Vulnerability – Challenges & Innovations

Sideways pancaking of a 4-story building …

… was avoided right next door by bracing the soft storey.

Xuankou secondary
school, Beichuan,
Sichuan, China

RENEW RISK

Inside the Black Box: How Vulnerability Functions Shape Cat Models

THE IMPORTANCE OF VULNERABILITY IN CATASTROPHE RISK MODELS

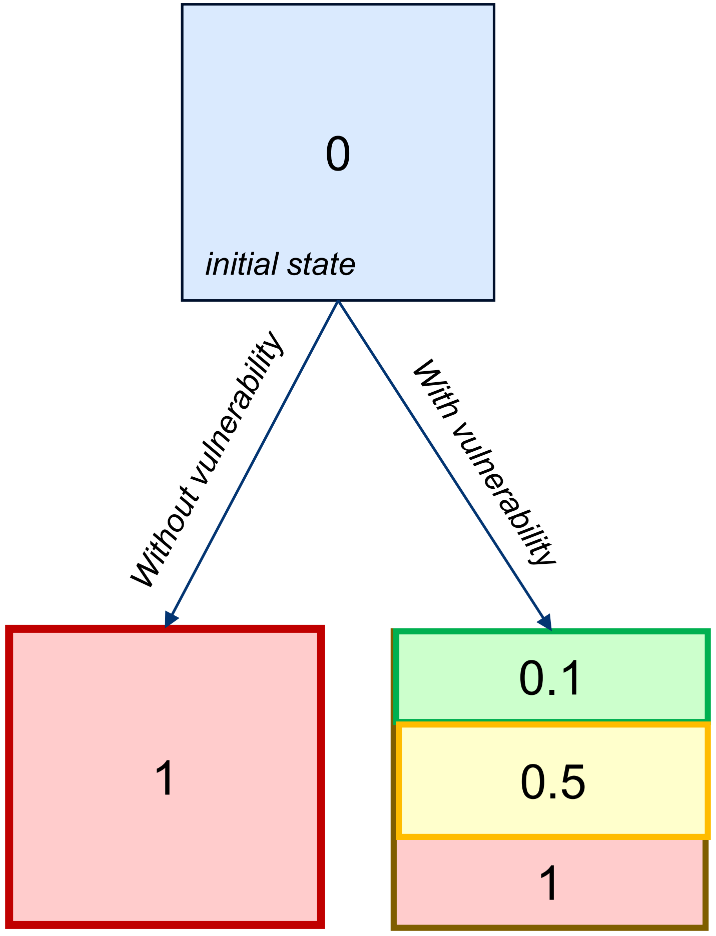

Indian Ocean Tsunami, 2004, Banda Aceh


NZ, infrastructure damage, PLA

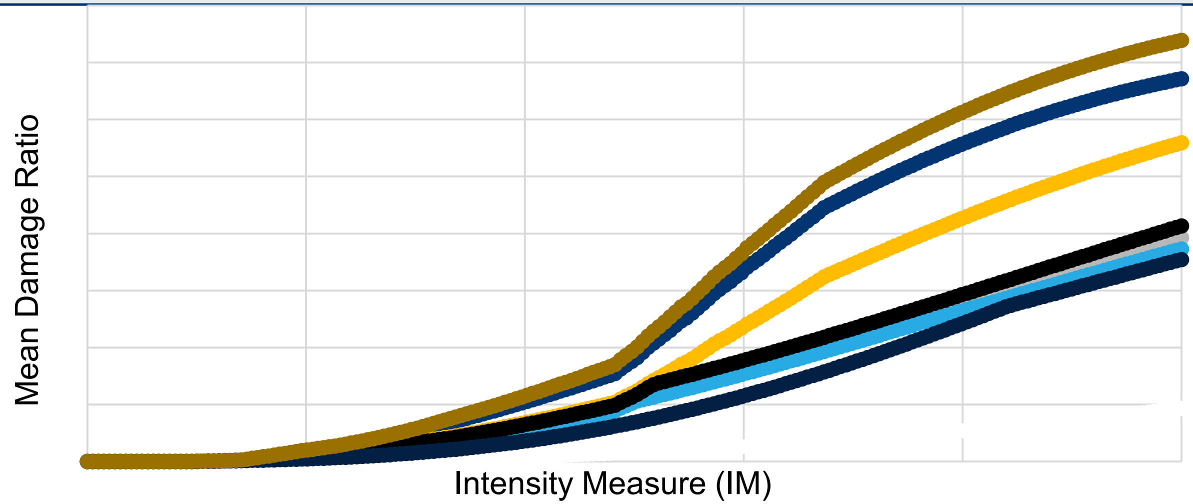

Hurricane Michael, 2018, Mexico

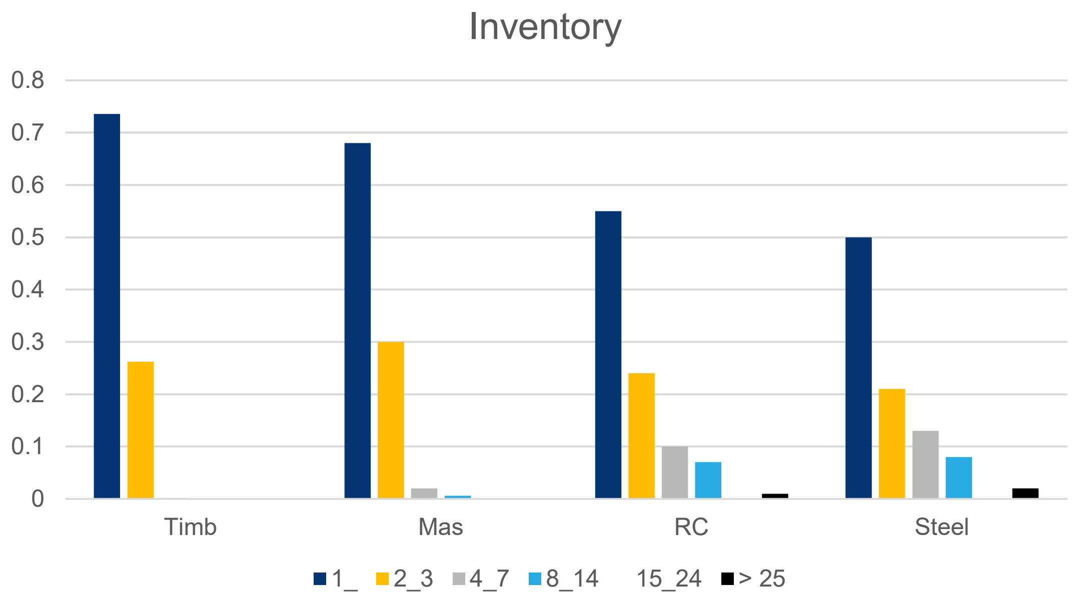
Hazard x Exposure x Vulnerability = **Loss**

