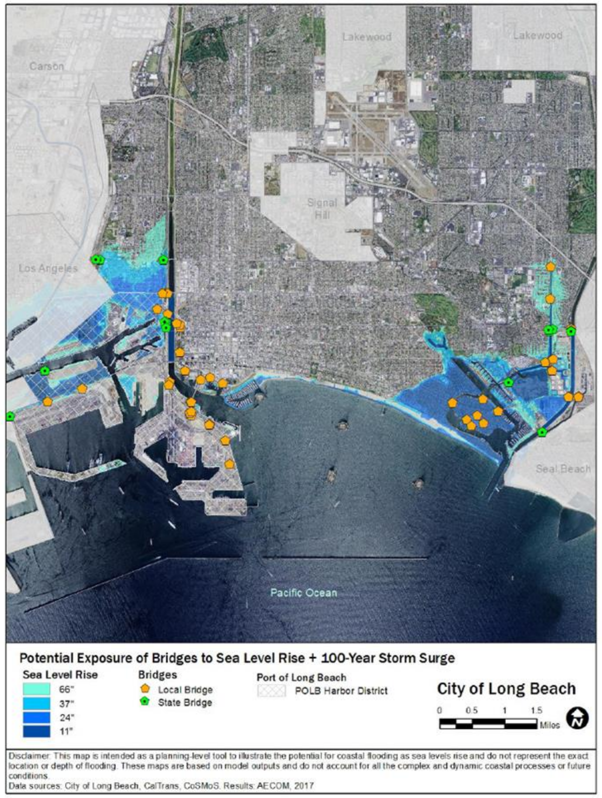
(Source: UNDRR 2019)

Hazard

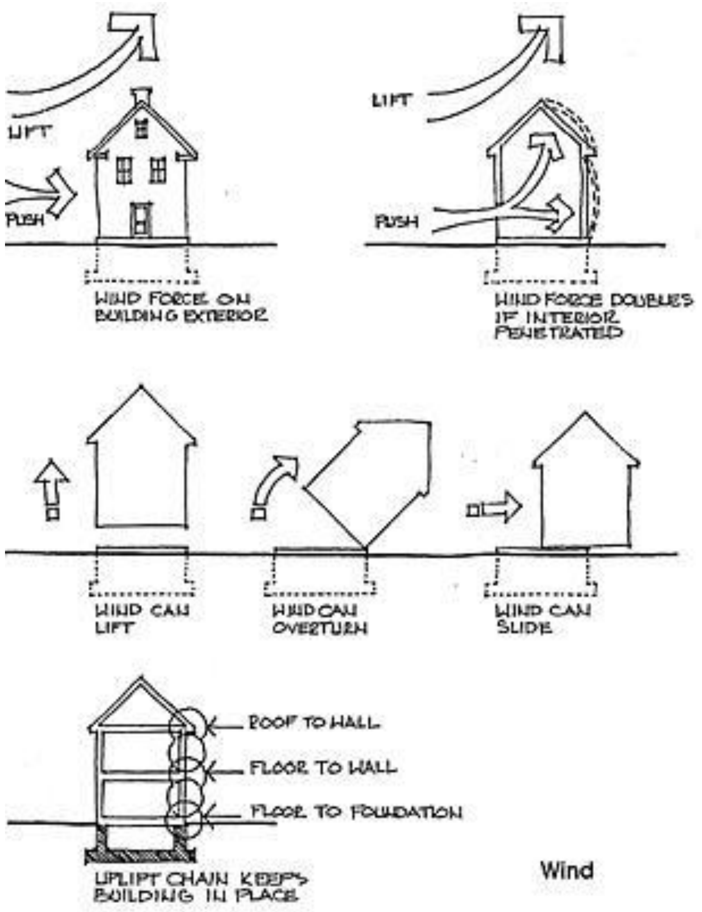
- Where? Extension
- How strong? Intensity
- When? Forecast, return period
- Duration?



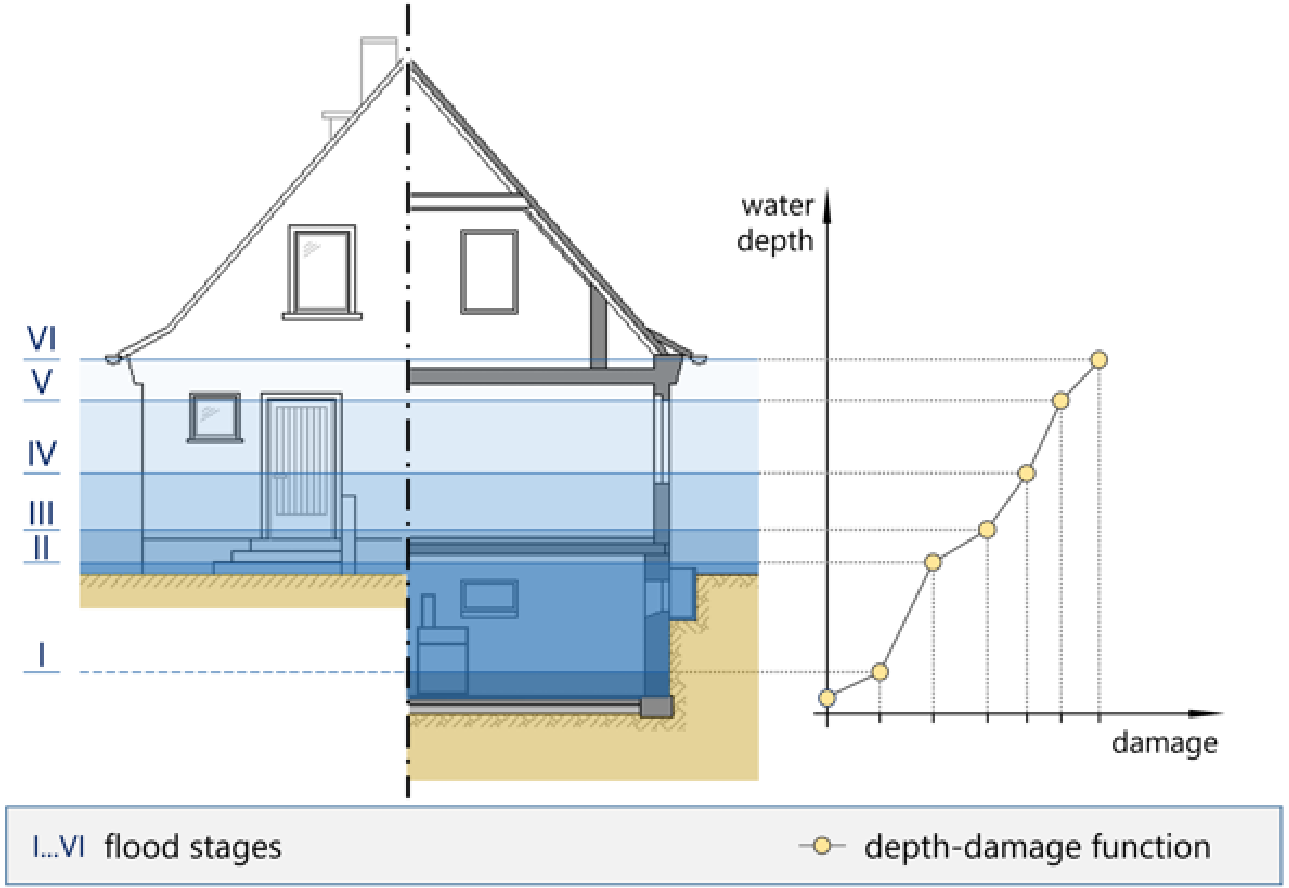




Building Vulnerability to Different Hazards

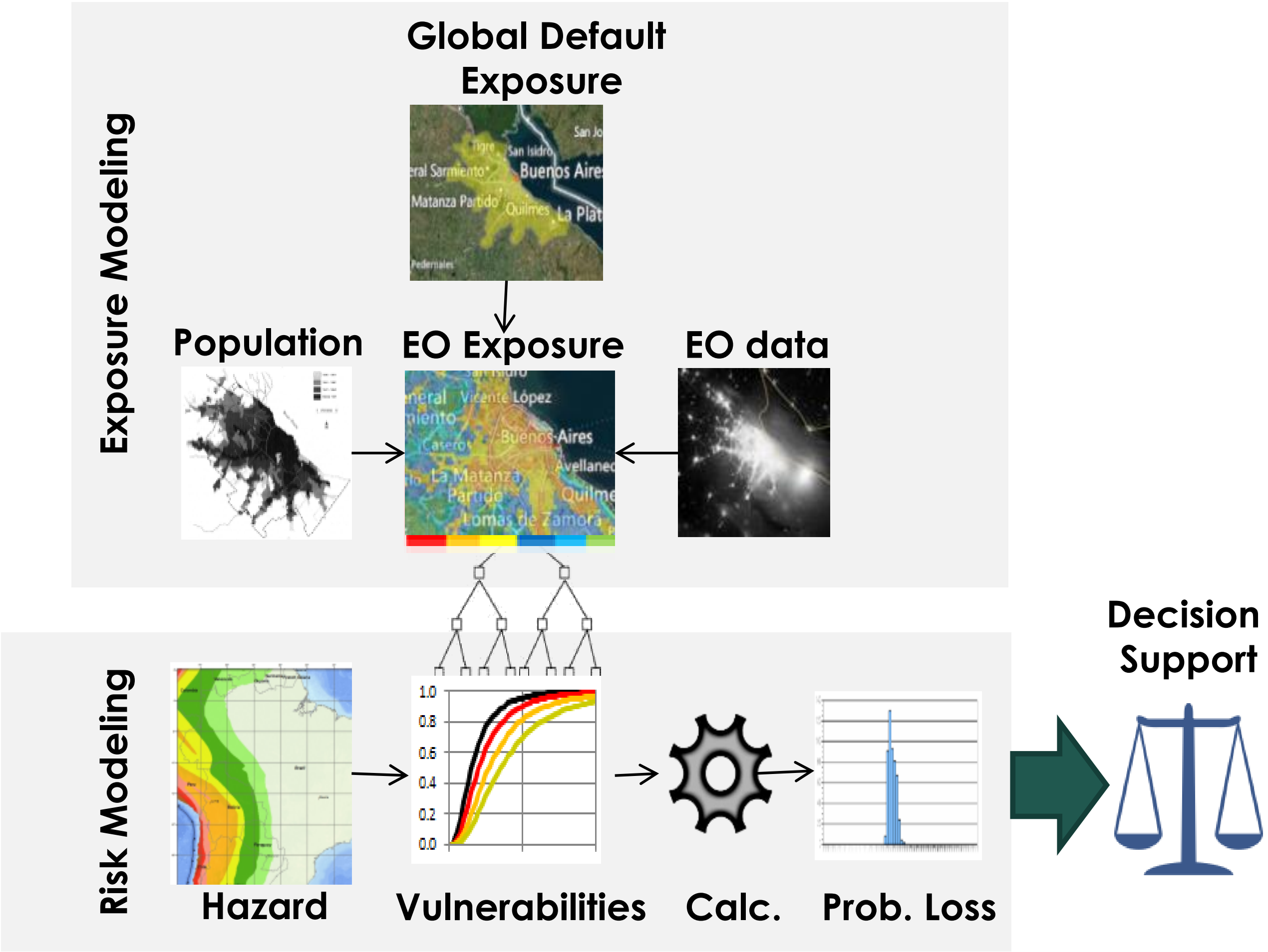


[Building vulnerability to wind diagram]

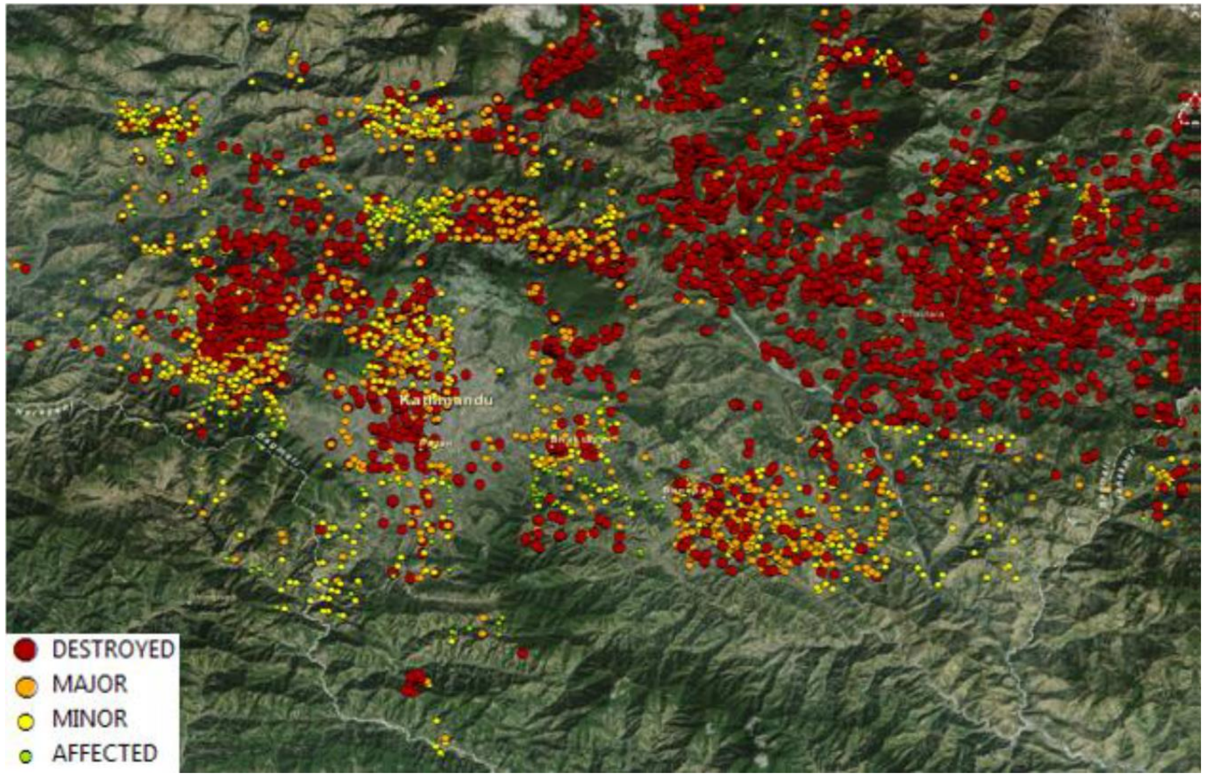


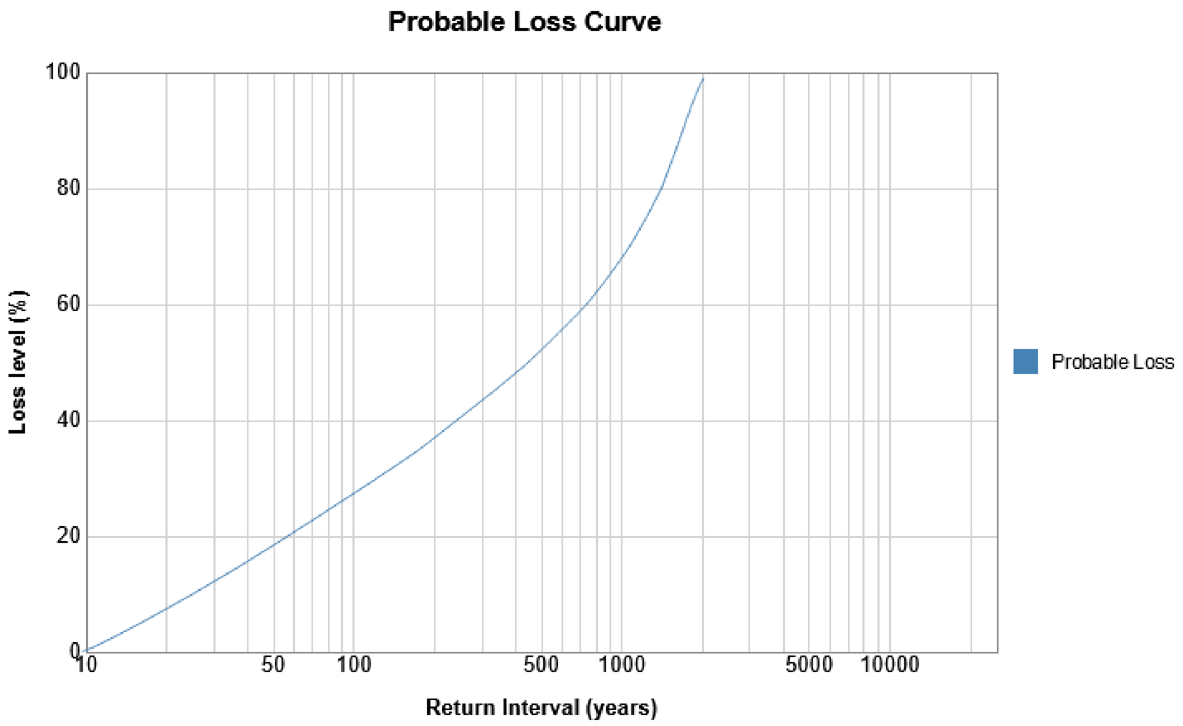
[Building vulnerability to floods diagram]

Risk Modelling



Types of Risk Analysis

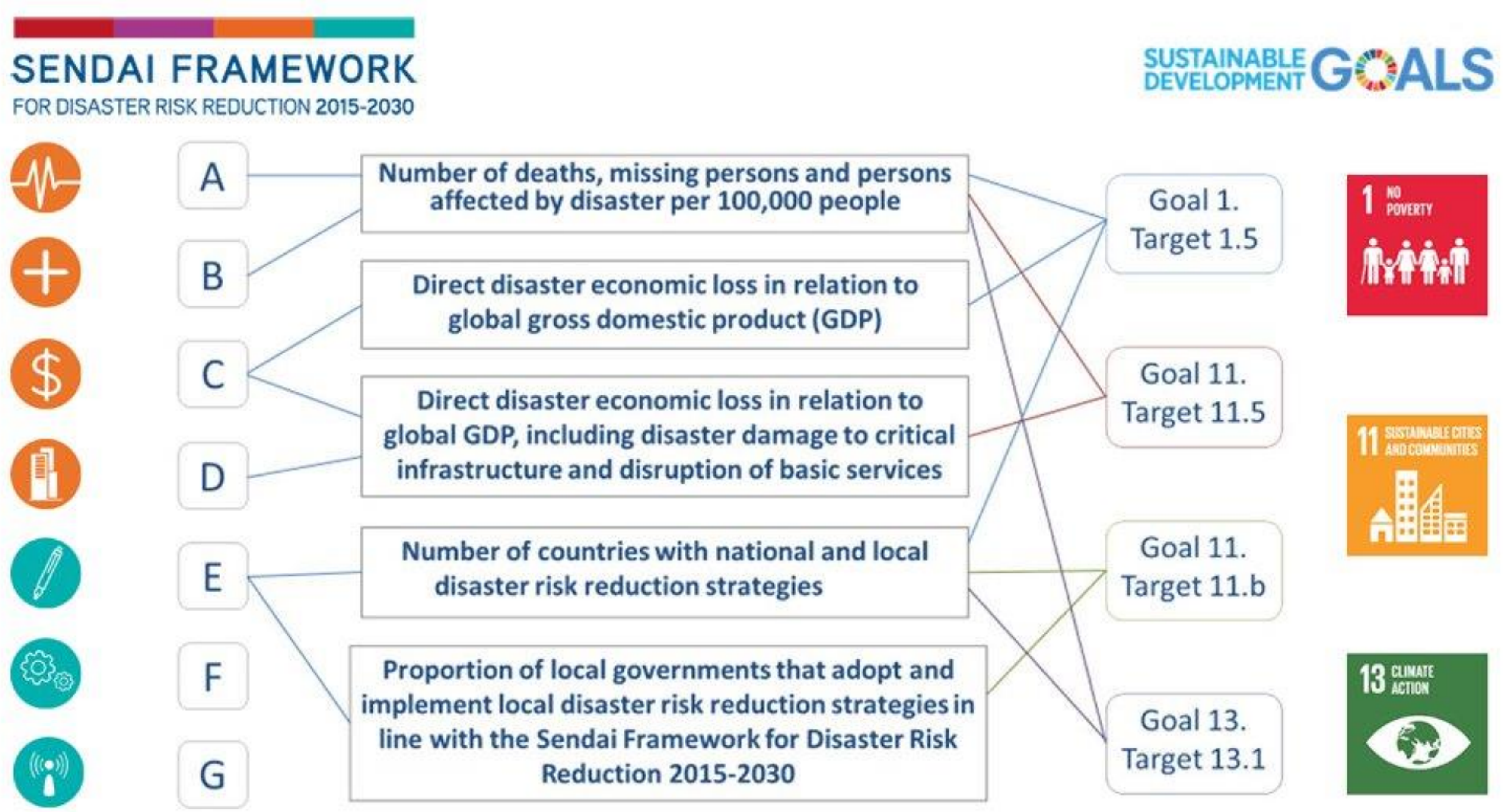




- Deterministic or "Scenario"
- Probabilistic

Sustainable Development and Disaster Risk Reduction

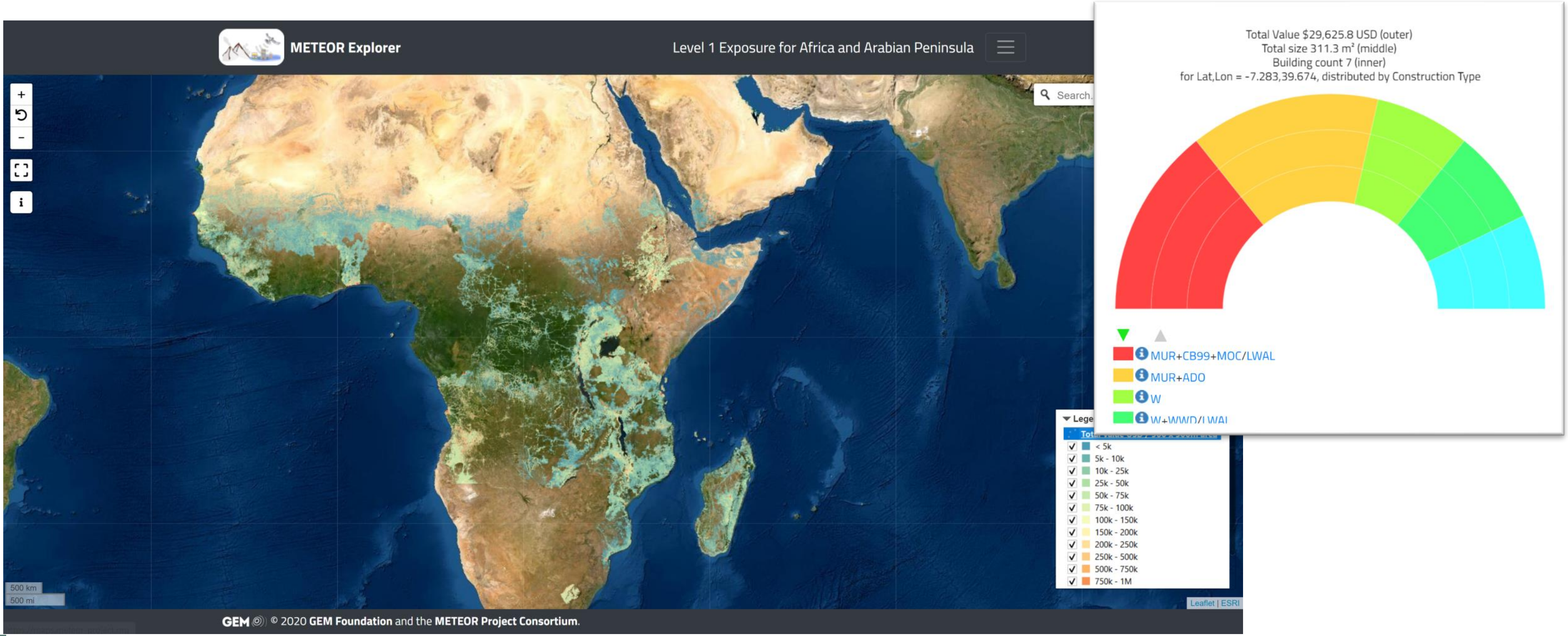
Sustainable Development and Disaster Risk Reduction



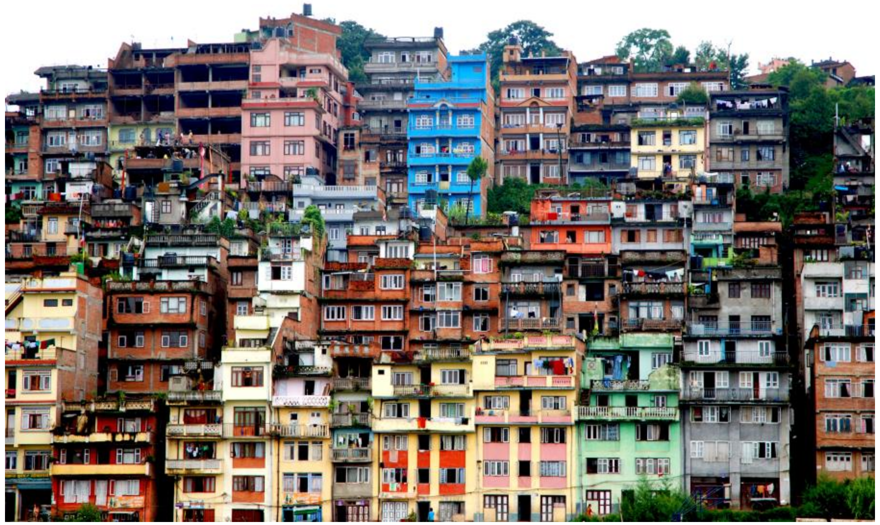
[Sustainable Development and DRR]

[Integrated monitoring of the global targets of the Sendai Framework and the Sustainable Development Goals]

What is Building Exposure for DRR?



Number of Buildings, Where, by Type and Cost, for the Purpose of Assessing Vulnerability and Hazard Proximity



Exposure Modelling is the Art of Distributing Inventoried People into Buildings

- Given the number of people, how many households?
- Given households, how much dwelling area?
- Given how much area of dwelling, how many buildings? How does this change in space?

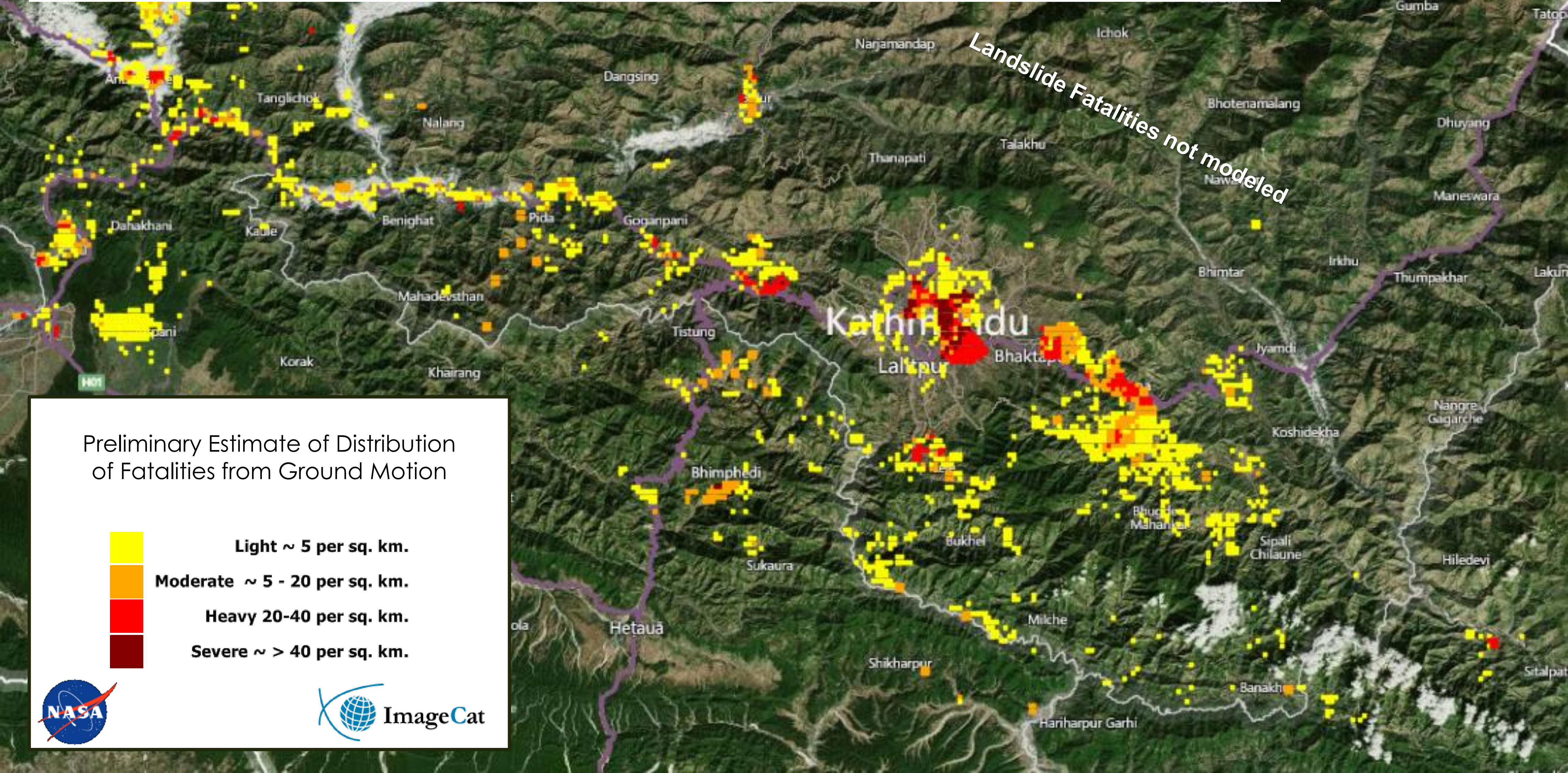
YES

- Is it cost effective to retrofit certain types of buildings regionally?
- Where should we focus retrofitting efforts?
- Are building codes cost effective, and where?
- What might happen after…
  - A hundred-year flood?
  - A large earthquake?
  - A volcanic eruption?
- There has just been a large earthquake…
  - What are the likely impacts?
  - Where is likely to have been affected the most?
  - How should we deploy resources?

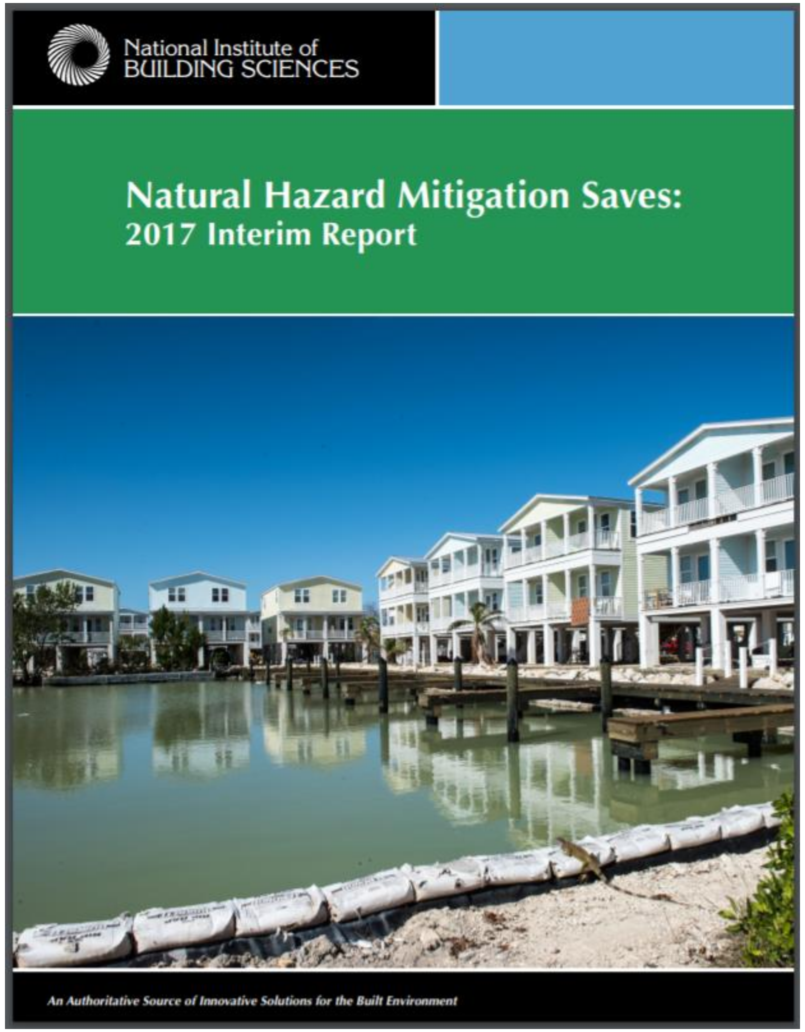
NO

- Is it cost effective to retrofit *this* building?
- Which buildings fell down? Which homes are flooded?
- Exactly how many buildings fell down?

Nepal Post-Earthquake Estimated for UNICEF



Natural Hazard Mitigation Saves $6 on Average for Every $1 Spent on Federal Mitigation Grants.



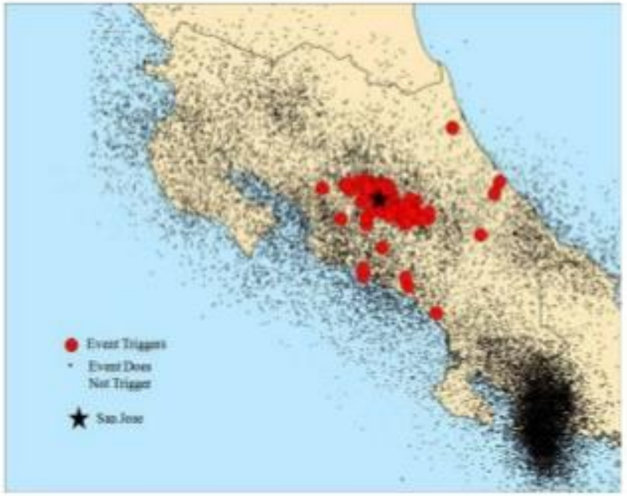
National Benefit-Cost Ratio (BCR) Per Peril *BCR numbers in this study have been rounded	Beyond Code Requirements	Federally Funded
Overall Hazard Benefit-Cost Ratio	$4:1	$6:1
Riverine Flood	$5:1	$7:1
Hurricane Surge	$7:1	Too few grants
Wind	$5:1	$5:1
Earthquake	$4:1	$3:1
Wildland-Urban Interface Fire	$4:1	$3:1

[Natural Hazard Mitigation Saves Report NIBS]

CAT Bonds in Developing Countries

Pricing of underlying peril risk*

Simulated Hurricane Tracks

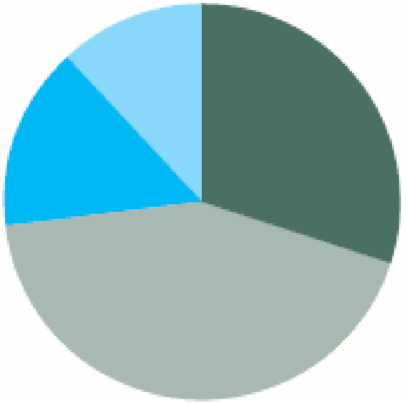


Simulated Earthquake Events (Epicenters)

* For Natural Peril premised bonds, catastrophe models are used to assess underlying base risk through stochastic simulation of natural disasters and associated economic costs.

[Source: Parametric Earthquake Cat Bond paper]

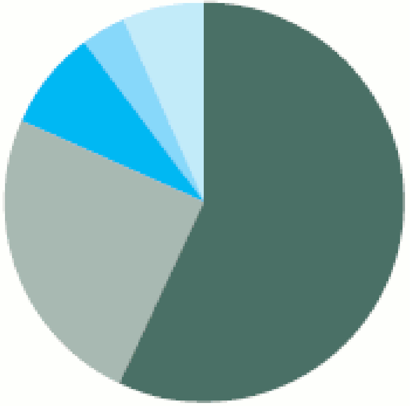
2007 Cat Bond Triggers



Indemnity	30%
Industry Index	43%
Parametric Index	15%
Modeled Loss	12%

Source: Swiss Re Capital Markets

2012 Cat Bond Triggers



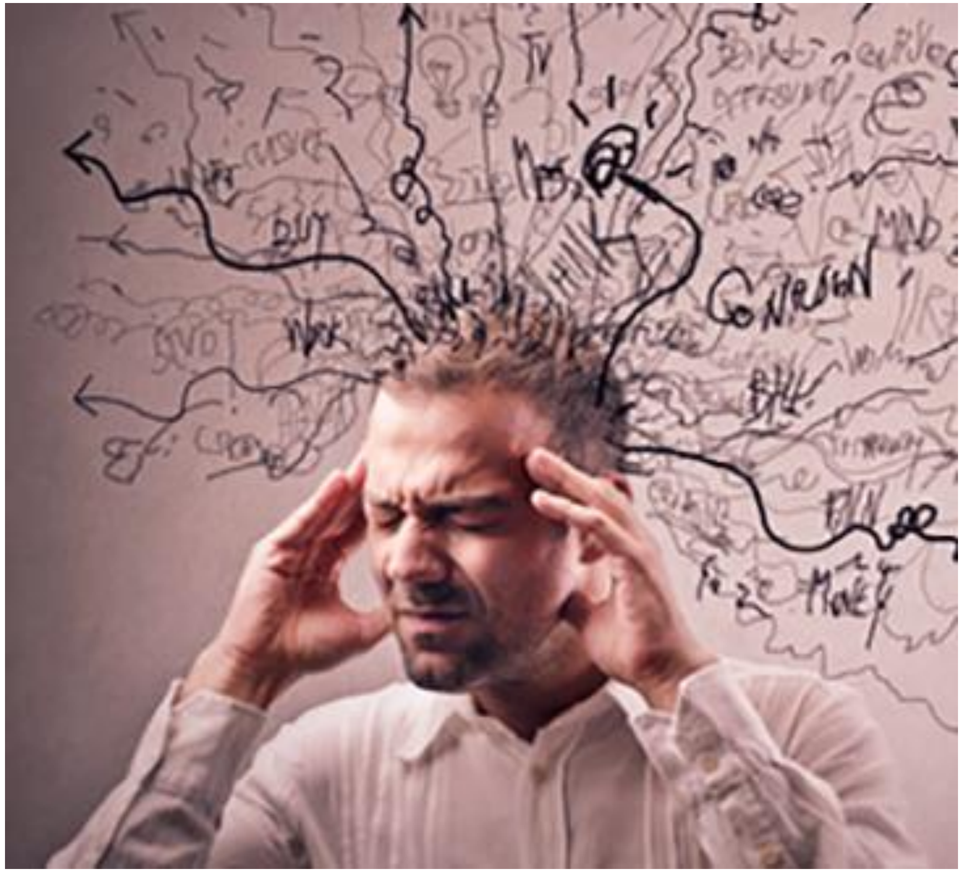
Indemnity	57%
Industry Index	25%
Parametric Index	8%
Modeled Loss	4%
Hybrid	6%

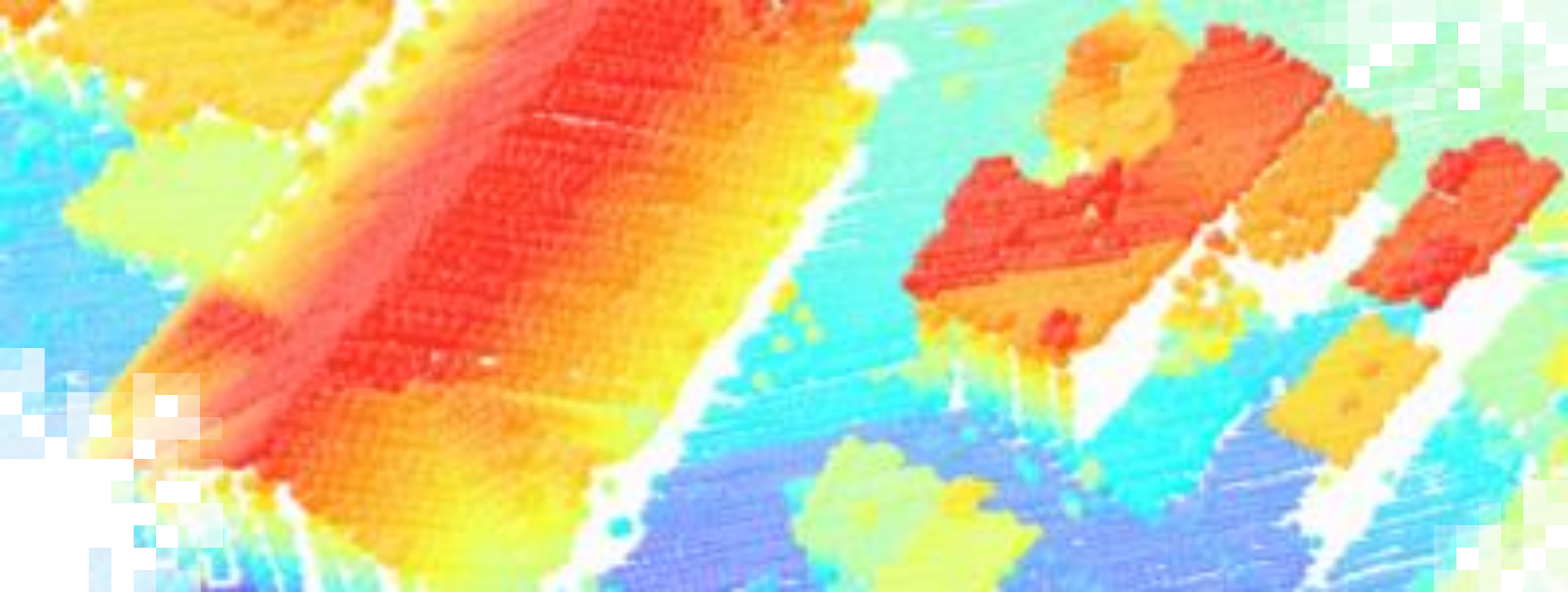
Expectations

- Cannot typically expect accurate number of buildings at the cell level – count is approximate
- Cannot expect more accuracy than in the original base data sets
- Cannot expect to always capture small unmapped rural areas
- Challenges in remote sensing that will impact results (low lights, cloud cover, tree canopies etc.)
- Can not repurpose the data for civic purposes such as address-specific information for tax purposes

Challenges

- Data Availability
- Permissions
- Processing challenges
- Bias
- Human error
- Data gaps
- Misperception
- Accuracy
- False precision
- Explaining the data with clarity
- Inappropriate legacies
- Turnover
- Obsolescence
- Advancing technologies (AI, UAV, additional sensors)

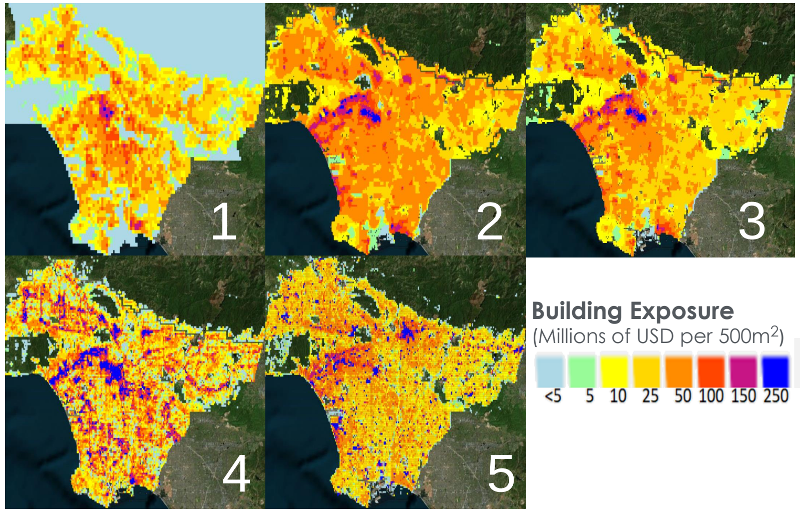




The Basic Process of Developing Exposure Data

Introduction to Building Exposure Data Development: Key Concepts

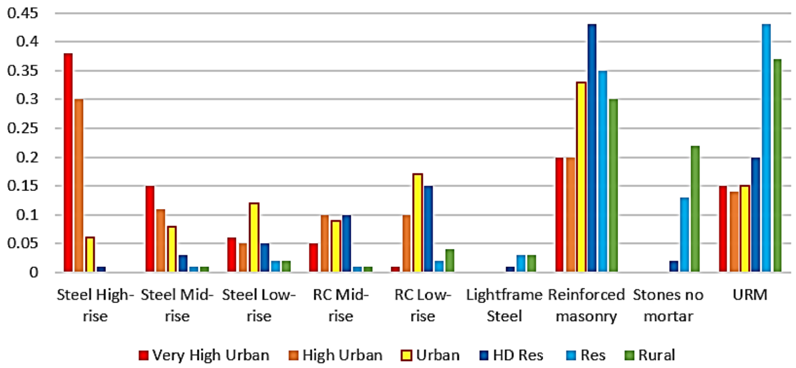
What are the different Types of Exposure Levels?



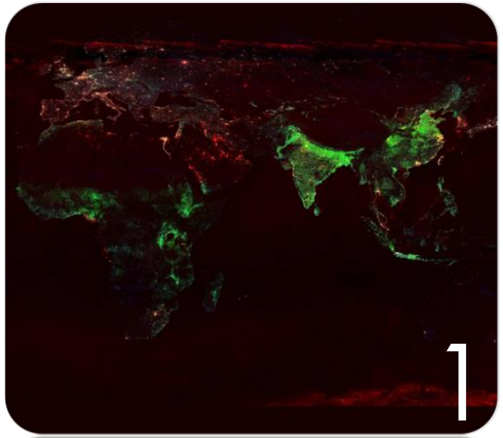
How is an Exposure Database Developed?

- Collect Census Population and Building data
- Development Patterns and Structural Distribution
- Estimation of Number of Buildings, Building Area and Height
- Replacement Cost Value Estimate

What is the role of Earth Observation Products?



Example of Data Types by Exposure Level

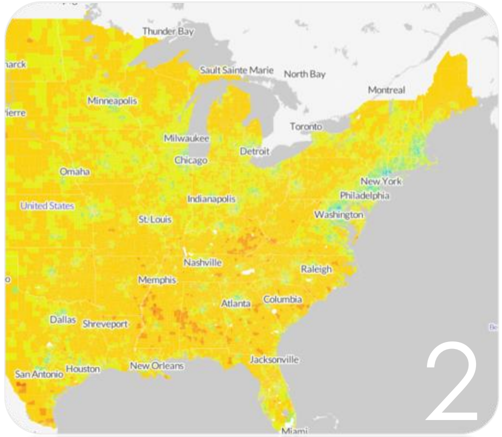


Global

PAGER, GED4ALL, GAR, METEOR, NASA Satellite Imagery or Data Products

Typically, global but can be continental or regional

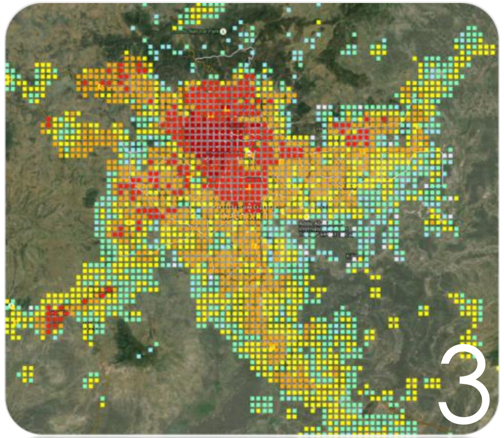
An aggregate of aggregated data



National

FEMA – HAZUS Data

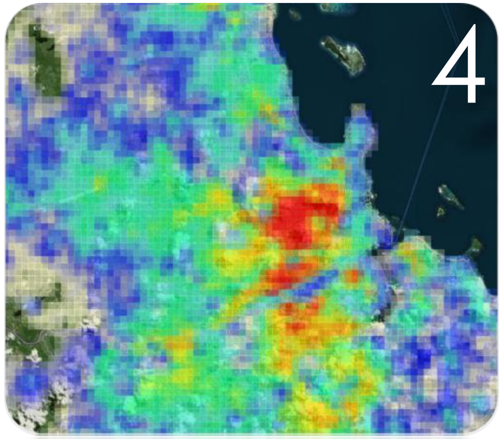
National Census



Sub-National

Local State data

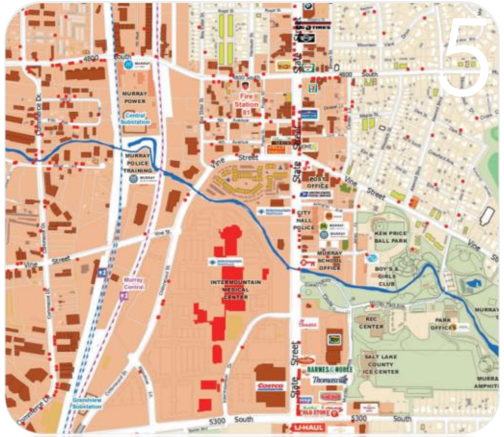
Study Region Information



Aggregate of Building Specific Data

OSM - building footprint data

Aggregated Building-specific data

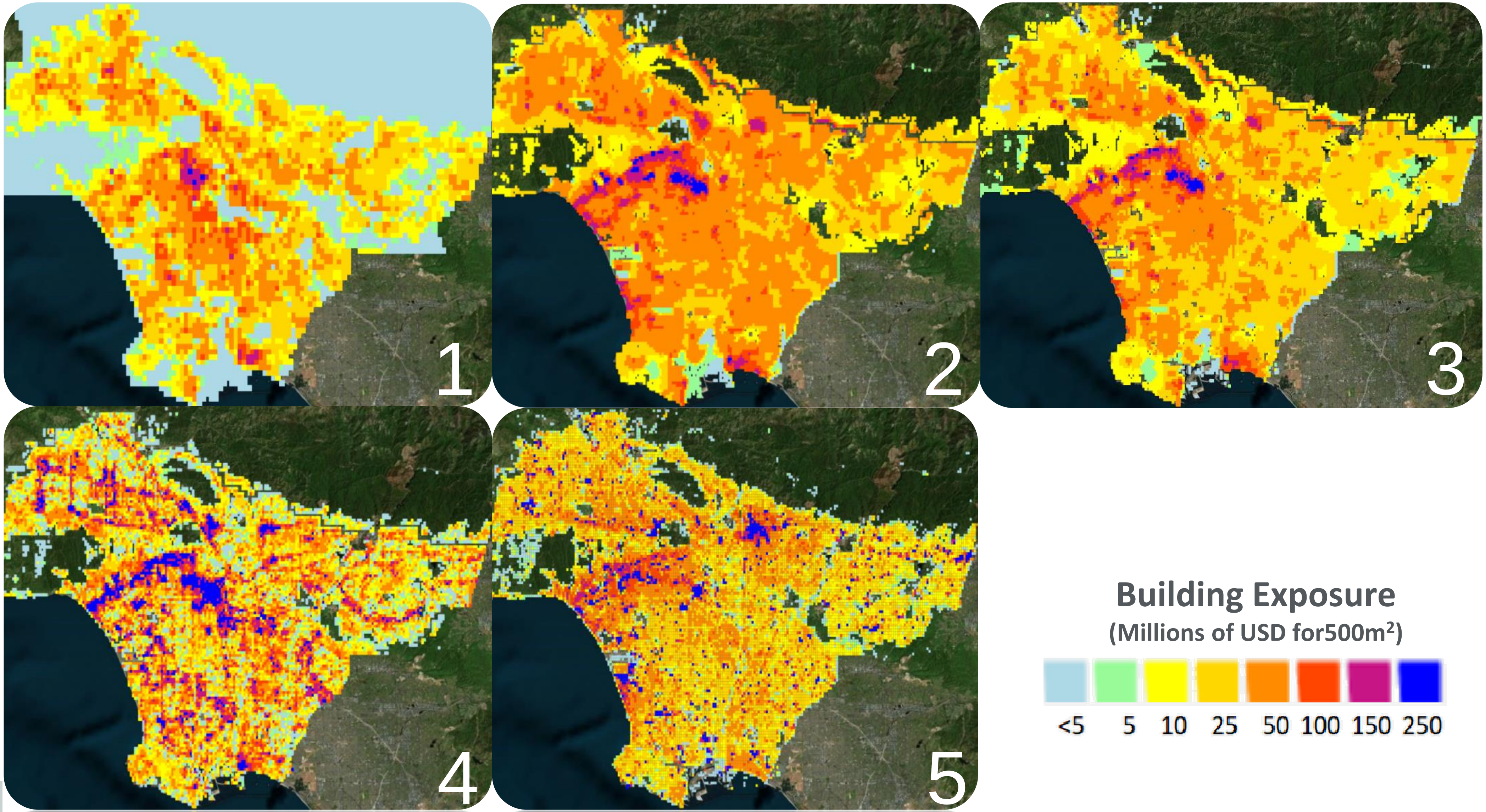


Building or Site-Specific Data

Engineer Surveys

Building and/or Site-specific data

Summary of the 5 Levels of Exposure Data



Steps for Developing a Building Exposure Database

I. Estimate the Number of Buildings and People by Geography
II. Estimate the Distribution of Buildings by Height (optional)
III. Estimate the Distribution of Building by Development Patterns (optional)
IV. Estimate the Structural Distribution by Development Pattern
V. Bringing It All Together
VI. Add Replacement Cost Values
VII. Add Essential Facilities (as needed)