Business Interruption



REPRESENTING VULNERABILITY IN CATASTROPHE RISK MODELS





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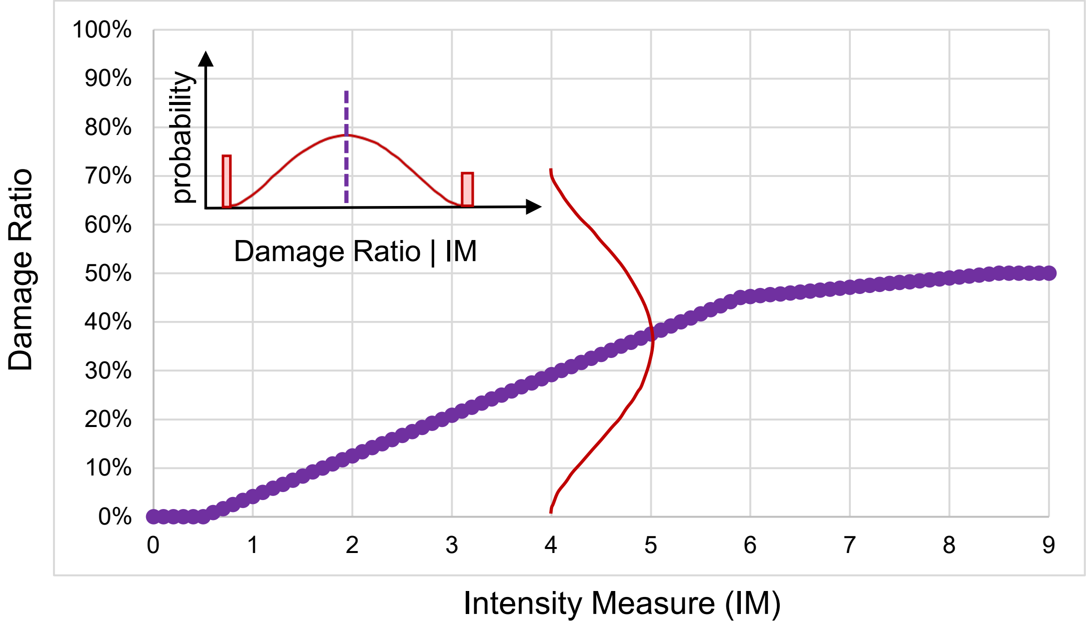
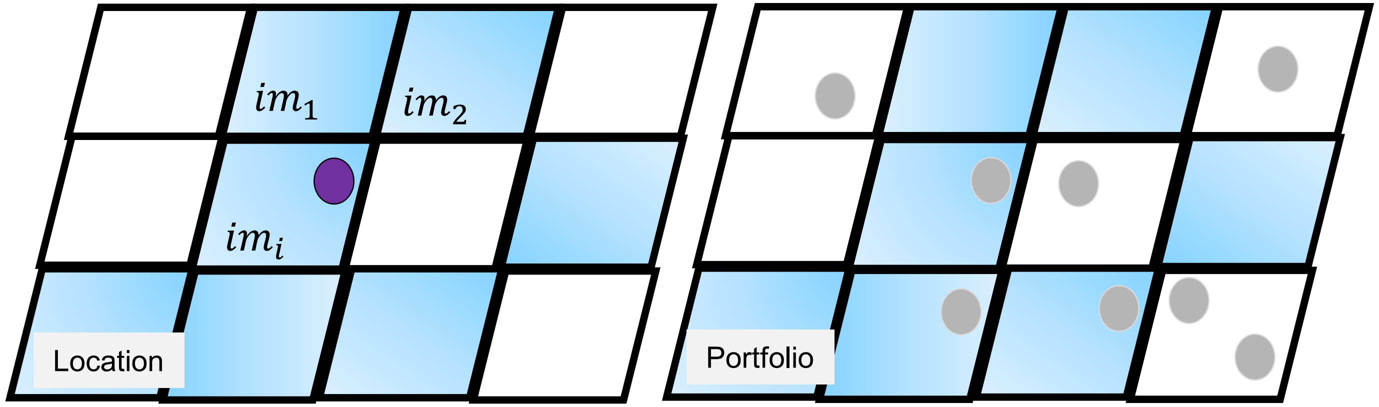
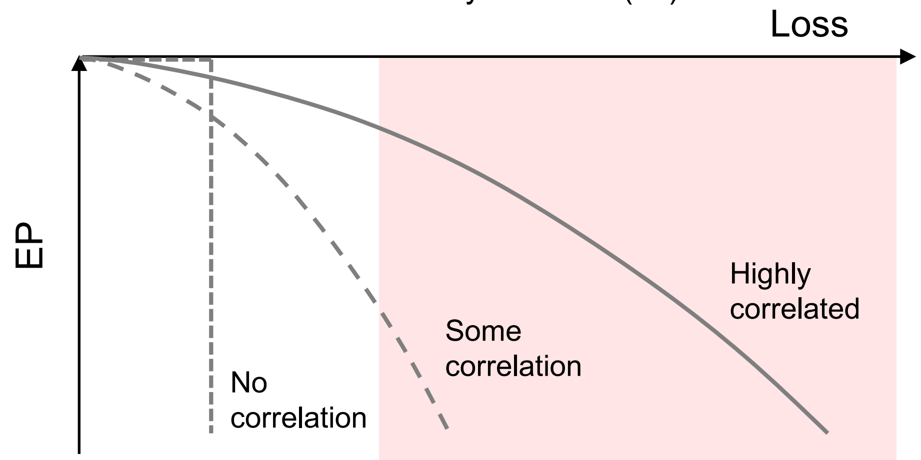