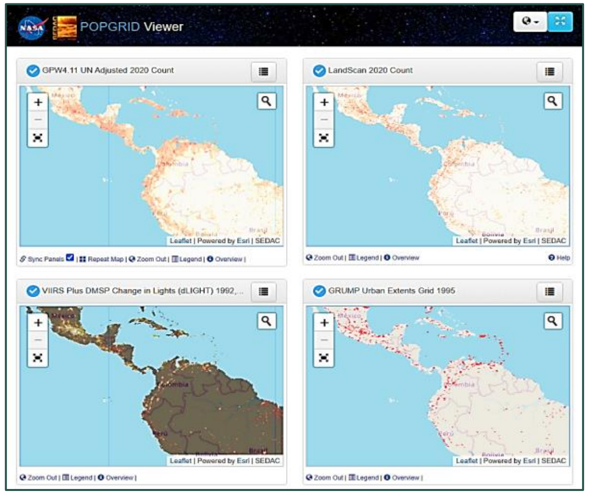
I. Estimate the number of buildings and people by geography

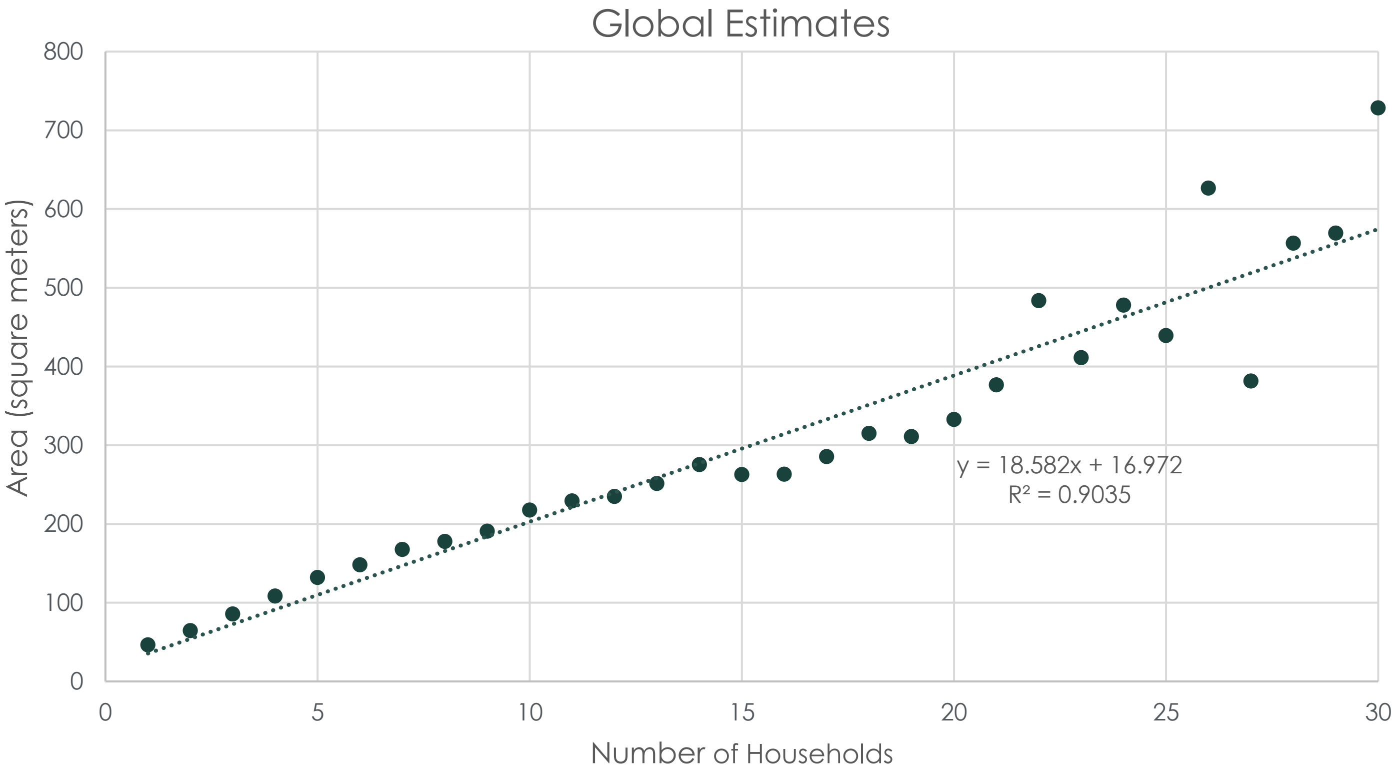
You can count buildings, or you can estimate number of buildings from population.

- Level 1: Population → Persons per Household → Average Area per Household, scale for non-residential
- Level 2: Population and Number of Households from Census
- Level 3: Refine Population and Building Counts using Land-use Data or Development Patterns
- Level 4: Aggregate from Building Footprints or Government Databases, Estimate Number of People
- Level 5: Use Building Specific Data, and Estimate Number of People

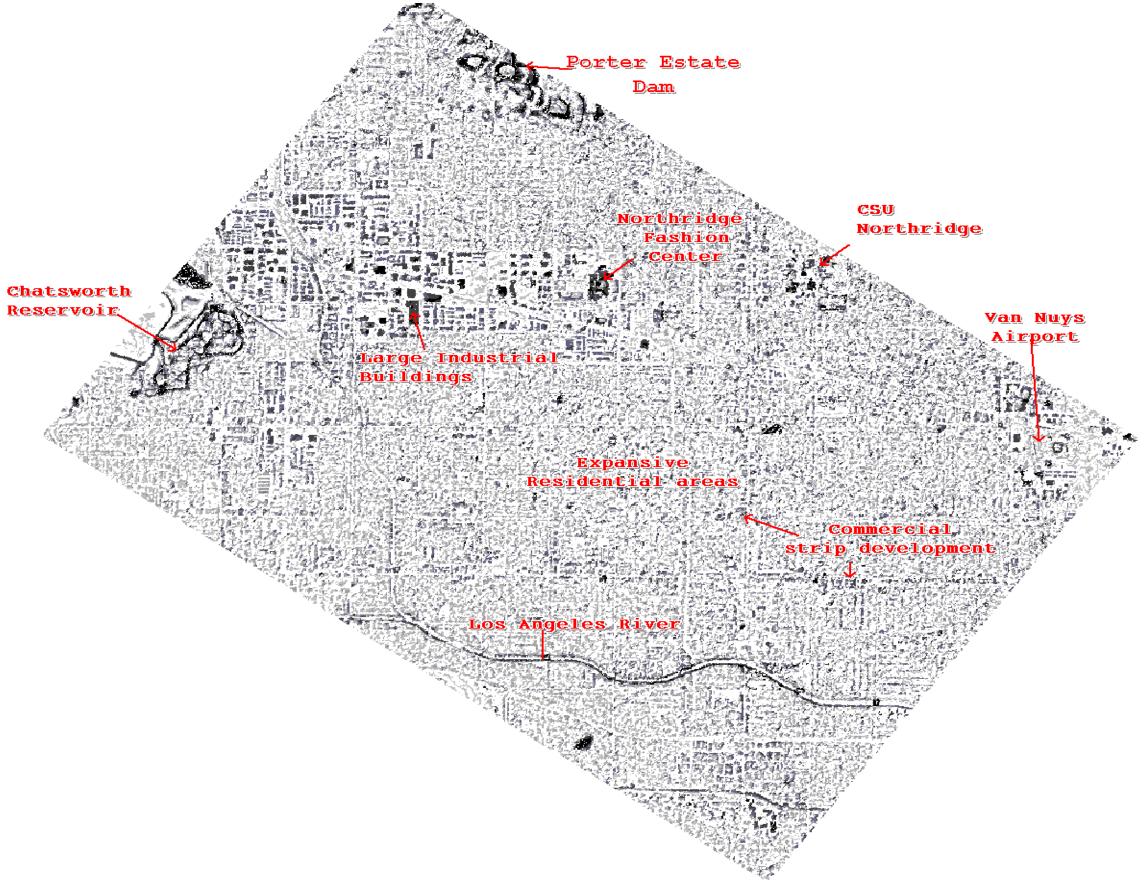
Estimate number of buildings and square footage per building

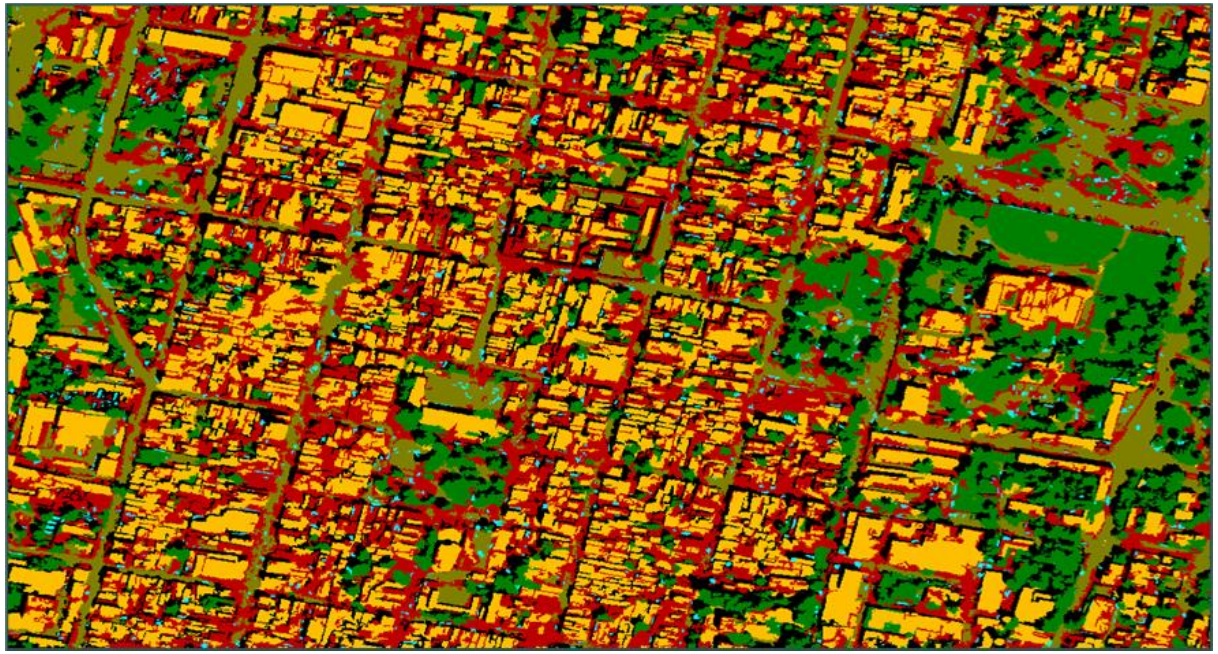
- People Per Household and Households per building
- Building Density by Earth Observation Factors
- OSM Building Data Footprint
- Height Profiles
- Micro-Census Data
- Population Density Correlation



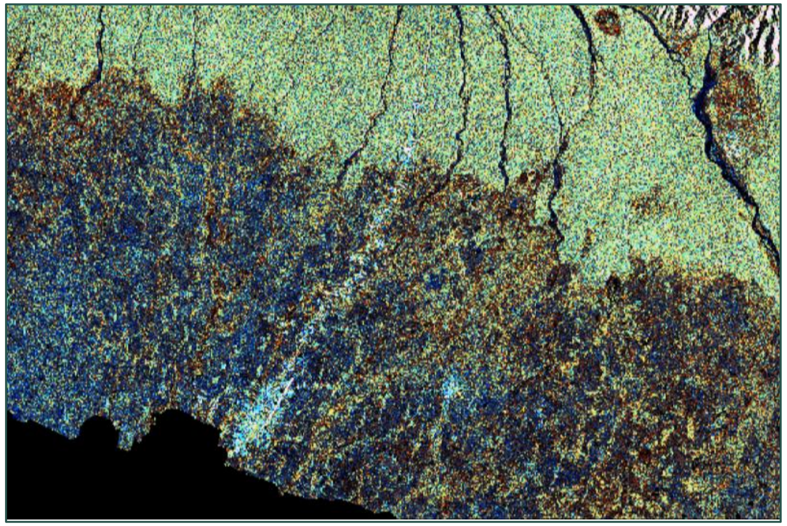
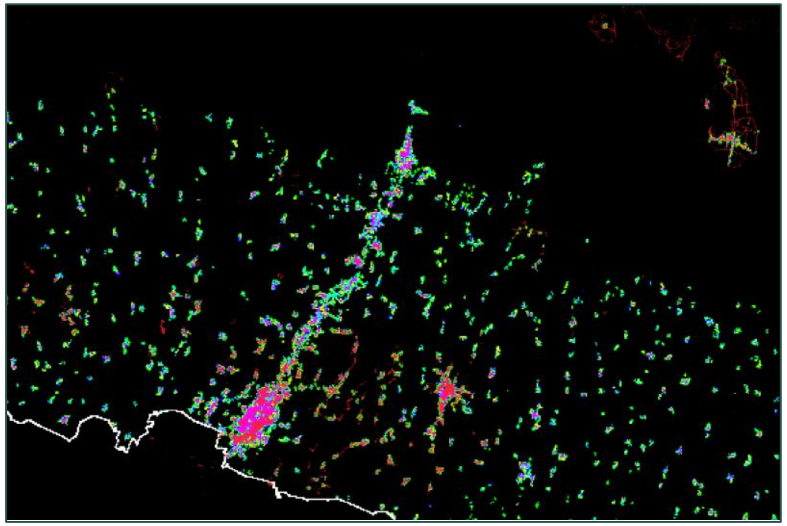
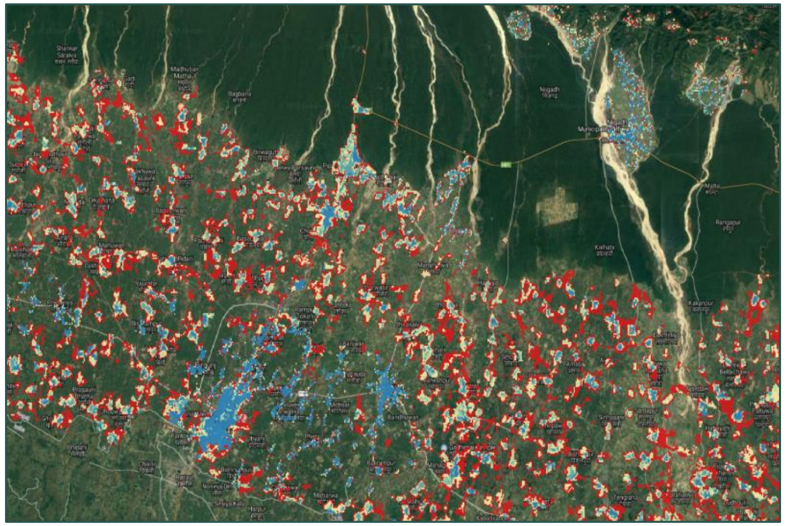


Estimate the Number of Buildings and Built-Up Area from Building Extraction





II. Estimate the Distribution of Buildings by Height

- Estimated from Global EO Products and Datasets (JRC, OSM)
- Extracted from LIDAR, SAR, Stereoscopic Optical
- Height can be attributed in Building Level Data
- Height can be assumed from Development Patterns
- Height can be used to assume Structure Type

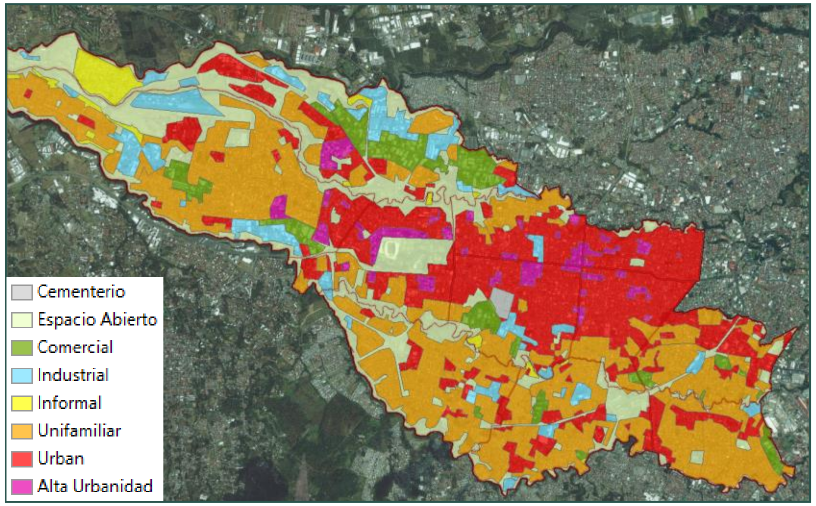
III. Estimate the Distribution of Building by Development Patterns:

Identifying and Delineating Development Patterns

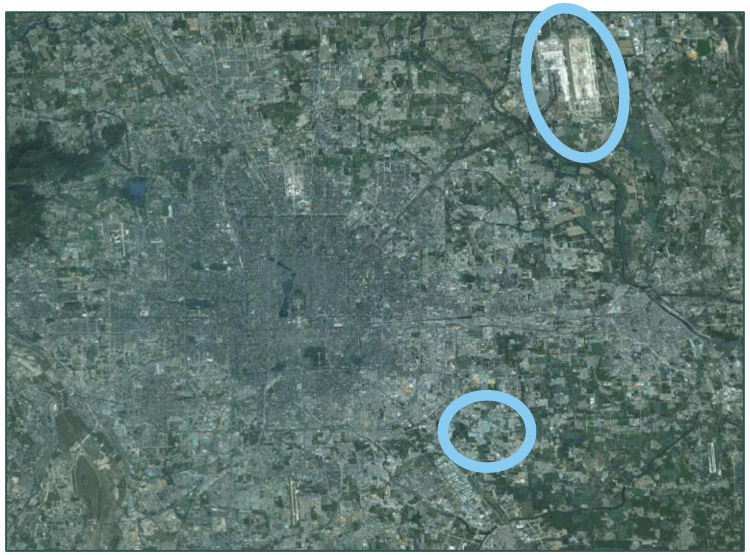
Identify local construction types

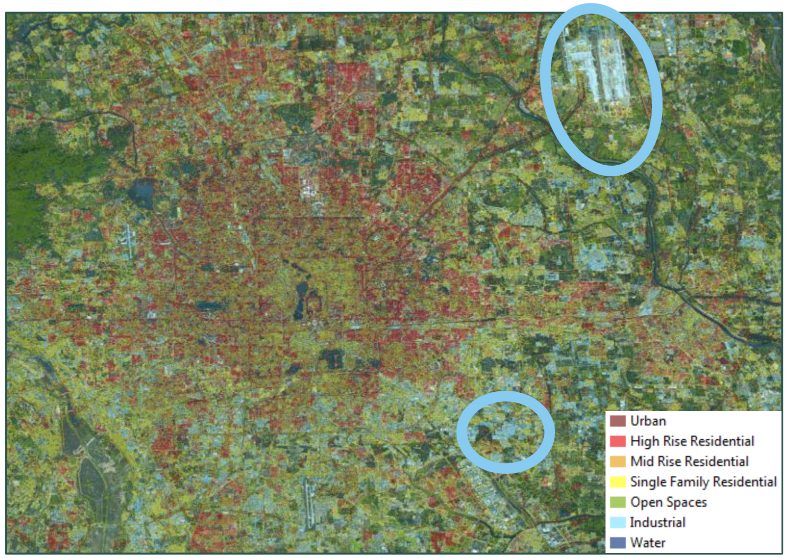
Classify Development Patterns

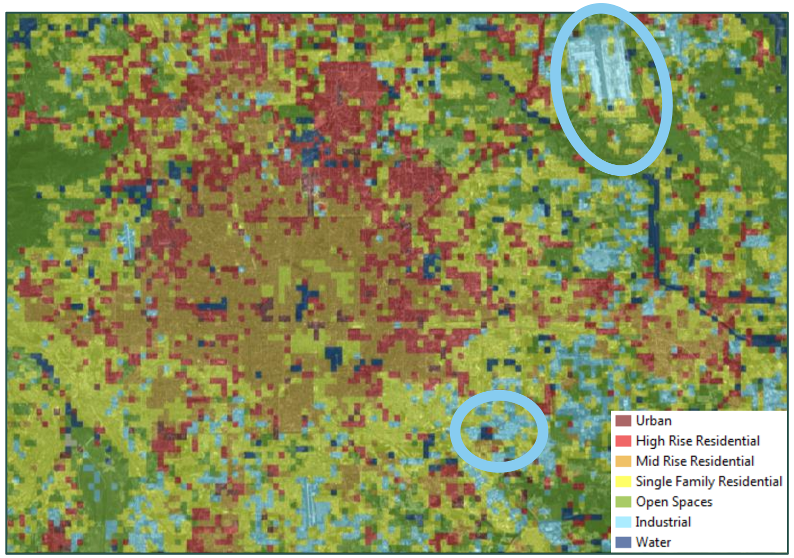
Delineation of Development Patterns

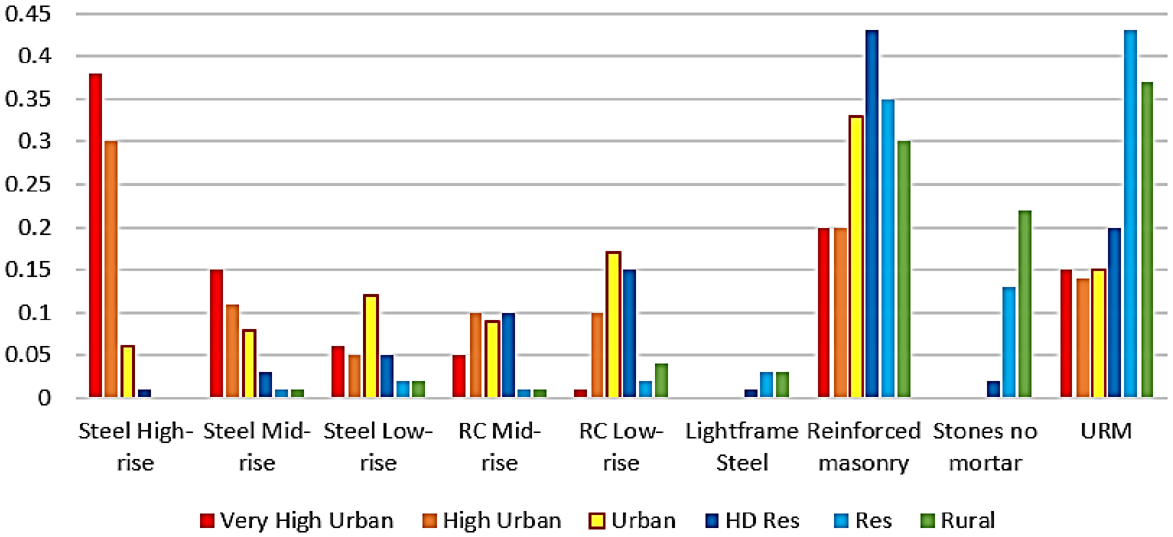


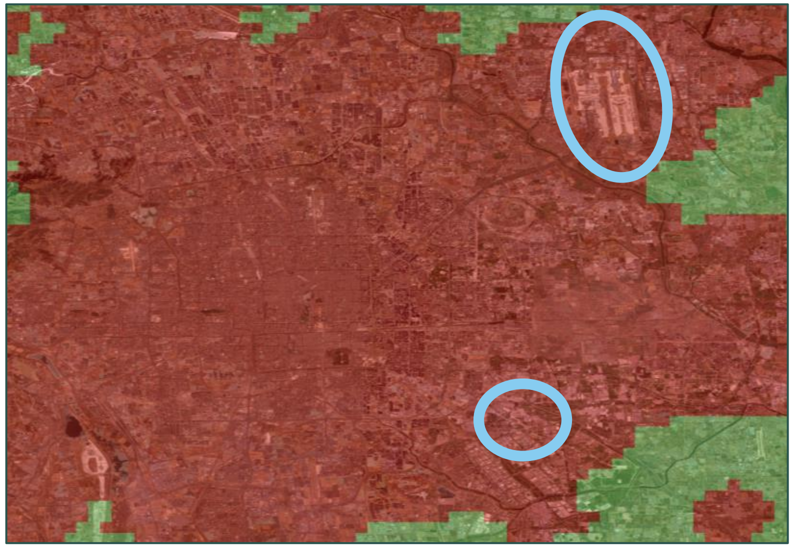
Benefits of Development Pattern Segmentation





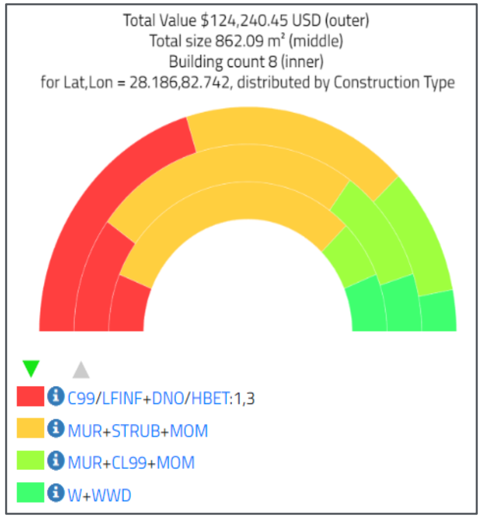






IV. Estimate the Structural Distribution by Development Pattern

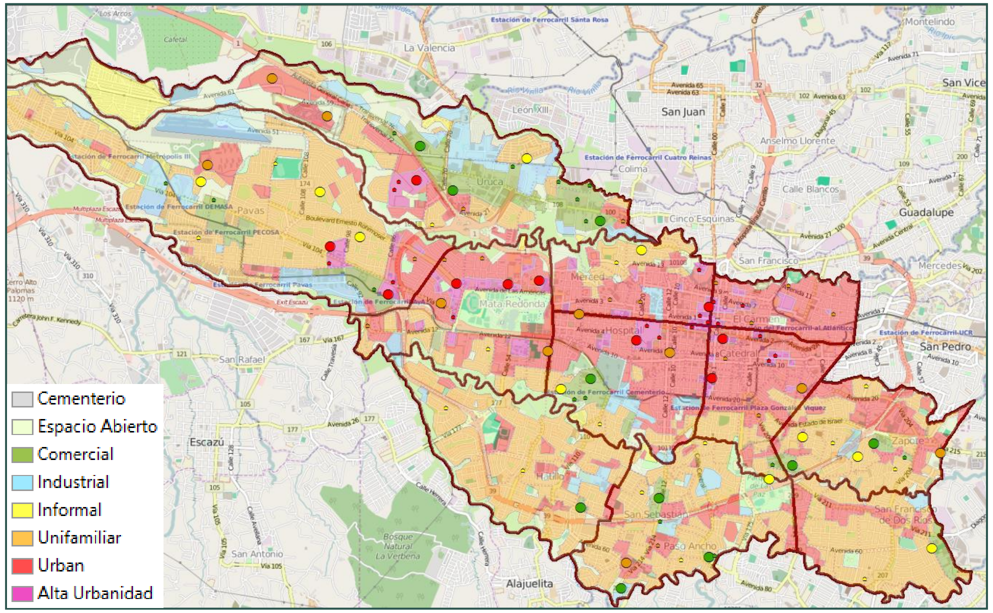
- Literature Review of Predominant Building Construction Types (PAGER, WHE)
- Attributes in Government Databases
- Interpretation of Satellite Data
- Virtual Reconnaissance
- Use Housing Census
- Stratified Sampling
- Expert Opinion
- Site Surveys



GEM Class	1	2	3	4	5	6	7
MUR+ADO/HBET:1,3	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
MUR+ADO/HBET:4,7	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CR/LFINF+DNO/HBET:1,3	49.4%	36.5%	13.7%	28.2%	7.7%	17.0%	18.9%
CR/LFINF+DNO/HBET:4,7	22.1%	35.3%	55.9%	23.2%	4.4%	44.8%	22.2%
CR/LFINF+DNO/HBET:8,20	0.0%	0.6%	3.3%	0.0%	0.0%	7.7%	1.1%
MATO/LN	0.0%	0.3%	0.0%	1.7%	23.1%	0.0%	0.0%
S/LFM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
S/LFBR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
S/LO	2.2%	1.2%	0.4%	8.7%	0.0%	0.0%	1.1%
S/LFINF	2.2%	0.4%	0.2%	2.9%	0.0%	2.6%	1.1%
MUR+CL99/HBET:1,2	15.6%	12.6%	5.2%	29.9%	53.8%	14.4%	32.2%

Sampling Strategies for Improving the Mapping Scheme

Randomized Location Select for Bayesian Stratified Sampling



On-Site Building Inspection

Field Tools:

- Inventory Data Capture Tool (IDCT)
- Paper surveys

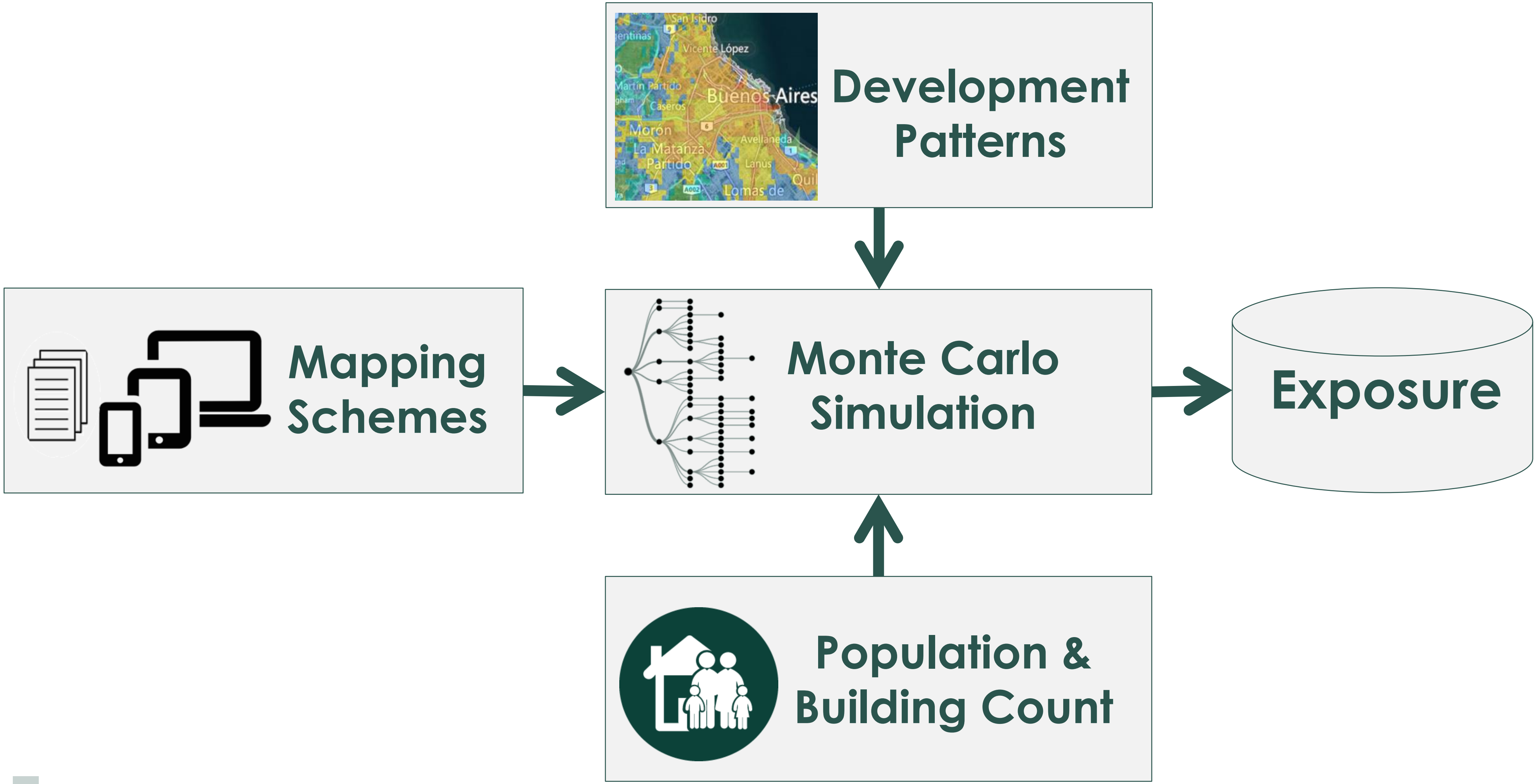
Geo-tagged photos:

- Ideal for linking to building footprints

IDCT Tool Workshop: Costa Rica Example

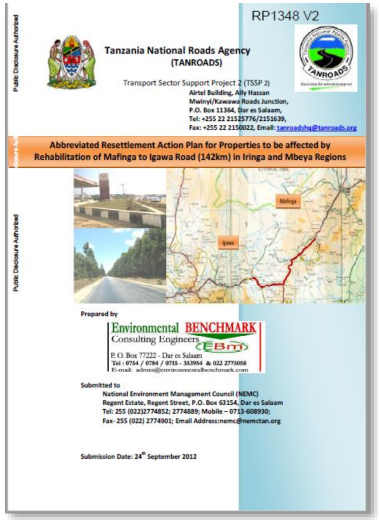
Local Communities will know More than International Reviewers

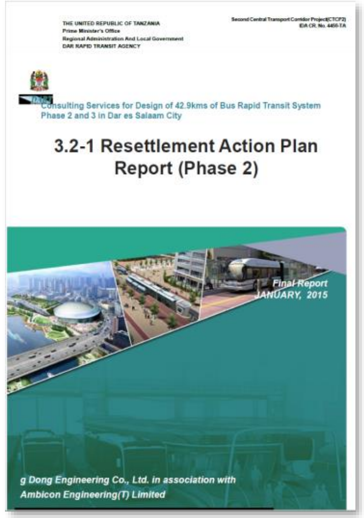
V. Bringing It All Together

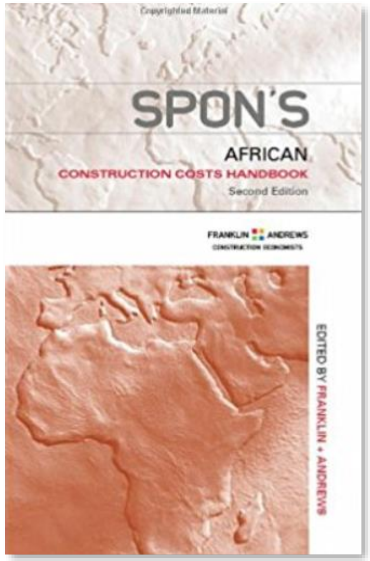


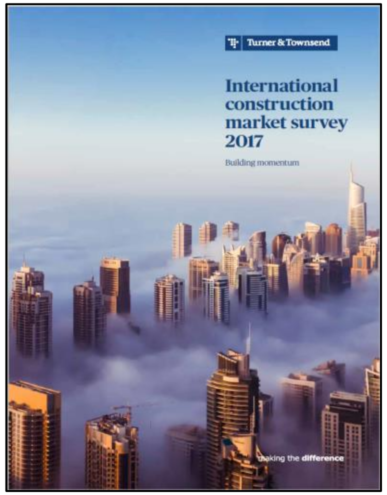
Add Replacement Cost Values

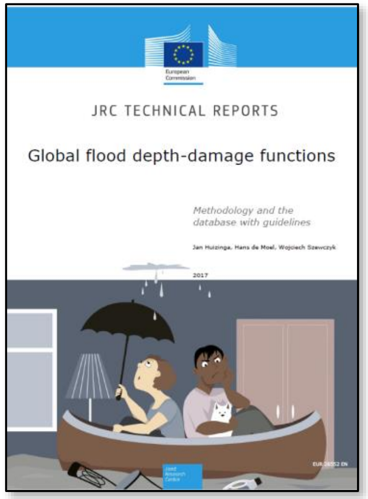
- Estimate square meter per building type
- Estimate building value per meter by building type or occupancy
- Use building construction manuals
- Expert opinions
- Scalable using building durability factors
- Use GDP or median income
- Can be difficult to estimate the replacement cost in some developing countries





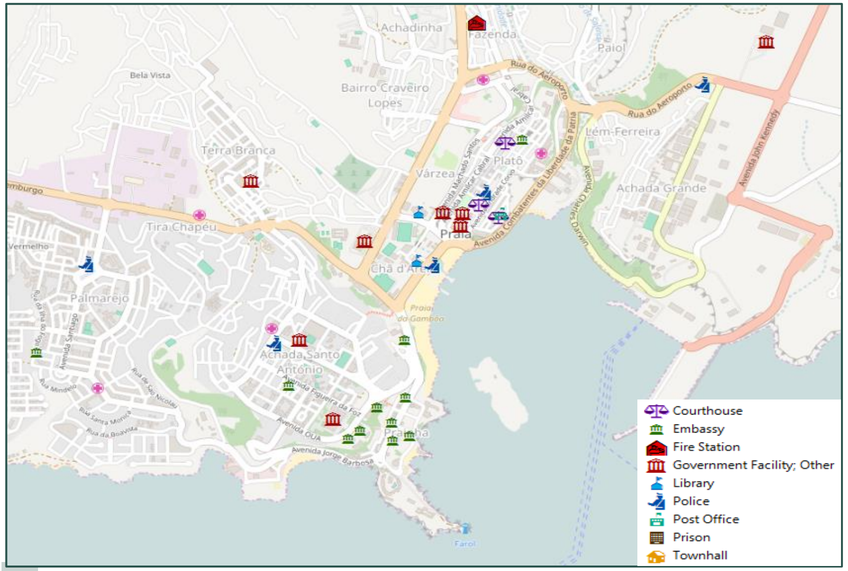


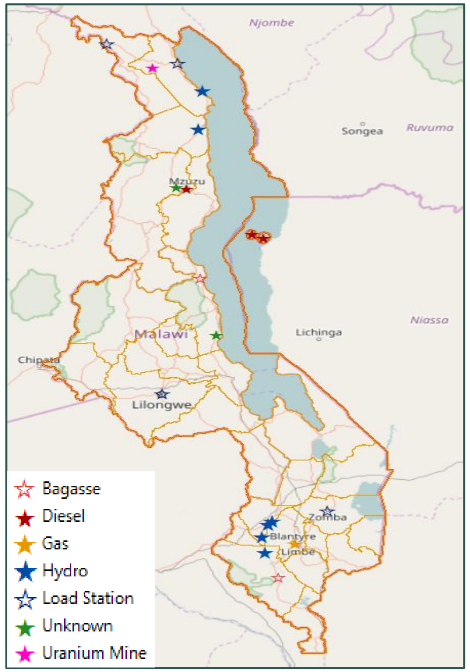


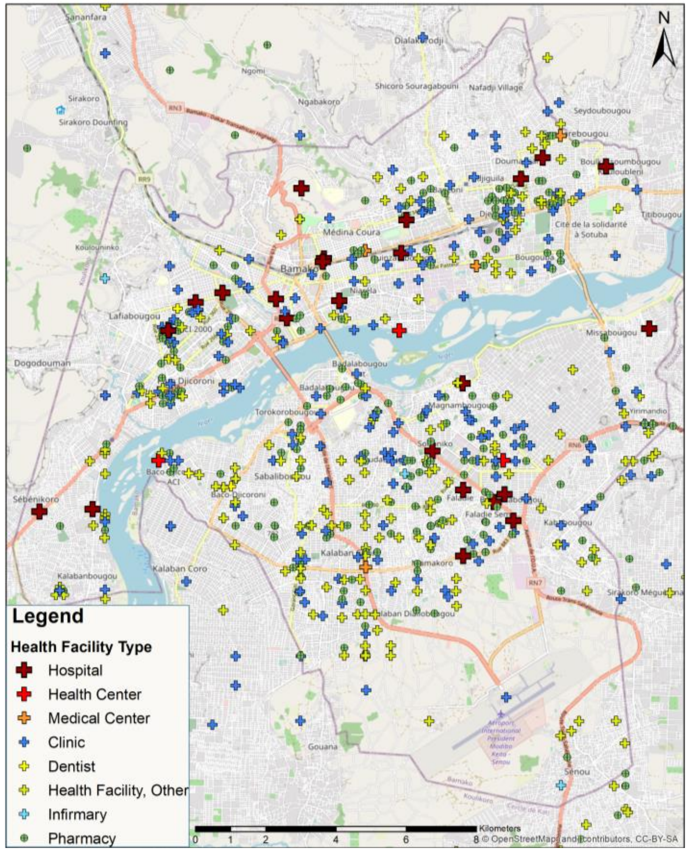


Add Essential Facilities

- Global or National Lifeline Databases (Dams, Electricity, Pipelines, Railroad, Ports)
- Humanitarian Data Exchange (UNESCO/UNICEF, HOTOSM)
- National or State Department of Education Databases
- National or State Department of Health Databases
- National Census Data

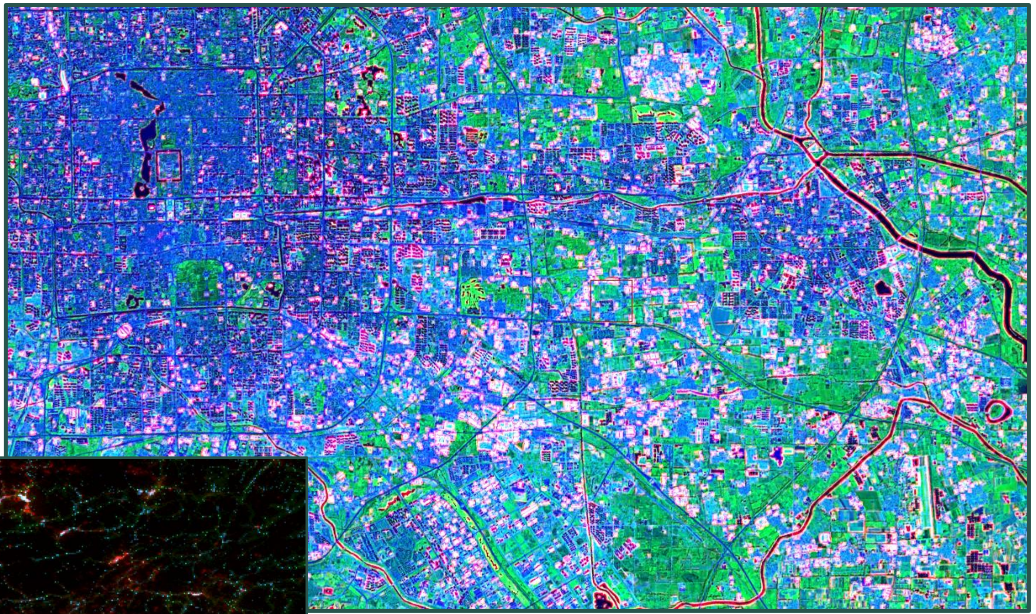


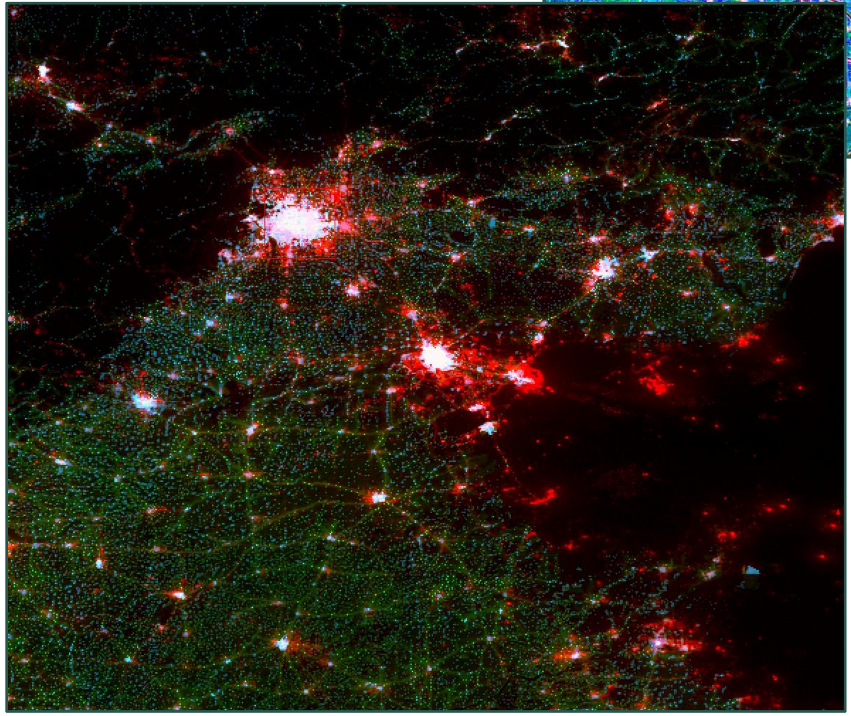


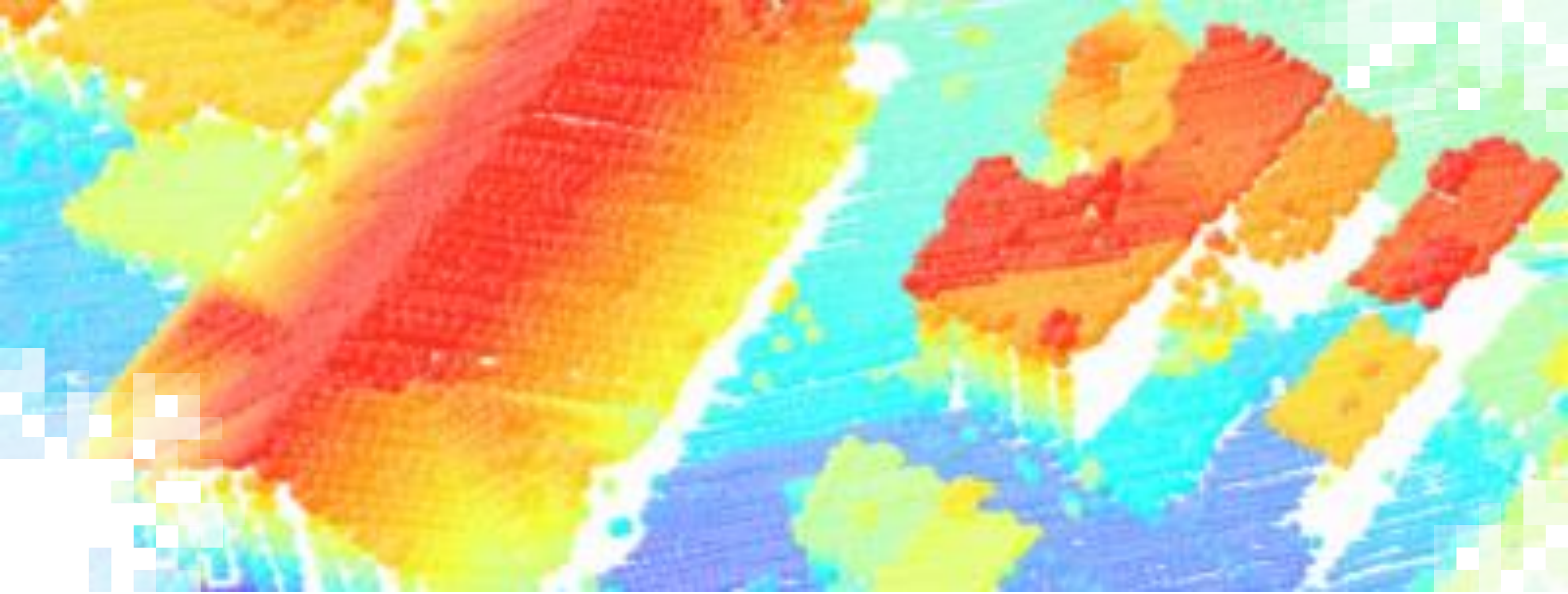


Summary: What is the role of EO in Developing Exposure Data?

- Global Urban/Rural or Urban Intensity Datasets
- Global Population and Building Datasets
- Segmentation of Development Patterns
- Building Footprint Extraction
- Average Building Size
- AI, ground-based sensors



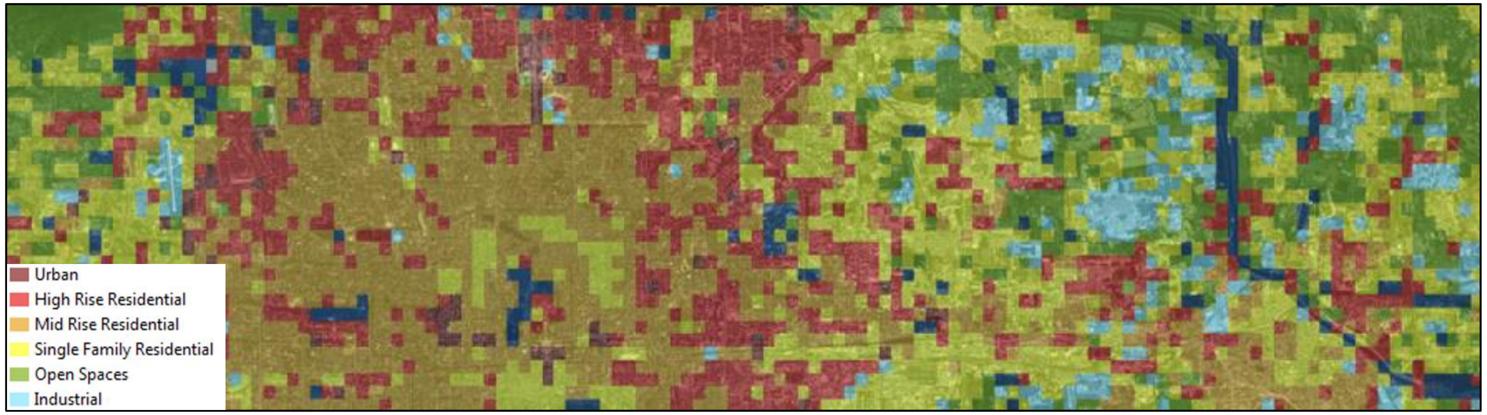




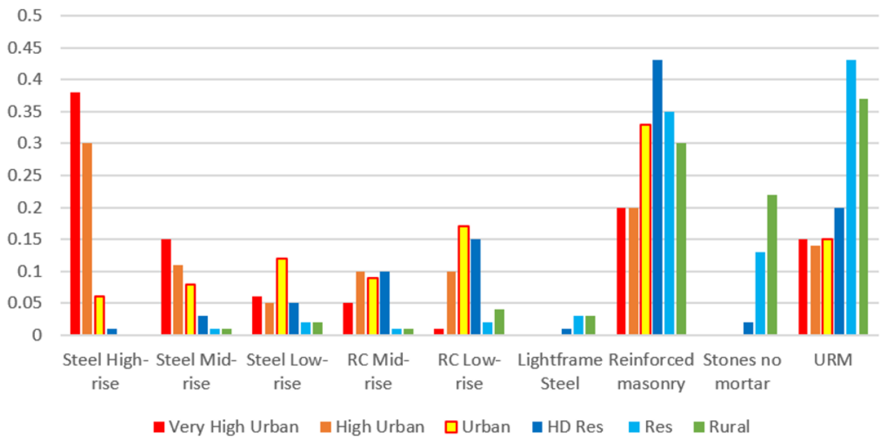
Structural Mapping Scheme Development and Building Sampling

Overview

- Development Patterns – what are they and why are they important?



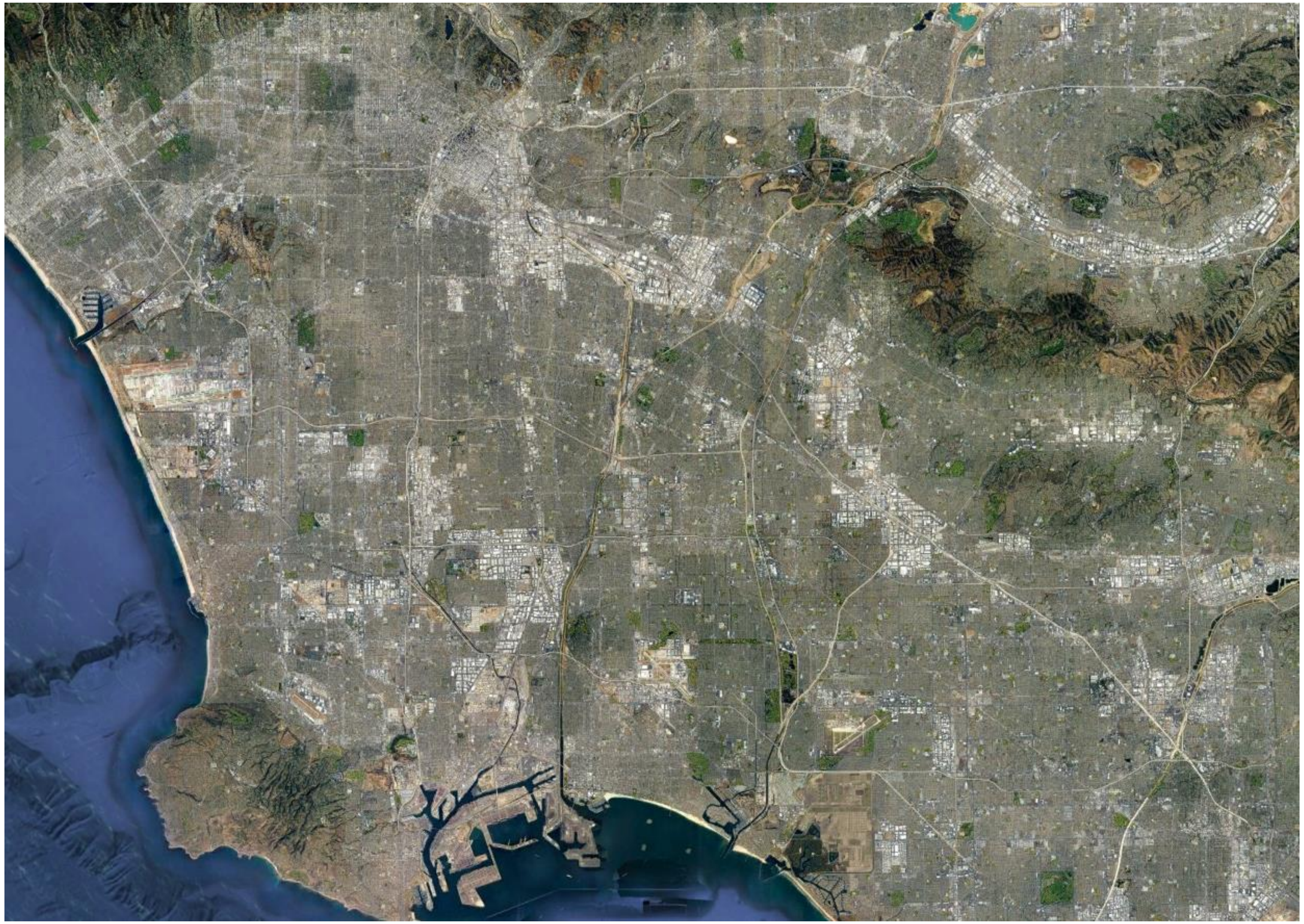
- Mapping Schemes – how are taxonomies defined and developed?

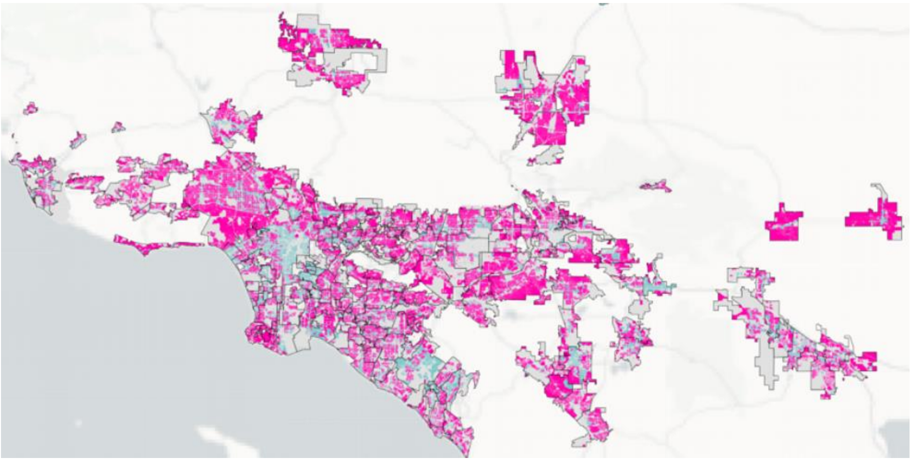


Development Patterns

- Country-specific homogeneous regions of building types and densities created using remote sensing data
  - The distribution of buildings within each development pattern will generally share the same:
    - Structural characteristics / building materials
    - Building height / number of stories
    - Occupancy
- Development patterns can be non-contiguous
- Development pattern data will differ by region
  - US residential regions ≠ Non-US residential regions

Why the Need?





Overview
- Predominately single-family residential
- Typical 1-2 story, light wood framed or engineered construction
- Multi-family and non-SFR regions would get washed out by the majority

Why the Need?

Types of Development Patterns - Rural

- Rural
  - Found outside of city boundaries
  - Typically associated with agricultural development
  - In developing countries, they consist of small, remote villages with single roads in and out and are developed using local construction practices and materials
  - Exclusively 1 and 2 stories

Afghanistan
Bangladesh
Bhutan
Burundi

Types of Development Patterns - Residential

- Residential
  - Dominated by single-family residential construction
  - Commercial properties, such as local markets are present, however residential is the primary occupancy
  - Built-up region may be dense, however open land (yards, vacant lots, etc.) will be present
  - All structures are typically low-rise, with a majority in the 1 to 2 story range

Afghanistan
Bangladesh
Bhutan
Burundi

Types of Development Patterns – High Density Residential

- High Density Residential
  - Typically found in and around urban centers
  - Majority of the population lives in multi-family residential housing
  - Buildings typically low-rise with occasional mid-rise structure

Afghanistan
Bangladesh
Bhutan
Burundi

Types of Development Patterns – Urban

- Urban
  - Found in and around major city centers
  - Buildings are tightly spaced and fairly regular in shape
  - Typically low to mid-rise residential and commercial structures, with the occasional high-rise

Afghanistan
Bangladesh
Bhutan
Burundi

Types of Development Patterns – High Urban

- High Urban
  - Found in and around major city centers
  - Similar to central business districts within major cities
  - Mid to high-rise apartment and office buildings, with occasional low-rise structure situated in between
  - Many countries will not have this development pattern

Afghanistan
Bangladesh
Bhutan
Burundi

Types of Development Patterns – Industrial

- Industrial
  - Areas dominated by ports, mining or industrial activities
  - Structures typically closely spaced and regular in shape
  - Majority of buildings are single-story warehouses
  - Supporting low-rise office and commercial structures nearby

Afghanistan
Bangladesh
Bhutan
Burundi

Other Special Types

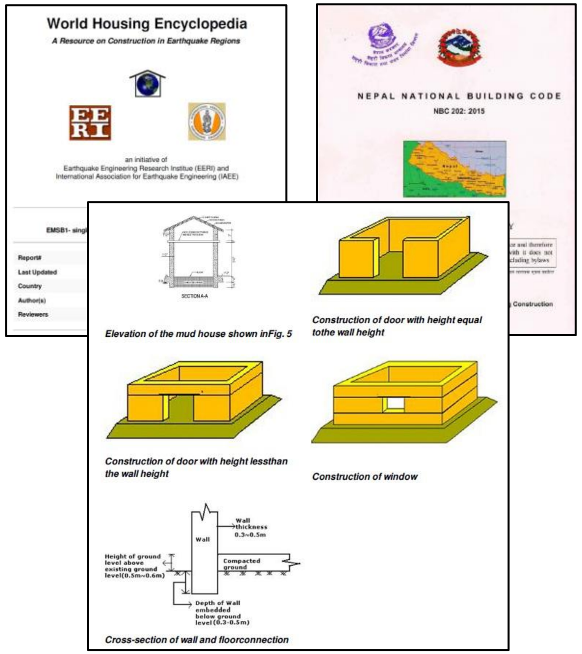
- Informal Housing
  - Dense, informal settlements
  - Typically found on edges of large cities and are small standalone structures with little to no space between adjacent buildings
  - Settlements are unplanned, non-engineered and use accessible local materials

- Very High Urban
  - Global central business districts
  - Dominated by high-rise, engineered construction

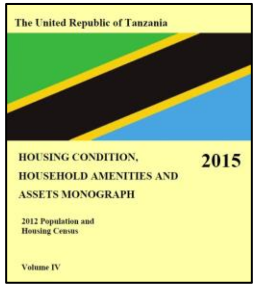
Mapping Scheme Basics

Heuristic Evaluations of Construction Patterns for Generating a Building Exposure Database

Identify Construction Types

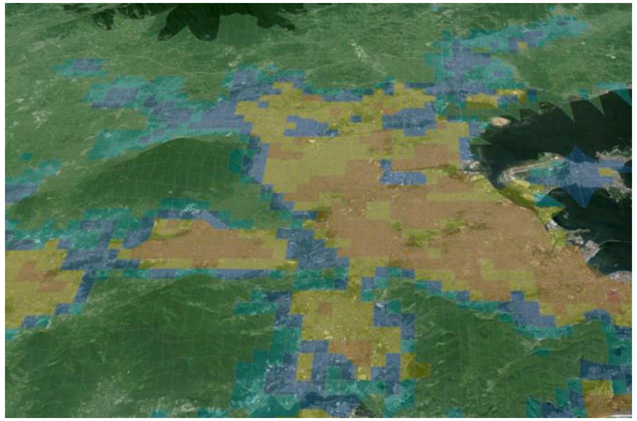


Gather/Organize Census Data



Indicator	Tanzania		Tanzania Mainland		Tanzania Zanzibar	
	Number	Percentage	Number	Percentage	Number	Percentage
Main Materials Used for Flooring						
Earth/Sand	5,569,460	60.0	5,498,025	60.9	71,436	28.6
Non Earth	3,650,472	39.3	3,471,757	38.5	178,716	71.4
Animal Dung	57,064	0.6	57,003	0.6	61	0.0
Main Materials Used for Walls						
Stones	96,930	1.0	55,557	0.6	41,373	16.5
Cement Bricks	1,881,994	20.3	1,743,695	19.3	138,299	55.3
Sundried Bricks	2,440,081	26.3	2,434,368	27.0	5,713	2.3
Baked Bricks	2,442,815	26.3	2,441,336	27.0	1,479	0.6
Timber	54,650	0.6	54,604	0.6	46	0.0
Timber and Iron Sheets	24,158	0.3	23,955	0.3	203	0.1
Poles and Mud	2,178,977	23.5	2,117,593	23.5	61,384	24.5
Grass	148,910	1.6	147,227	1.6	1,683	0.7
Tent	8,483	0.1	8,451	0.1	32	0.0

Construct Mapping Schemes Per Built-up Environment



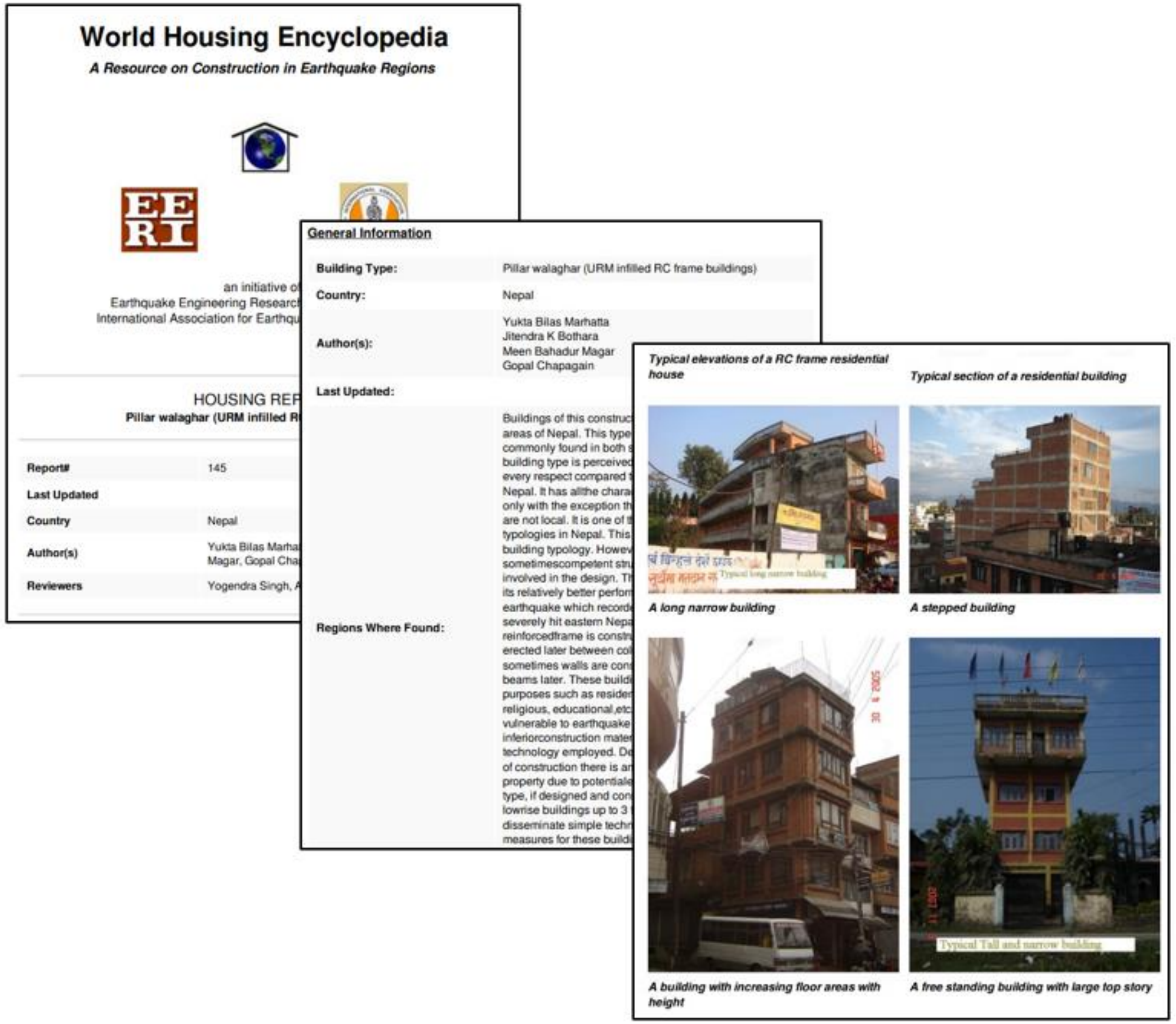
Development Pattern	W3	W5	S	C1H	C3L	C3M	C3H	M	RS	UFB	INF
1	0.04	0.09			0.16			0.15	0.01	0.07	0.48
2	0.01	0.05			0.53			0.05	0.02	0.05	0.30
3					0.50	0.10				0.30	0.10
5					0.05	0.60	0.05			0.30	
6				0.04	0.10	0.60	0.16			0.10	
7			0.25		0.25					0.40	0.10

Mapping Scheme Basics – Identify Construction Types

- Scholarly / Online Reports

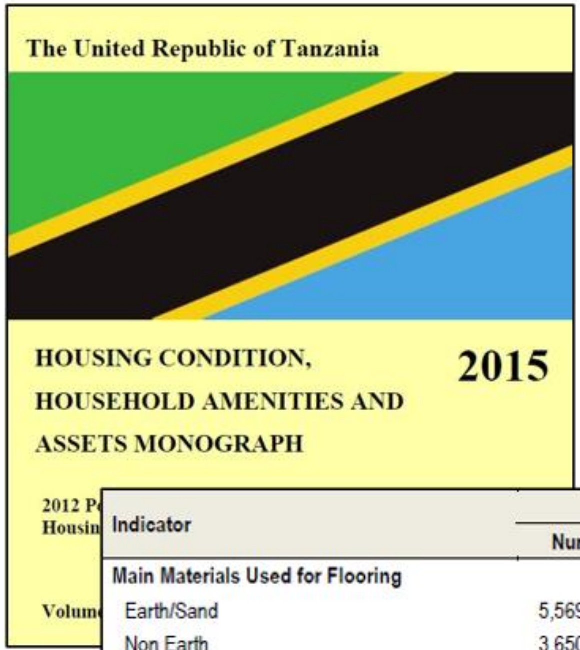
  Pro: In-depth descriptions of structural materials, lateral force-resisting systems, construction methodologies, regionality and known structural deficiencies

  - World Housing Encyclopedia
  - Post-Disaster Needs Assessment



Mapping Scheme Basics – Identify Construction Types

- Country Specific Assessments
  - Pro: General overview of the built-up environment for a given country is provided. Data is often region specific and will typically provide statistics regarding wall, roof and floor materials.
  - Con: Availability can be limited. Information is typically limited to construction materials (not LFRS).



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Tent	8,483	0.1	8,451	0.1	32	0.0

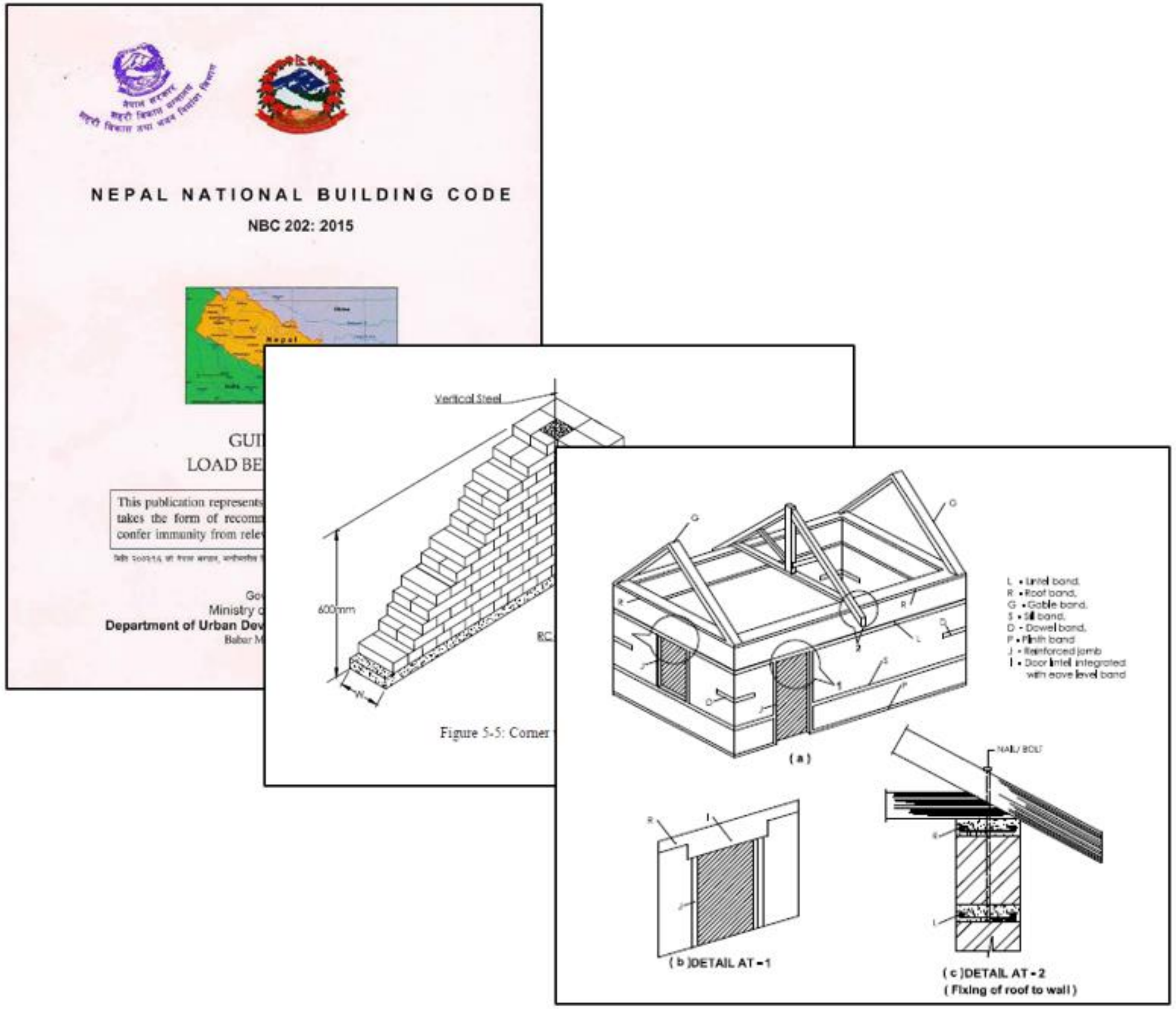
Mapping Scheme Basics – Identify Construction Types

- Global Building Databases
  - Pro: General overview of the built-up environment for a given country. Detailed descriptors of lateral force-resisting systems
  - Con: Will need to adjust for development pattern specific distributions. Not all countries available (proxies used)

Country Name	V	V1	V2	V3	V4	V5	S3	C	C3L	C3N	C3H	RM	M	M1	M2	A	RE	RS	RS1	RS2	RS3	DS	UFE	UCE	MS	TU	INF	UNK
Afghanistan									0.016							0.707		0.234					0.043					
Angola						0.25										0.5											0.25	
Bangladesh				0.04		0.089			0.159				0.154					0.005					0.07				0.483	
Benin						0.037							0.249			0.667							0.047					
Bhutan	0.1059	0.02	0.15						0.15							0.0235	0.0556		0.36		0.0666		0.034	0.0317			0.0027	
Burkina Faso						0.0471							0.7232											0.1269			0.1028	
Burundi	0.002					0.02										0.506							0.41	0.062				
Cambodia		0.007		0.563		0.114																	0.126	0.19				
Central African Republic	0.01					0.05			0.05				0.05			0.75							0.04				0.05	
Chad						0.037							0.249			0.667							0.047					
Comoros	0.45																		0.15					0.15			0.25	
the Democratic Republic of the Congo	0.051					0.22							0.065			0.173			0.004				0.273	0.089			0.124	
Djibouti	0.2419					0.1398							0.0022			0.2914		0.0344						0.1355			0.1548	
Eritrea	0.069					0.132			0.007									0.416			0.089		0.014	0.117			0.155	
Ethiopia	0.18					0.5							0.05			0.05		0.09					0.01				0.12	
Gambia													0.7			0.125								0.125			0.05	
Guinea								0.02					0.32			0.44											0.22	
Guinea-Bissau								0.02					0.32			0.44											0.22	
Haiti				0.01					0.12									0.02						0.75			0.1	
Kiribati	0.7								0.05															0.25				
the Lao People's Democratic Republic	0.8164																	0.0892					0.0944					
Lesotho						0.0452										0.0327		0.0061		0.328	0.1141		0.0461	0.4278				
Liberia	0.0034					0.7874												0.0079					0.1408	0.0489			0.0117	
Madagascar	0.1					0.15										0.1								0.55			0.1	
Malawi	0.01												0.36			0.47	0.03						0.13					
Mali									0.02			0.04	0.18			0.58								0.18				
Mauritania						0.25			0.35							0.25								0.15				
Mozambique	0.07												0.37			0.4							0.13	0.03				
Myanmar	0.0011					0.5502							0.2575										0.0025				0.1888	
Nepal	0.05					0.171										0.012		0.493					0.204				0.07	
Niger						0.27										0.3							0.05				0.38	
Rwanda	0.0086					0.4388										0.5345		0.0024					0.0125	0.0023			0.001	
Sao Tome and Principe	0.6																						0.15				0.25	
Senegal						0.25			0.35							0.25								0.15				
Sierra Leone	0.0052					0.2581										0.6183		0.0022					0.0054	0.0713			0.0395	
the Solomon Islands	0.9645																							0.0151			0.0205	
Somalia	0.05					0.5							0.15			0.05		0.08						0.02			0.15	
South Sudan	0.07					0.86							0.06										0.01					
Sudan	0.0763					0.4703							0.2746			0.0763							0.0856	0.0169				
the United Republic of Tanzania	0.0219					0.2349										0.263		0.0104					0.2633	0.2029			0.0035	
Timor-Leste	0.3301					0.3084										0.0152		0.0064					0.2862				0.0537	
Togo						0.183										0.3482		0.0374					0.05	0.3			0.08	
Tuvalu	0.2273					0.183		0.559																			0.0307	
Uganda						0.25										0.1		0.05					0.5	0.05			0.05	
Vanuatu	0.0833					0.5641		0.1783																0.1513			0.023	
Yemen						0.0275							0.1343			0.0183		0.4517				0.117		0.2482				
Zambia						0.0775							0.0957			0.3088		0.0543					0.2508	0.2128				

Mapping Scheme Basics – Identify Construction Types

- Building Code
  - Pro: Country (or region) specific guidelines using applicable materials and construction techniques.
  - Con: Enforcement can often be limited, therefore specifications (per code) may not be reflected in the field. Access to the code may be limited. Technical background may be required to interpret code.



Mapping Scheme Basics – Identify Construction Types

- User Submitted / Online Imagery / Ground Survey
  - Pro: Widely available via online photos, street-view, online photos, etc. Post-event (damage) videos/photos often available. Identify correlation between roof type (shape, covering, etc.) and wall materials/structural system
  - Con: May be limited (rural regions are often not covered, ground photos only).

Mapping Scheme Basics – Identify Construction Types

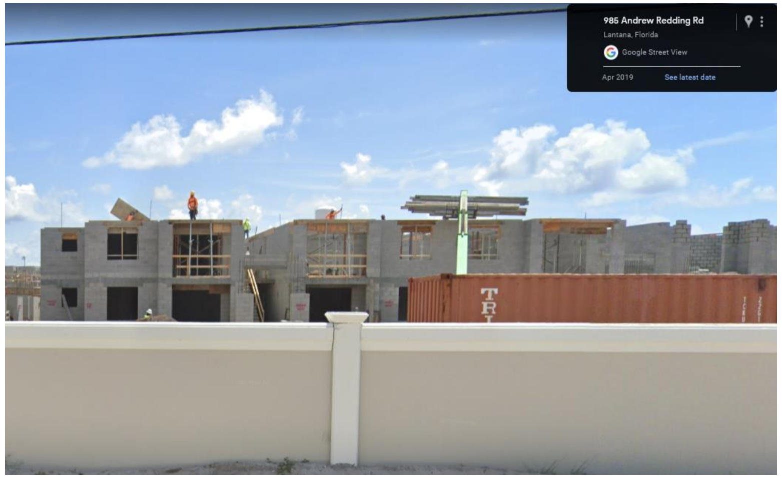
Satellite Image				
Ground Photo				
Construction Photo				

Mapping Scheme Basics – Identify Construction Types

Check all sides (if possible)

Historic Satellite Imagery

Historic Ground Imagery



Mapping Scheme Basics – Distributing Building Attributes

- Use any available census / housing data (rural, residential)

Table 2.5 Housing characteristics

Percent distribution of households by housing characteristics, according to residence, Bangladesh 2014

Housing characteristics	Residence: Urban	Residence: Rural	Total
Flooring material[1]			
Earth, sand	32.5	81.5	67.8
Wood planks	0.4	0.2	0.2
Ceramic tiles	5.6	0.3	1.8
Cement	61.0	17.7	29.8
Roof materials			
Natural roof	0.2	1.7	1.3
Palm/bamboo	0.1	0.1	0.1
Wood plank/card board	0.1	0.0	0.0
Tin	70.0	90.8	85.0
Wood	0.2	0.2	0.2
Ceramic tiles	0.5	0.1	0.2
Cement	28.4	5.3	11.8
Roofing shingles	0.3	1.5	1.1
Other	0.1	0.3	0.2
Wall materials			
Jute stick/palm trunk	0.8	2.9	2.3
Mud/dirt	4.4	14.5	11.7
Bamboo with mud	4.5	8.9	7.7
Tin	30.2	48.3	43.3
Cement	52.6	15.9	26.2
Stone with lime/cement	1.6	0.5	0.8
Bricks	4.9	7.0	6.4
Wood planks	0.6	1.1	1.0
Other	0.3	0.9	0.7
Rooms used for sleeping			
One	37.2	31.7	33.2
Two	36.2	37.7	37.3
Three or more	26.7	30.6	29.5
Total	100.0	100.0	100.0
Persons per sleeping room			
1-2	63.2	66.2	65.3
3-4	29.1	26.4	27.2
5-6	6.5	6.5	6.5
7+	1.2	0.8	1.0
Total	100.0	100.0	100.0
Number	4,844	12,456	17,300

[1]"Other" flooring material is a combination of palm, bamboo, parquet, polished wood, and carpet

Table 12.10: Households by Main Type of House and Material Used for Construction of Walls, 2016 PHC

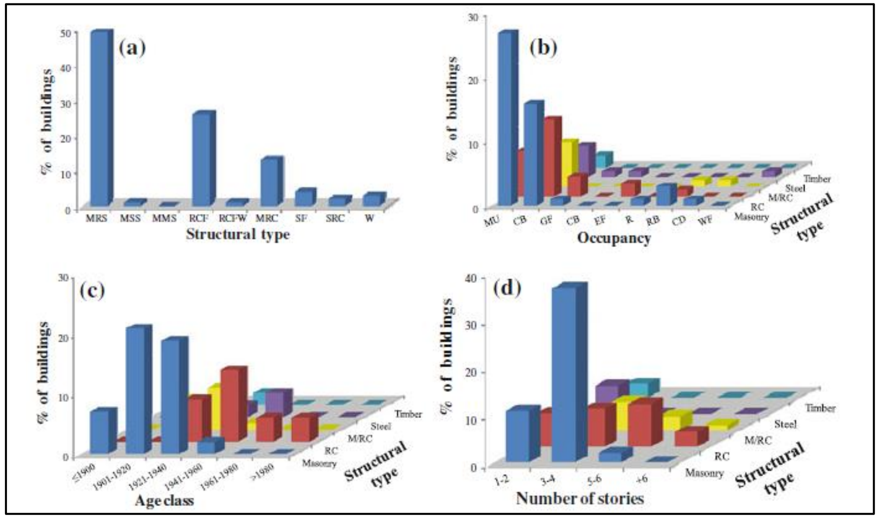
Main Type of House	Main Wall Material: Cane/ Tree trunks	Stick and mud	Masonite /Cardboard	Stone with mud	Burned Mud Bricks	Mud Bricks	Stone with lime/cement	Advanced Stone	Sand/Concrete Blocks	Advanced Burned Bricks	Corrugated Iron/ Metal sheets	Other (Specify)	Total
Rontabole/ Mokhoro	1,479	13,522		99,872	368	4,728	4,677	87	2,888	167		12	127,800
Heisi	174	1,786		10,134	235	1,666	2,676	106	4,429	328		2	21,536
Polata	282	4,590		44,205	4,027	6,974	27,866	1,145	89,778	3,758		31	182,656
Malaene		206		3,127	3,871	1,893	13,279	762	79,921	3,902		1	106,962
Optaka	23	127		3,509	1,580	768	7,447	894	32,786	4,366		9	51,509
Apartment/ Town House			117				1,006	256	3,967	2,383		4	7,733
Bungalow/ Mansion			65				2,899	881	15,924	6,397		11	26,177
Mansion													
Temporary Structure/ Mok'huk'hu			484								12,600		13,084
Total	1,958	20,231	666	160,847	10,081	16,029	59,850	4,131	229,693	21,301	12,600	70	537,457

Country Name	W	W1	W2	W3	W4	S	S1	S1L	S1M	S1H	S2	S2L	S2M	S2H	S3	S4	S4L
Afghanistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aland Islands	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Albania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algeria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
American Samoa	0.00	0.46	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Andorra	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00
Angola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Anguilla	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Antarctica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Antigua and Barbuda	0.00	0.44	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Argentina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Armenia	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Aruba	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Australia	0.06	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Austria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Azerbaijan	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bahamas	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bahrain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bangladesh	0.01	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Barbados	0.57	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Belarus	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.09						
Belgium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Belize	0.70	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Benin	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bermuda	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bhutan	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bolivia	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bosnia and Herzegovin	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Botswana	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Bouvet Island	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Brazil	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						

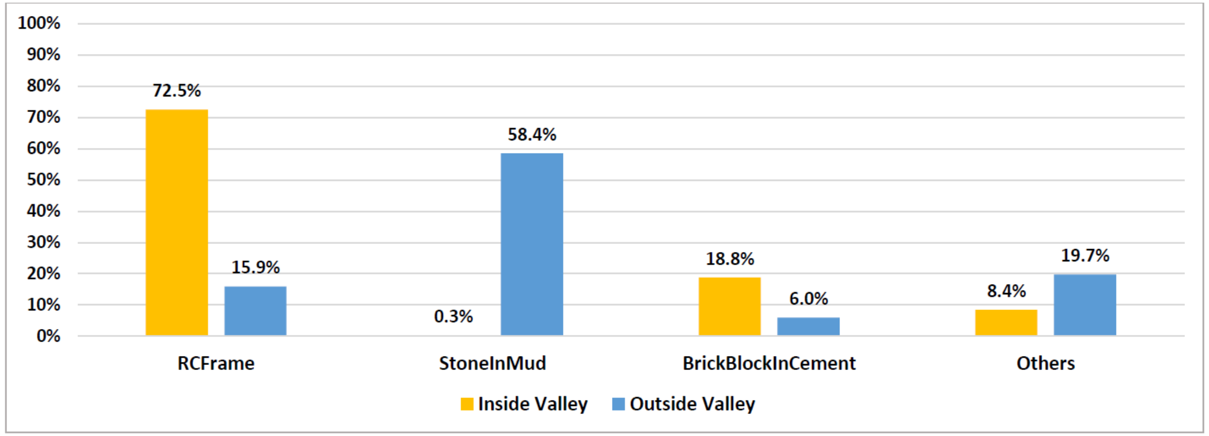
Wall Type	PAGER
Jute stick/palm trunk	W3 (Wood)
Mud/dirt	M (Mud Walls)
Bamboo with mud	W5 (Wattle and Daub)
Tin	INF (Informal Construction)
Cement	C3 (Non-ductile RC Frame w/ URM Infill)
Stone with lime/cement	RS (Rubble Stone)
Bricks	UFB (URM Fire Brick)
Wood Planks	W3 (Wood frame unbraced post/beam)
Other	M (Mud Walls)

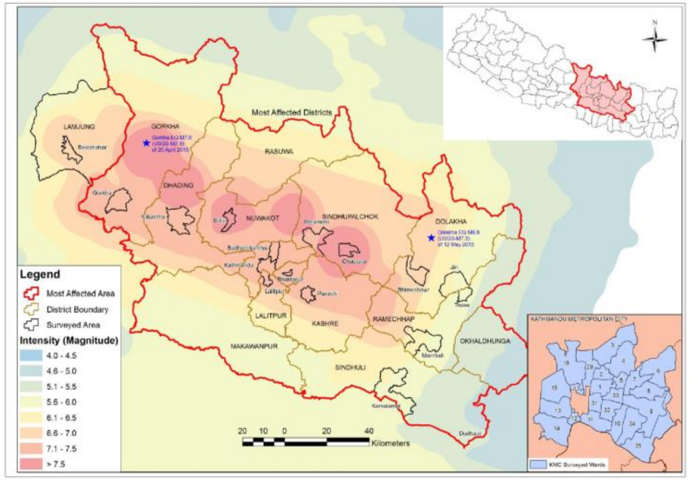
Mapping Scheme Basics – Distributing Building Attributes

- Use any available country-specific exposure studies (all development patterns)



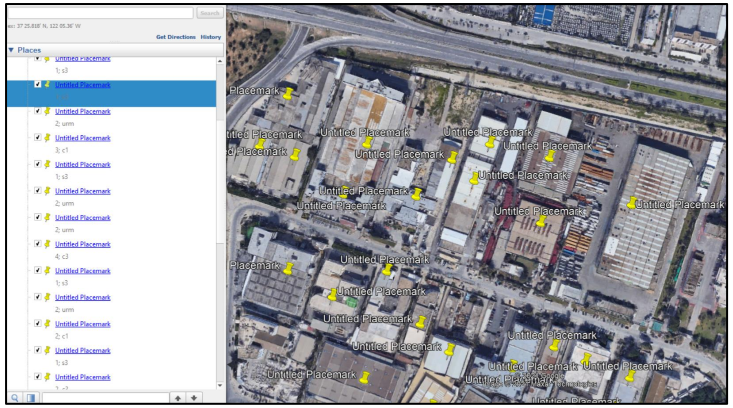
3.1 BUILDING TYPOLOGY

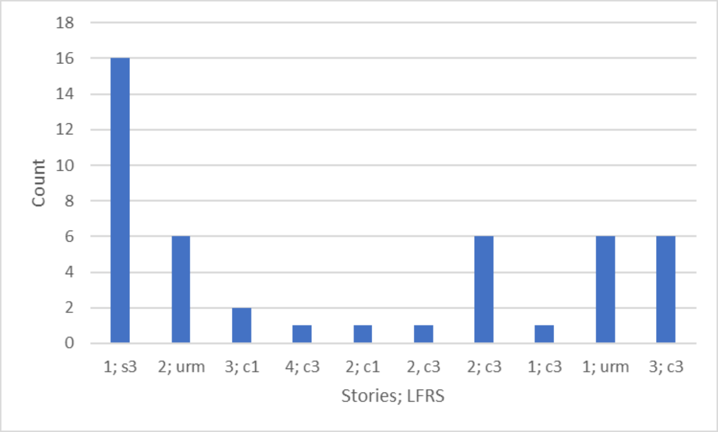


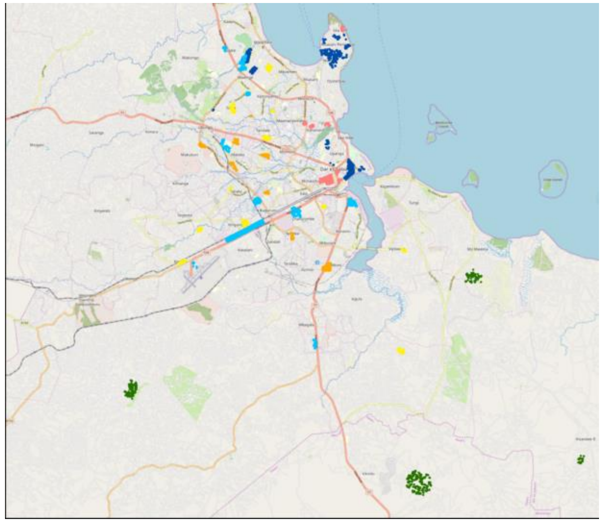


Mapping Scheme Basics – Distributing Building Attributes

- Stratified sampling/categorization for development/validation
  - Desktop or Field Survey







STR	DP1	DP2	DP4	DP5	DP6	DP7
UNREINFORCED CONCRETE BLOCK MASONRY (1 to 3 STORIES)	91.6	82.7	96.0	52.2	63.8	68.1
WATTLE AND DAUB (WALLS WITH BAMBOO/LIGHT TIMBER LOG/REED MESH AND POST)	5.4					0.2
INFORMAL CONSTRUCTIONS	2.3	0.4	3.6	1.7	3.1	0.7
REINFORCED CONCRETE MOMENT FRAME (1 to 3 STORIES)	0.2	0.4		2.6	4.4	3.8
WOOD	0.2	0.4				0.5
UNREINFORCED RUBBLE STONE MASONRY	0.2					
UNREINFORCED FIRED CLAY MASONRY		15.6				
NON-DUCTILE REINFORCED CONCRETE INFILLED FRAME (1 to 3 STORIES)		0.4	0.4	26.3	13.1	12.7
NON-DUCTILE REINFORCED CONCRETE INFILLED FRAME (4 to 7 STORIES)				10.2	4.6	1.2
REINFORCED CONCRETE MOMENT FRAME (8 to 20 STORIES)				3.2	2.4	
NON-DUCTILE REINFORCED CONCRETE INFILLED FRAME (8-20 STORIES)				1.3	4.8	
UNREINFORCED CONCRETE BLOCK MASONRY (4 to 7 STORIES)				1.1	0.4	
REINFORCED CONCRETE MOMENT FRAME (4 to 7 STORIES)				0.8	2.0	0.7
STEEL				0.6	1.5	12.0

Mapping Scheme Basics – Final Thoughts

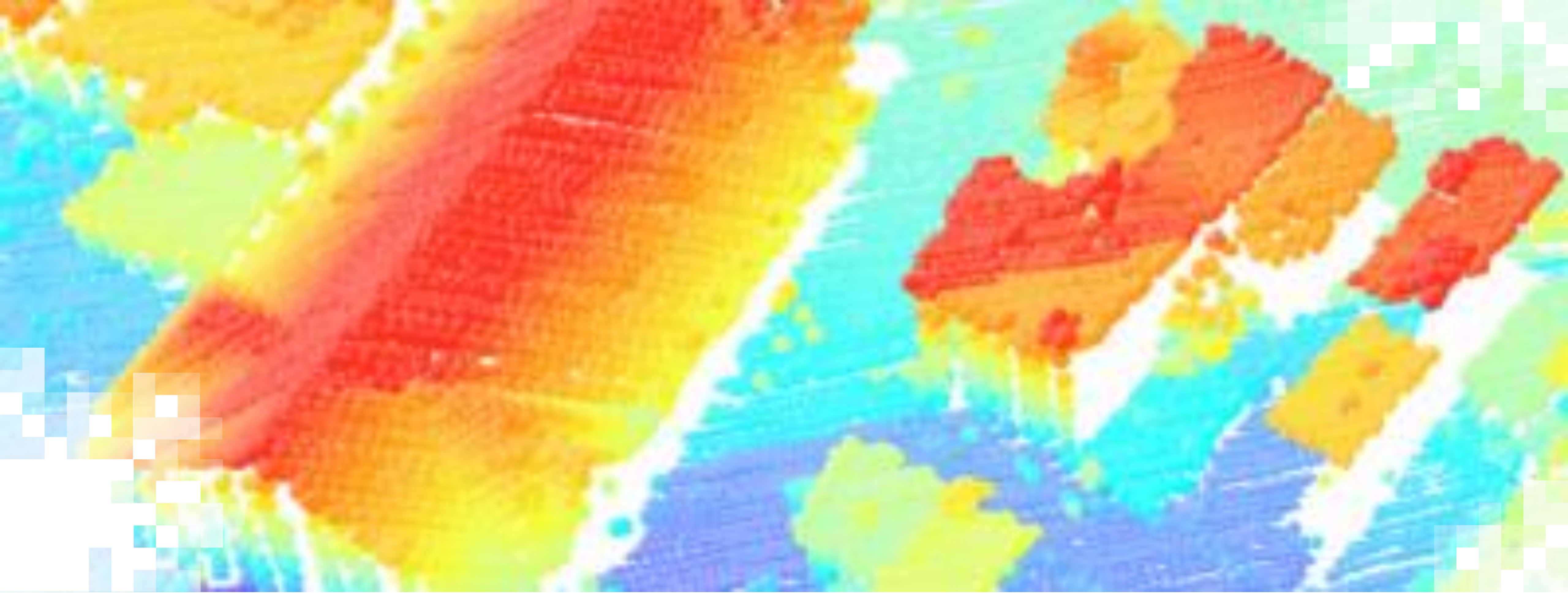
Mapping Scheme Breakdown by Development Pattern Type

Construction Type	DP1	DP2	DP4	DP5	DP6	DP7
UNREINFORCED CONCRETE BLOCK MASONRY (1 to 3 STORIES)	91.6	82.7	96.0	52.2	63.8	68.1
WATTLE AND DAUB (WALLS WITH BAMBOO/LIGHT TIMBER LOG/REED MESH	5.4					0.2
INFORMAL CONSTRUCTIONS	2.3	0.4	3.6	1.7	3.1	0.7
REINFORCED CONCRETE MOMENT FRAME (1 to 3 STORIES)	0.2	0.4		2.6	4.4	3.8
WOOD	0.2	0.4				0.5
UNREINFORCED RUBBLE STONE MASONRY	0.2					
UNREINFORCED FIRED CLAY MASONRY		15.6				
NON-DUCTILE REINFORCED CONCRETE INFILLED FRAME (1 to 3 STORIES)		0.4	0.4	26.3	13.1	12.7
NON-DUCTILE REINFORCED CONCRETE INFILLED FRAME (4 to 7 STORIES)				10.2	4.6	1.2
REINFORCED CONCRETE MOMENT FRAME (8 to 20 STORIES)				3.2	2.4	
NON-DUCTILE REINFORCED CONCRETE INFILLED FRAME (8-20 STORIES)				1.3	4.8	
UNREINFORCED CONCRETE BLOCK MASONRY (4 to 7 STORIES)				1.1	0.4	
REINFORCED CONCRETE MOMENT FRAME (4 to 7 STORIES)				0.8	2.0	0.7
STEEL				0.6	1.5	12.0

- Online search identify all relevant construction types/materials unique to the region
- Identify / validate construction types via satellite or ground imagery
- Make use of census/region/field survey data for preliminary mapping schemes
- Stratified sampling to develop/validate mapping schemes for other development patterns

Sanity Check

- Do the results make sense?
  - Height profiles
  - Local materials
  - Engineered construction



Case Study: Walkthrough of Building Exposure Data for Tunisia

Case Study Objective

- Perform a multi-hazard study for the Republic of Tunisia for flood and earthquake risks
  - Tasks Included
    - Exposure development and review for incorporation into a format suitable for loss estimation and data collection
    - Guidance on vulnerability assignment
    - Assessment of risk
    - Visualization within a BI tool

Identify Homogenous Zones (Development Patterns)

*rural not shown

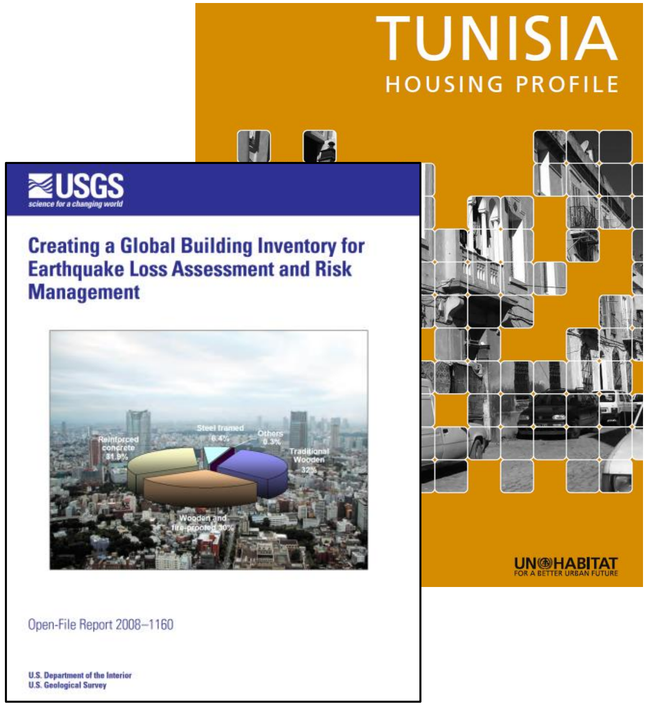
Assess the Built-Up Environment

- What type of permitted (and non-permitted) construction and building materials are prevalent throughout the country?

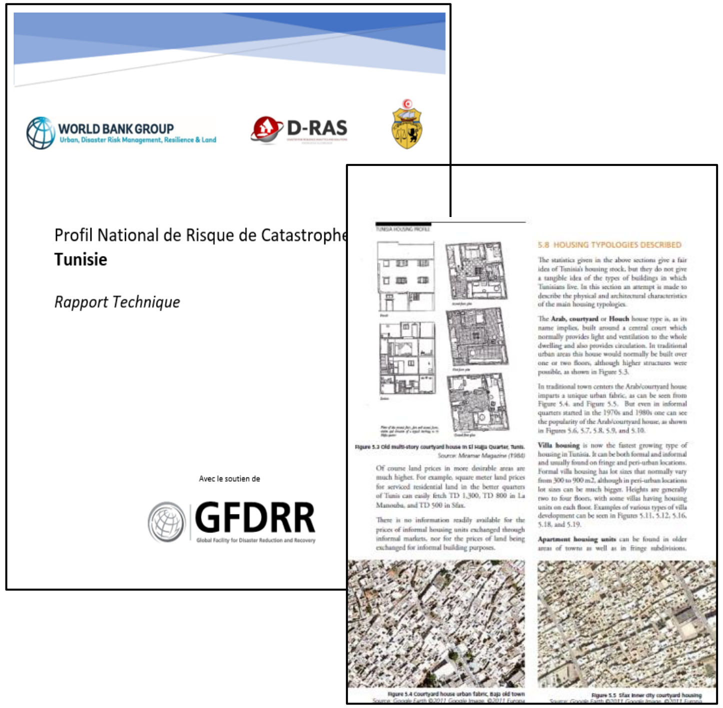
Ground Imagery




Census / Housing Data



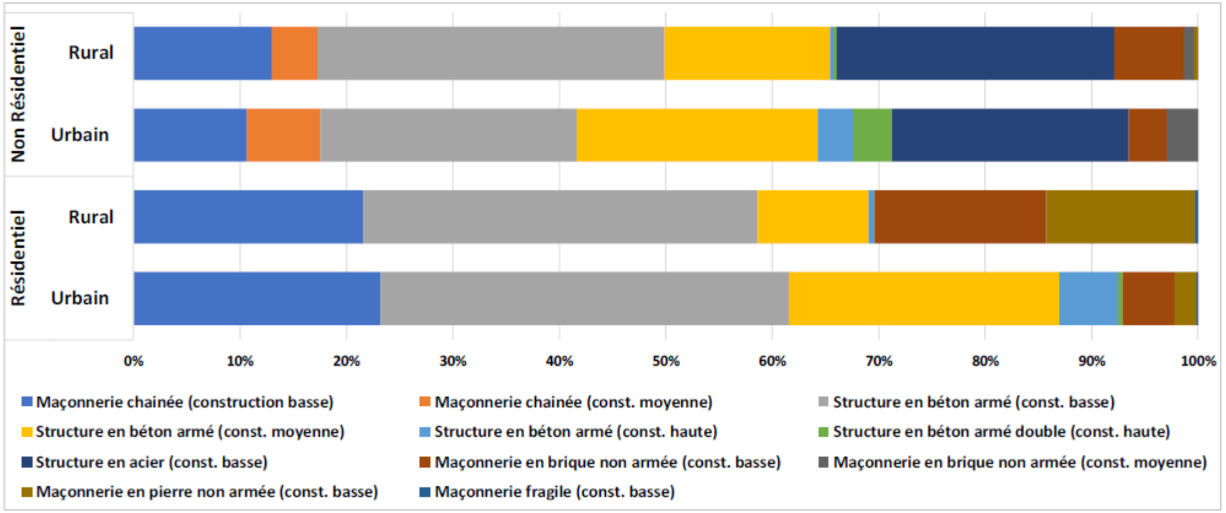
Country Profile Studies / Surveys

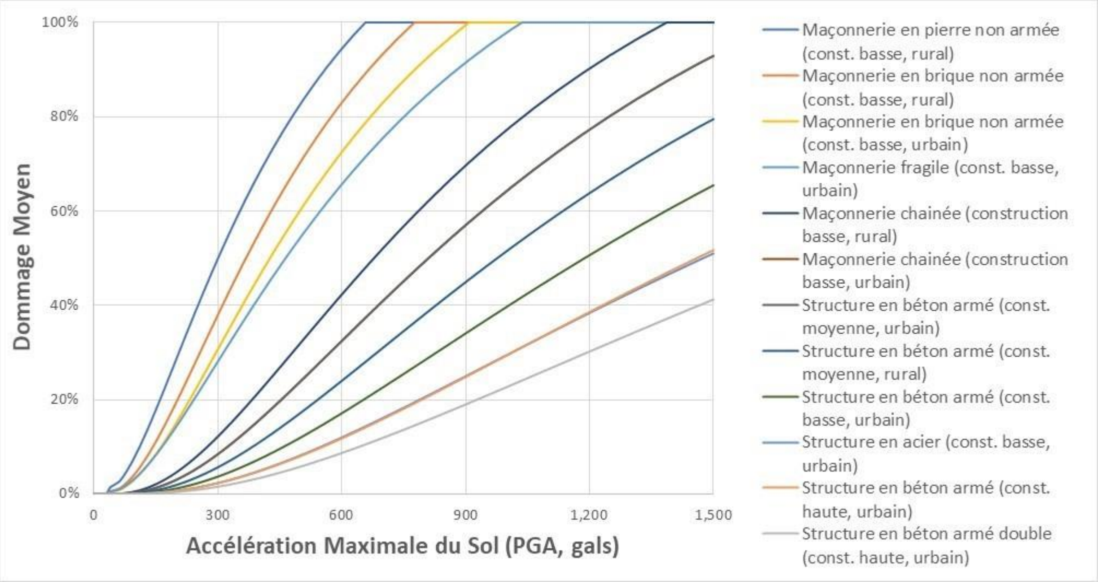


National Catastrophe Risk Profile (World Bank)

- Country specific survey documenting structural types and associated vulnerability curves

ID	Lateral Force-Resisting System (LFRS)	Description
1	Maçonnerie en pierre non armée	Unreinforced Masonry (URM), Stone
2	Maçonnerie en brique non armée	URM Fired Brick
3	Maçonnerie fragile	Fragile Masonry
4	Maçonnerie chainée	Confined Masonry
5	Structure en béton armé	Reinforced Concrete with URM
6	Structure en acier	Steel Frame with URM
7	Structure en béton armé double	Engineered, RC Frame





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1	Maçonnerie en pierre non armée	Unreinforced Masonry (URM), Stone
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6	Structure en acier	Steel Frame with URM
7	Structure en béton armé double	Engineered, RC Frame

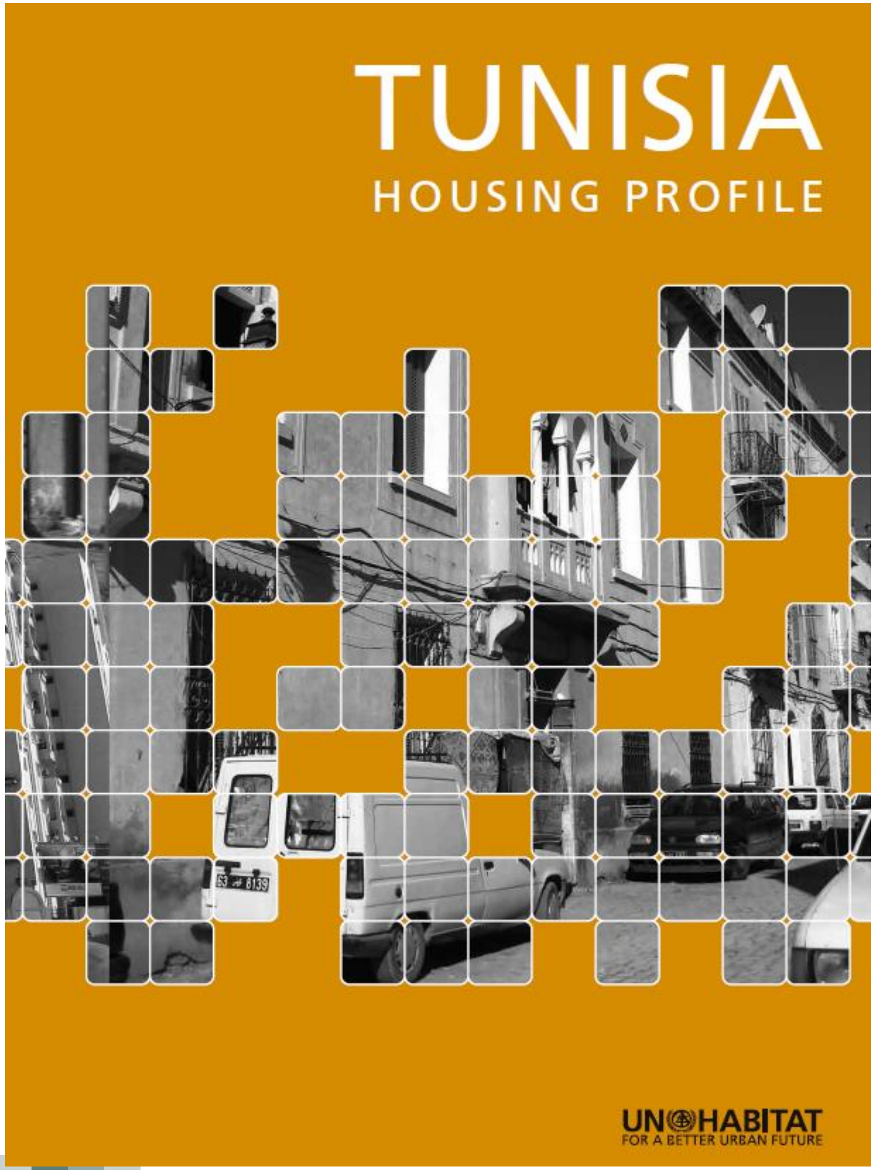
Natural Disaster Risk Financing & Insurance in Tunisia (World Bank, Ernst & Young)

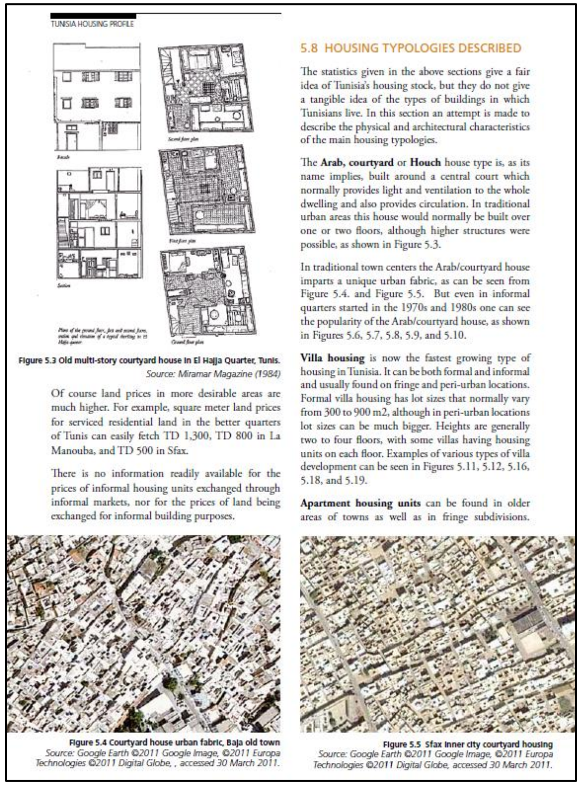
Governorate	Type of House	Number of homes by type of housing (2014)	Number of homes by type of housing (2020)	Surface area / type of housing (m²) 2014)	Surface area / type of housing (m²) (2020)	cost of m² of the building (TND)	Reconstruction cost (TND) / type of housing (2014)	Reconstruction cost (TND) / type of housing (2020)
Tunis	Traditional housing	27,029	30,232	2,702,900	3,023,225	800	2,162,320,000	2,418,580,321
Tunis	Rudimentary housing	1,989	2,225	69,615	77,865	380	26,453,700	29,588,774
Tunis	Semi-detached housing or floor of semi-detached housing	185,369	207,337	15,941,734	17,831,017	1,200	19,130,080,800	21,397,220,093
Tunis	villa or duplex	51,921	58,074	7,788,150	8,711,137	1,400	10,903,410,000	12,195,592,166
Tunis	Apartment	77,040	86,170	9,398,880	10,512,758	1,250	11,748,600,000	13,140,947,109
		343,348	**384,039**	**35,901,279**	**40,156,002**		**43,970,864,500**	**49,181,928,464**
Ariana	Traditional housing	10,809	11,878	1,016,046	1,116,514	800	812,836,800	893,210,851
Ariana	Rudimentary housing	517	568	17,061	18,748	380	6,483,180	7,124,243
Ariana	Semi-detached housing or floor of semi-detached housing	94,700	104,064	11,932,200	13,112,067	1,200	14,318,640,000	15,734,480,304
Ariana	villa or duplex	40,567	44,578	5,679,380	6,240,962	1,400	7,951,132,000	8,737,347,251
Ariana	Apartment	33,982	37,342	2,956,434	3,248,769	1,250	3,695,542,500	4,060,961,144
		180,575	**198,430**	**21,601,121**	**23,737,060**		**26,784,634,480**	**29,433,123,794**

- Building count per governorate, per industry
  - Identify distribution of the various occupancies and building types (5 types of residential, retail, financial and tourism) for a given governorate
  - Provides starting point for mapping schemes, given a vulnerability can be assigned to each occupancy type
  - Suitable for:
    - Predominately residential development patterns
      - Rural
      - Single-family residential
      - High density residential

GADM_NAME	Traditional housing	Rudimentary housing	Semi-detached housing or floor of semi-detached housing	villa or duplex	Apartment	Retail	Financial	Tourism
Tunis	7.1%	0.5%	48.7%	13.6%	20.2%	9.6%	0.2%	0.0%
Ariana	5.5%	0.3%	48.2%	20.6%	17.3%	8.0%	0.1%	0.0%
Ben Arous (Tunis Sud)	7.7%	0.3%	51.3%	19.9%	13.4%	7.4%	0.0%	0.0%
Manubah	16.0%	0.2%	53.3%	17.4%	4.3%	8.7%	0.0%	0.0%
Nabeul	20.6%	0.3%	49.1%	19.1%	3.9%	7.0%	0.1%	0.0%
Zaghouan	36.9%	0.6%	28.5%	25.5%	1.2%	7.2%	0.1%	0.0%
Bizerte	15.4%	0.3%	61.6%	12.5%	3.4%	6.7%	0.1%	0.0%
Béja	39.8%	0.8%	34.4%	16.5%	1.2%	7.4%	0.0%	0.0%
Jendouba	28.0%	1.0%	19.2%	44.4%	1.8%	5.4%	0.1%	0.0%
Le Kef	40.0%	0.5%	35.4%	17.3%	0.9%	5.8%	0.0%	0.0%
Siliana	52.7%	0.6%	19.5%	20.3%	0.8%	5.9%	0.1%	0.0%
Sousse	22.1%	0.3%	30.2%	26.2%	13.5%	7.7%	0.1%	0.0%
Monastir	28.0%	0.3%	41.5%	17.2%	5.9%	7.1%	0.1%	0.0%
Mahdia	43.7%	0.3%	17.7%	28.3%	3.1%	6.9%	0.1%	0.0%
Sfax	13.5%	0.2%	21.8%	48.6%	8.7%	7.0%	0.1%	0.0%
Kairouan	50.5%	0.3%	30.3%	12.4%	0.7%	5.7%	0.1%	0.0%
Kassérine	46.9%	0.6%	32.0%	14.0%	1.1%	5.5%	0.0%	0.0%
Sidi Bou Zid	40.4%	0.4%	13.8%	39.2%	1.0%	5.2%	0.0%	0.0%
Gabès	29.1%	0.3%	47.2%	15.2%	2.0%	6.3%	0.0%	0.0%
Médenine	30.7%	0.4%	10.7%	51.3%	0.9%	6.1%	0.0%	0.0%
Tataouine	29.9%	0.3%	45.7%	16.3%	2.1%	5.7%	0.0%	0.0%
Gafsa	25.2%	0.4%	36.6%	25.0%	7.2%	5.5%	0.1%	[illegible]
Tozeur	56.3%	0.3%	14.3%	21.7%	0.9%	6.3%	0.1%	0.1%
Kebili	40.7%	0.2%	8.4%	42.6%	0.6%	7.6%	[illegible]	[illegible]

Tunisia Housing Profile (UNHABITAT)





TUNISIA HOUSING PROFILE

Figure 5.3 Old multi-story courtyard house in El Hajja Quarter, Tunis.
Source: Miramar Magazine (1984)

Of course land prices in more desirable areas are much higher. For example, square meter land prices for serviced residential land in the better quarters of Tunis can easily fetch TD 1,300, TD 800 in La Manouba, and TD 500 in Sfax.

There is no information readily available for the prices of informal housing units exchanged through informal markets, nor for the prices of land being exchanged for informal building purposes.

5.8 HOUSING TYPOLOGIES DESCRIBED

The statistics given in the above sections give a fair idea of Tunisia's housing stock, but they do not give a tangible idea of the types of buildings in which Tunisians live. In this section an attempt is made to describe the physical and architectural characteristics of the main housing typologies.

The **Arab, courtyard** or **Houch** house type is, as its name implies, built around a central court which normally provides light and ventilation to the whole dwelling and also provides circulation. In traditional urban areas this house would normally be built over one or two floors, although higher structures were possible, as shown in Figure 5.3.

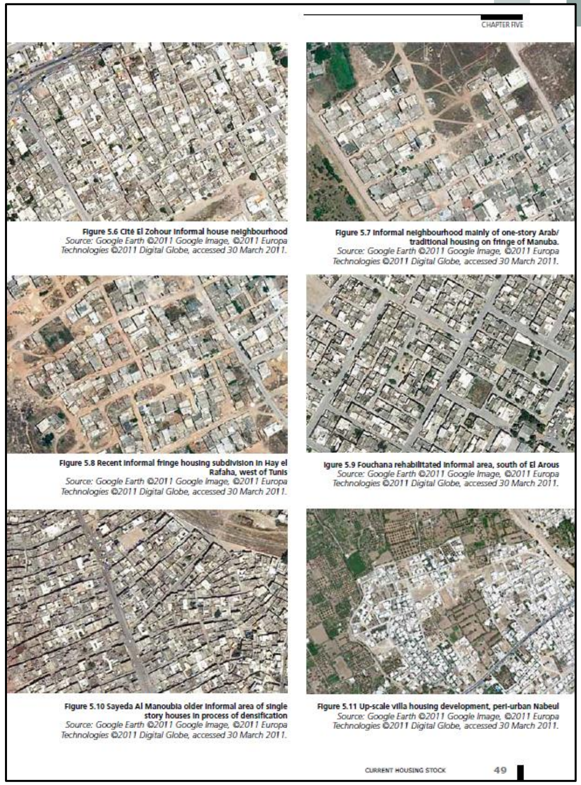
In traditional town centers the Arab/courtyard house imparts a unique urban fabric, as can be seen from Figure 5.4. and Figure 5.5. But even in informal quarters started in the 1970s and 1980s one can see the popularity of the Arab/courtyard house, as shown in Figures 5.6, 5.7, 5.8, 5.9, and 5.10.

Villa housing is now the fastest growing type of housing in Tunisia. It can be both formal and informal and usually found on fringe and peri-urban locations. Formal villa housing has lot sizes that normally vary from 300 to 900 m2, although in peri-urban locations lot sizes can be much bigger. Heights are generally two to four floors, with some villas having housing units on each floor. Examples of various types of villa development can be seen in Figures 5.11, 5.12, 5.16, 5.18, and 5.19.

Apartment housing units can be found in older areas of towns as well as in fringe subdivisions.

Figure 5.4 Courtyard house urban fabric, Baja old town
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, , accessed 30 March 2011.

Figure 5.5 Sfax inner city courtyard housing
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.



CHAPTER FIVE

Figure 5.6 Cité El Zohour informal house neighbourhood
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.

Figure 5.7 Informal neighbourhood mainly of one-story Arab/ traditional housing on fringe of Manuba.
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.

Figure 5.8 Recent informal fringe housing subdivision in Hay el Rafaha, west of Tunis
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.

igure 5.9 Fouchana rehabilitated informal area, south of El Arous
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.

Figure 5.10 Sayeda Al Manoubia older informal area of single story houses in process of densification
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.

Figure 5.11 Up-scale villa housing development, peri-urban Nabeul
Source: Google Earth ©2011 Google Image, ©2011 Europa Technologies ©2011 Digital Globe, accessed 30 March 2011.

CURRENT HOUSING STOCK 49

- Description and visualization of each of the five different housing types mentioned in the E&Y spreadsheets
- Allows us to validate structural assumptions using ground imagery
- Suitable for:
  - Predominately residential development patterns

Tunis Building Inventory/Survey (University of Tunis El Manar)

ORIGINAL RESEARCH PAPER

An inventory of buildings in the city of Tunis and an assessment of their vulnerability

Afef Khalfet Mansour · Najla Bouden Romdhane · Noureddine Boukadi

Received: 4 August 2012 / Accepted: 7 April 2013 / Published online: 23 April 2013

Abstract Tunis is a densely populated city. Its building stock was constructed without any seismic design code and mostly over soft soils. These facts make a seismic risk assessment of the city necessary. To prepare a large-scale vulnerability assessment of the buildings of Tunis, the following methodology was employed: (1) a collection of data based on a rapid visual screening procedure was gathered using an inventory form. These data were composed of files and information placed at the disposal of the authors by the municipality of Tunis. The data also contained information gathered by surveys carried out by engineering departments and information gathered from building owners. (2) A classification of building typologies was carried out considering construction material, structural system, age, height, function and state of maintenance. A measure of seismic vulnerability was assigned to each typology considering the first two parameters. (3) A large-scale vulnerability assessment using two methods was conducted for buildings for which few data were available. Vulnerability methods inspired by the EMS98 concepts and the Italian GNDT concepts were modified and applied to pilot-scale buildings located in the downtown zone (Habib Bourguiba Avenue) and in the old zone (Medina). The data analysis, through the application of the two methods, suggests that the vulnerability of buildings surveyed in Tunis is significant and risk mitigation efforts are necessary.

Keywords Building inventory · Ordinary buildings · Historic buildings · Vulnerability assessment

1 Introduction

Tunis, the capital city of Tunisia since the twelfth century, is located in the northeast of Tunisia. It has a population of over 700,000 people according to the 2004 census.

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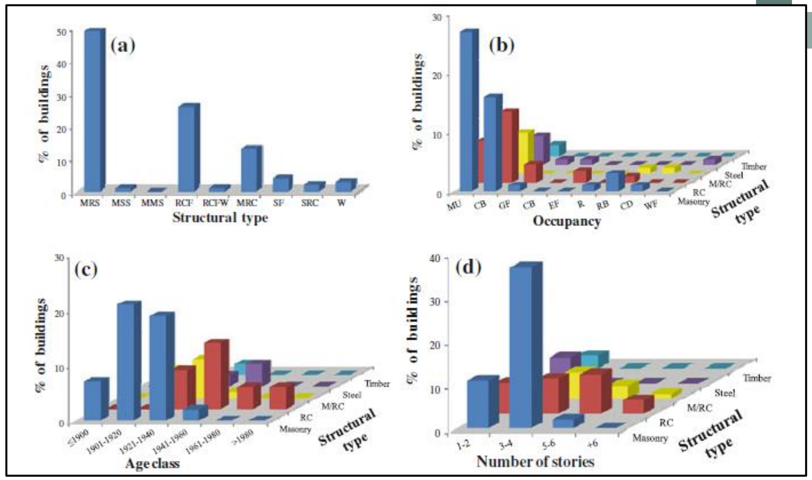
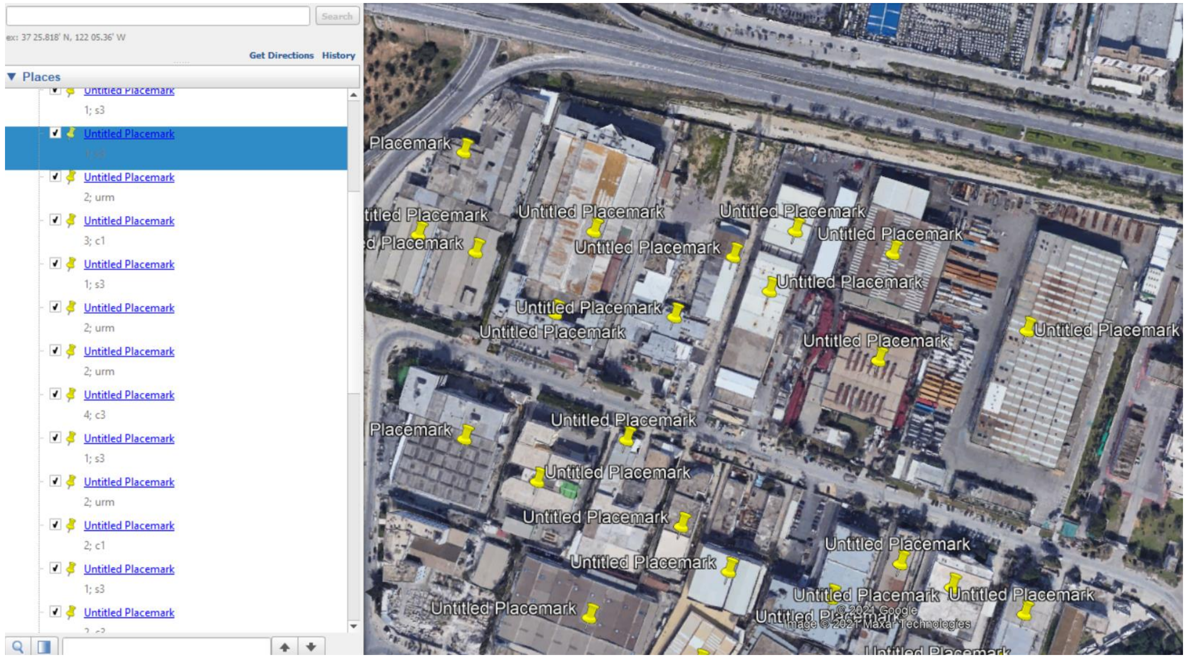
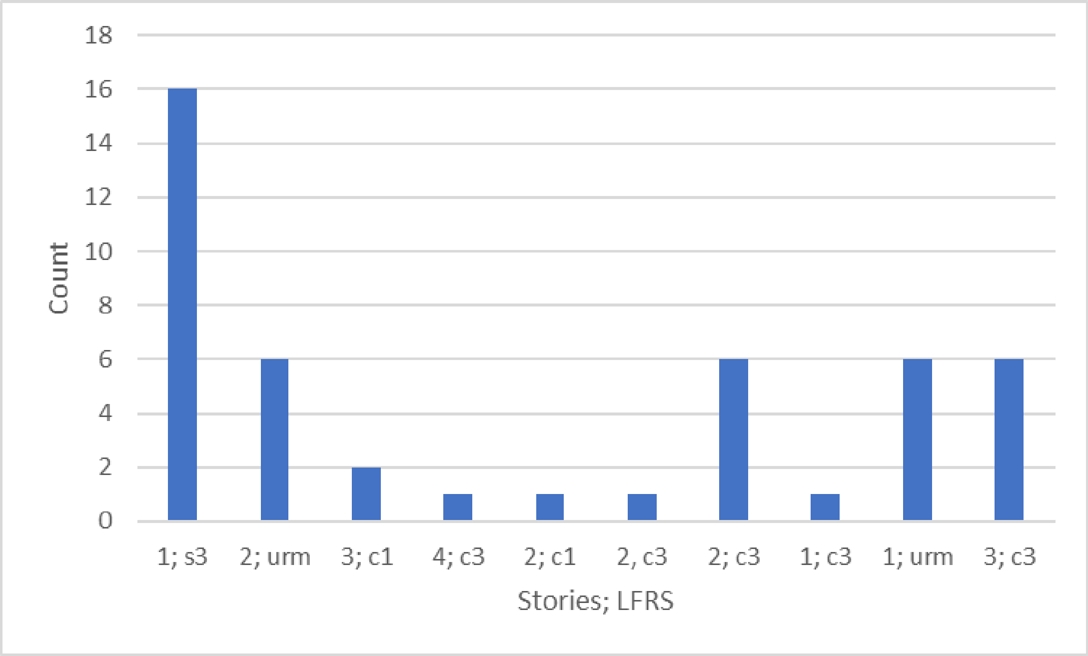
Department of Geology, Faculty of Sciences of Tunis, University of Tunis El Manar, Tunisia



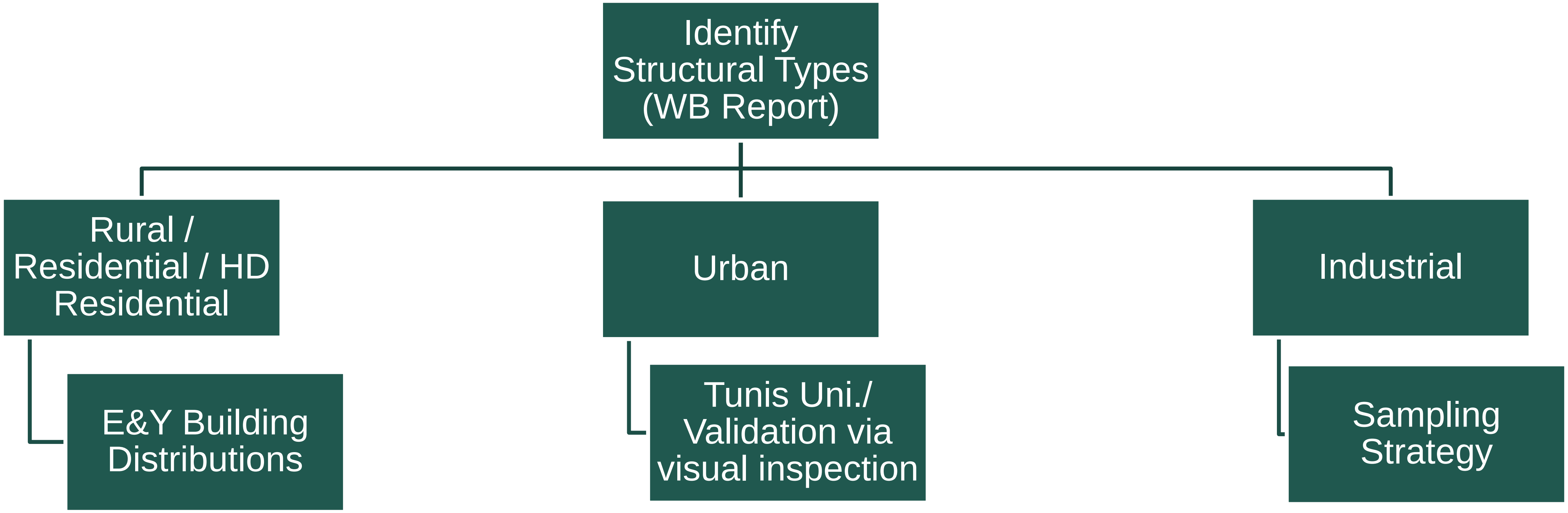
- Non-residential statistics
- Direct observation and statistical breakdown of structural types unique to the downtown (urban) region
  - LFRS
  - Story heights
  - Occupancies
  - Age
- Suitable for:
  - Predominately urban development patterns

Sampling for Industrial Development Patterns





- Statistics regarding Industrial regions not available in sourced data
  - E&Y data provides # lots and lot size but no information regarding structure
- Sampling strategy to determine structural distribution
  - Street-view imagery available via Google Maps and Mapillary
  - Record structural information and height distribution

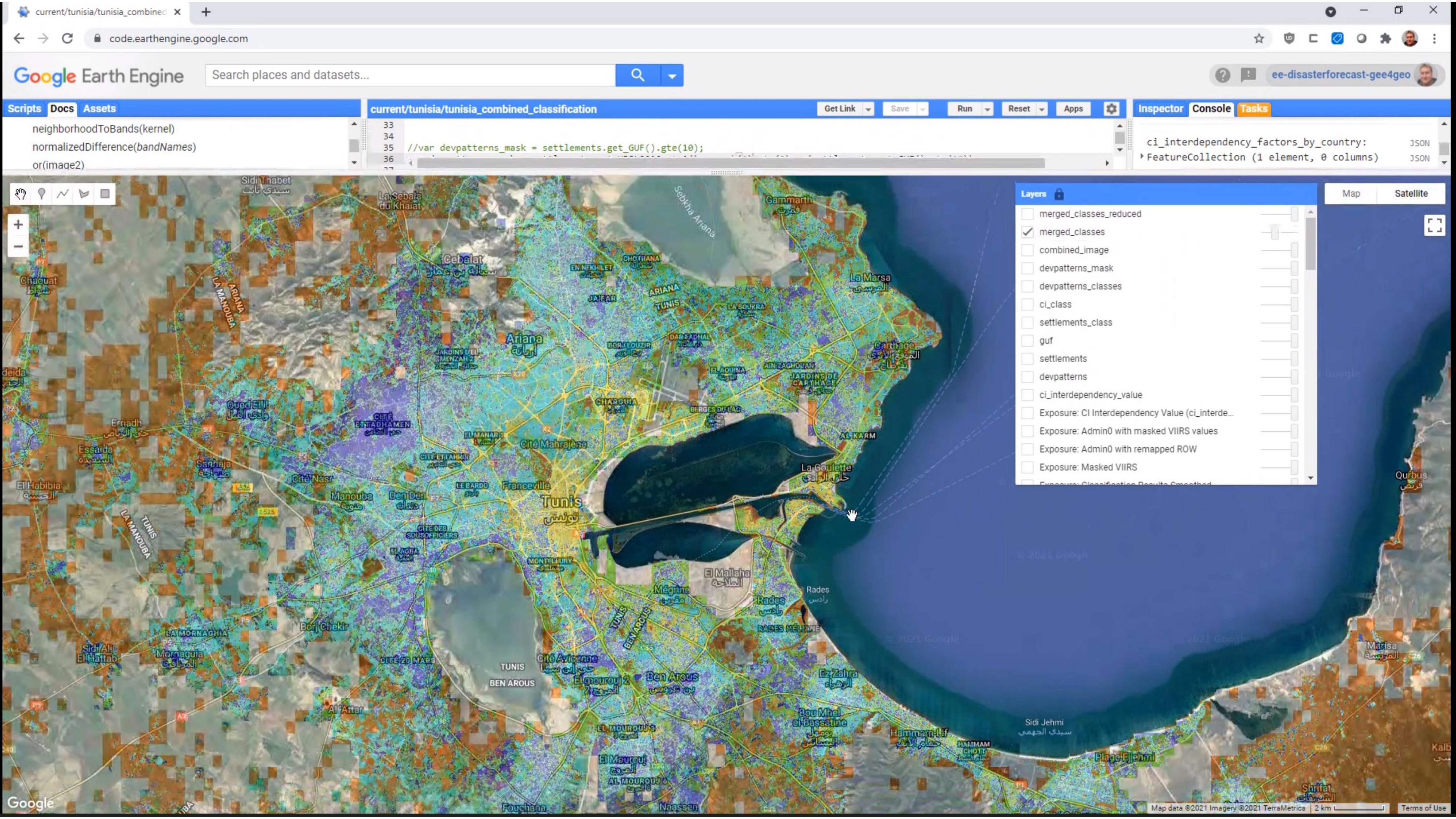


Structural Type	Rural	Residential	HD Residential	Urban	Industrial
Maçonnerie chainée (construction basse)	22.7%	24.0%	24.3%	7.8%	3.9%
Maçonnerie chainée (const. moyenne)				5.2%	2.6%
Structure en béton armé (const. basse)	0.1%	52.4%	31.5%	17.2%	16.0%
Structure en béton armé (const. moyenne)		15.0%	8.9%	15.5%	14.4%
Structure en béton armé (const. haute)		0.7%	1.0%	2.4%	2.2%
Structure en béton armé double (const. haute)				1.9%	
Structure en acier (const. basse)					34.8%
Maçonnerie en brique non armée (const. basse)	39.9%	6.0%	18.2%	12.3%	14.9%
Maçonnerie en brique non armée (const. moyenne)				9.2%	11.2%
Maçonnerie en pierre non armée (const. basse)	35.3%	2.0%	16.1%	28.5%	
Maçonnerie fragile (const. basse)	2.0%				

Development Modeling

- Used Machine Learning to classify development patterns
  - Digitized region for training

- Processing done in Google Earth Engine platform
  - Availability of data
  - Ease to pre-process data (combine datasets, data normalization)
  - Built-in learning models
  - Export features
- Resolution: 15 arc-seconds (~450 meters)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Google Earth Engine
Search places and datasets...
ee-disasterforecast-gee4geo
Scripts Docs Assets
neighborhoodToBands(kernel)
normalizedDifference(bandNames)
or(image2)
current/tunisia/tunisia_combined_classification
Get Link Save Run Reset Apps
35 //var devpatterns_mask = settlements.get_GUF().gte(10);
Inspector Console Tasks
ci_interdependency_factors_by_country: JSON
FeatureCollection (1 element, 0 columns) JSON
Layers
merged_classes_reduced
merged_classes
combined_image
devpatterns_mask
devpatterns_classes
ci_class
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ci_interdependency_value
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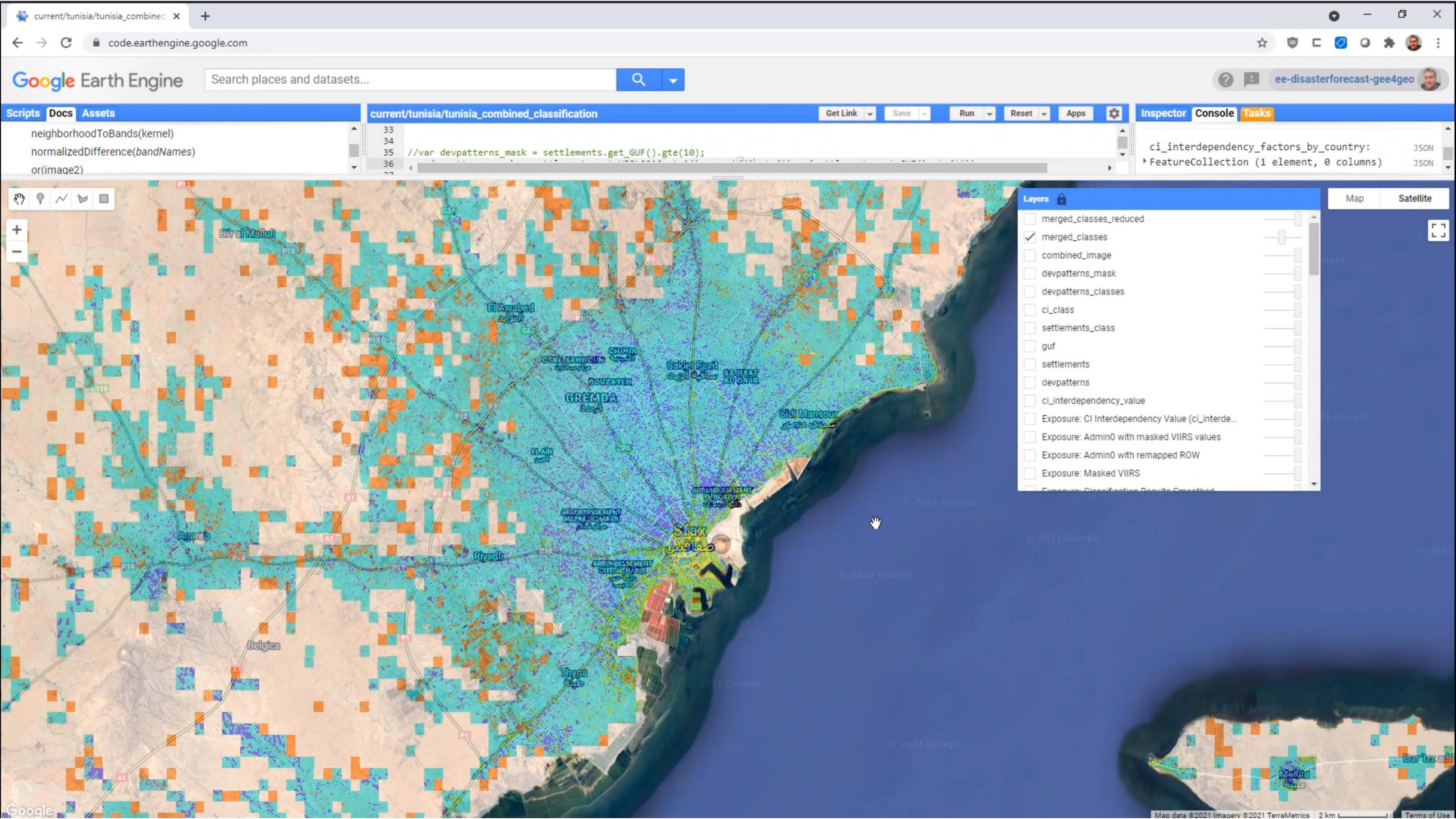
Exposure: Admin0 with masked VIIRS values
Exposure: Admin0 with remapped ROW
Exposure: Masked VIIRS
Map Satellite
Tunis
Ariana
La Marsa
Carthage
La Goulette
Rades
Ben Arous
Manouba
Cité Mahrajène
Sidi Jehmi
Map data ©2021 Imagery ©2021 TerraMetrics 2 km Terms of Use



current/tunisia/tunisia_combined
code.earthengine.google.com
Google Earth Engine
Search places and datasets...
ee-disasterforecast-gee4geo
Scripts
Docs
Assets
neighborhoodToBands(kernel)
normalizedDifference(bandNames)
or(image2)
current/tunisia/tunisia_combined_classification
Get Link
Save
Run
Reset
Apps
//var devpatterns_mask = settlements.get_GUF().gte(10);
Inspector
Console
Tasks
ci_interdependency_factors_by_country:
FeatureCollection (1 element, 0 columns)
JSON
Layers
merged_classes_reduced
merged_classes
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Exposure: Admin0 with masked VIIRS values
Exposure: Admin0 with remapped ROW
Exposure: Masked VIIRS
Map
Satellite
Bir al Malluli
El Awabed
GREMDA
Sakiet Ezzit
Sidi Mansour
Sfax
Agareb
Riyadh
Belgica
Thyna
Melitta
Map data ©2021 Imagery ©2021 TerraMetrics
2 km
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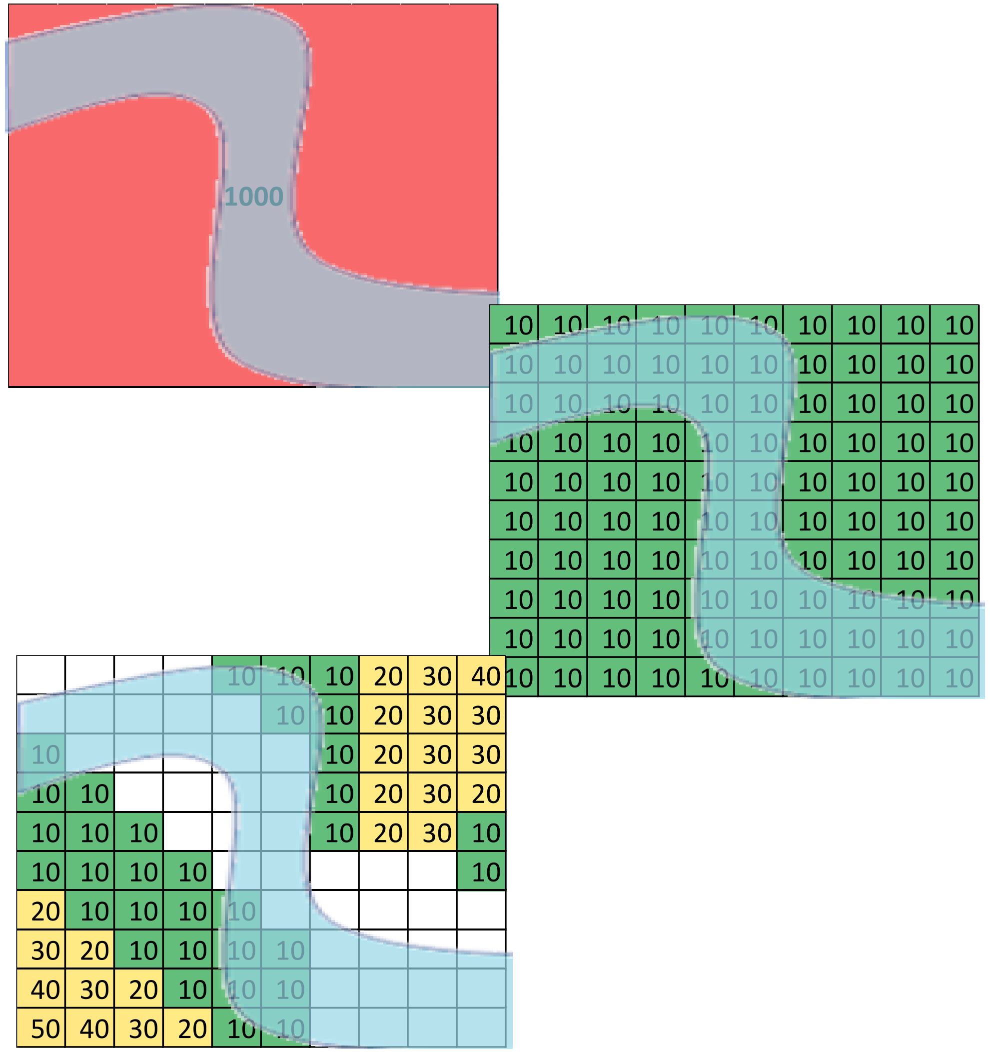
Exposure Disaggregation

- Geographically distribute the exposure onto classified grid
  - Model density of the exposure using remote sensing signal
  - Model proportion of each exposure type in each development pattern
- Apply mapping scheme to assign damage functions
- Exposure types to disaggregate
  - General Residential/General Commercial/ General Industrial
  - Education/Financial/Health/Tourism
- Exposure types that will not be analyzed
  - Point specific: Port/ Transport /Dams
  - No adequate damage function: Agriculture/Roads

Exposure Refinement for Flood Risk

- Flood model require higher resolution data than earthquake
- Exposure near riverine area must be capture properly to have true understanding of risk
- For Tunisia, we refined exposure to 90m in region with flood hazard



Hazard Data

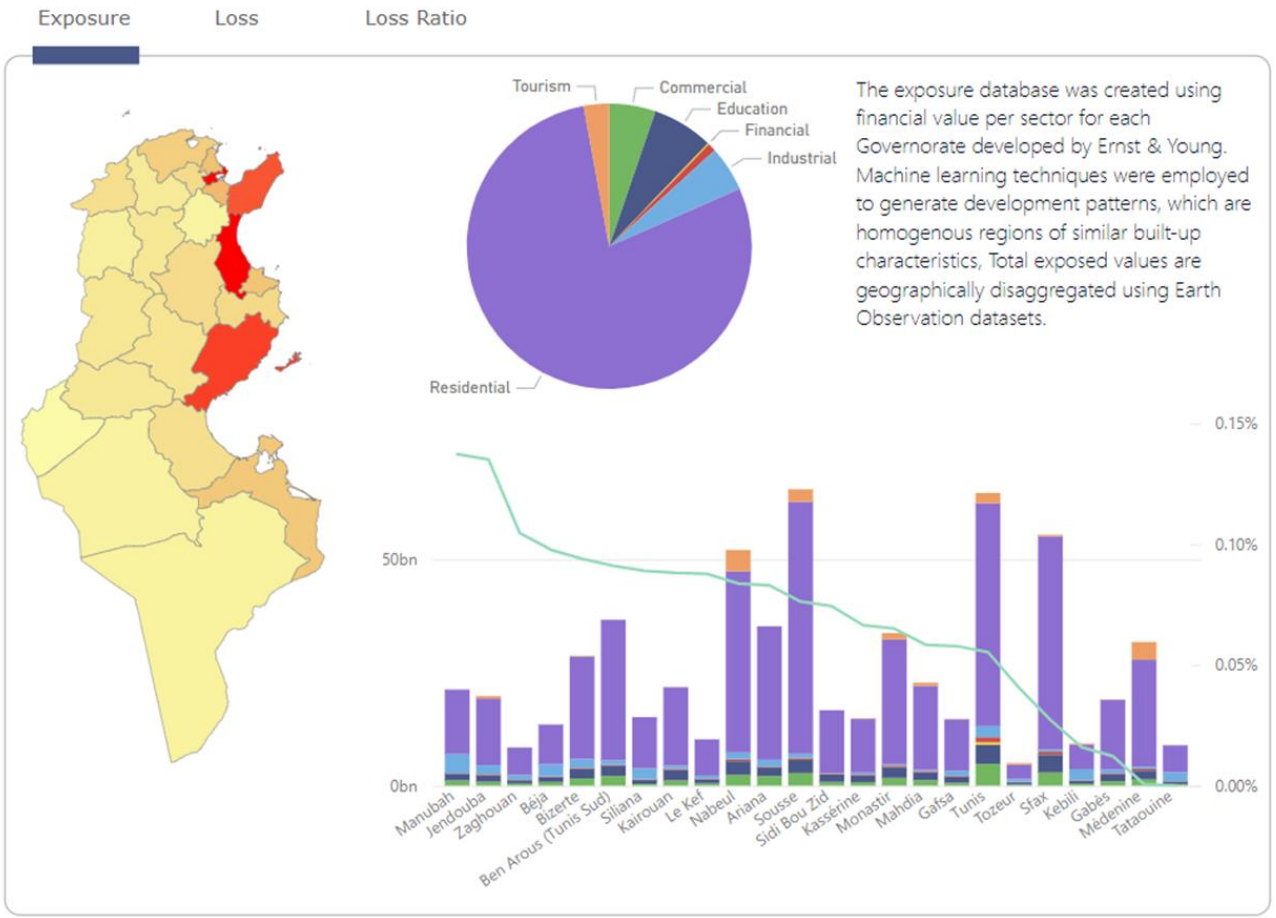
- Flood
  - Fluvial defended, Fluvial Undefended and Pluvial data
  - 10 return periods (5, 10, 20, 50, 100, 200, 250, 500, 1000)
- Earthquake
  - Gridded return period PGA
  - 7 return periods (20, 50, 100, 250, 500, 2500, 5000)

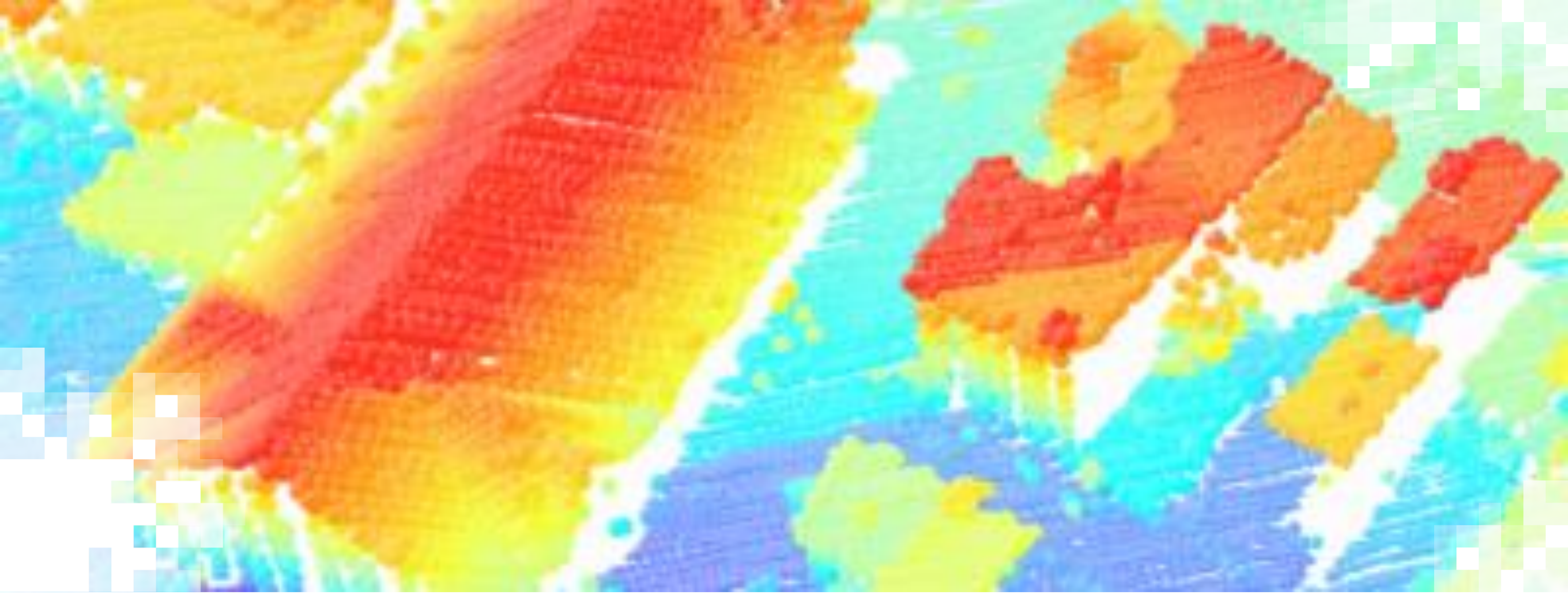
Pluvial 1 in 1000 year

PGA on Rock 2500-year

Damage/Loss Calculation

- Calculate Loss from return period hazard for each exposure grid using appropriate vulnerability
- Calculate Annualized Average Loss (AAL) for each grid
- Aggregate AAL for each governorate





Part 1:
Summary

Summary

- What is exposure data, and how is it used in the loss estimation process?
- The basic process of developing exposure data
- Structural mapping scheme development and building sampling
- Case Study: walkthrough of building exposure data for Tunisia

Looking Ahead

- Part 2: Development of Site-Specific Exposure Data with EO
  - Developing a building-level exposure data set for HAZUS Flood Study in New York
  - Using Earth Observations to develop a building structures dataset
  - Case study: Sampling from streetview to characterize vulnerability

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Thank You!