SECONDARY UNCERTAINTY

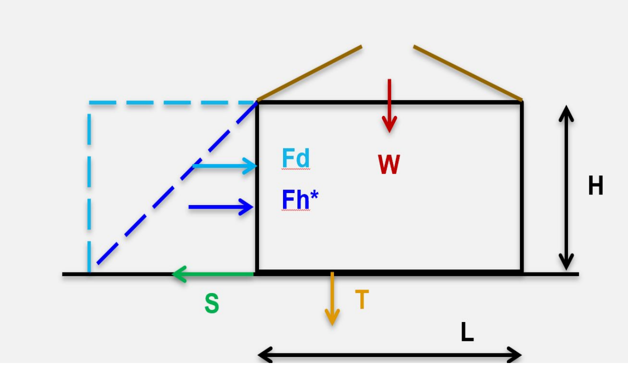


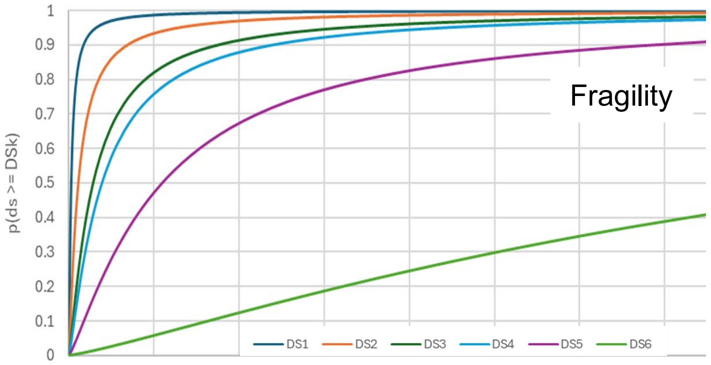




CATRISX Services Ltd. n.d. *Drivers of Lower Tail Loss Inflation in Earthquake CAT Models: An Example from 1994 Northridge*. London: Lighthill Risk Network.

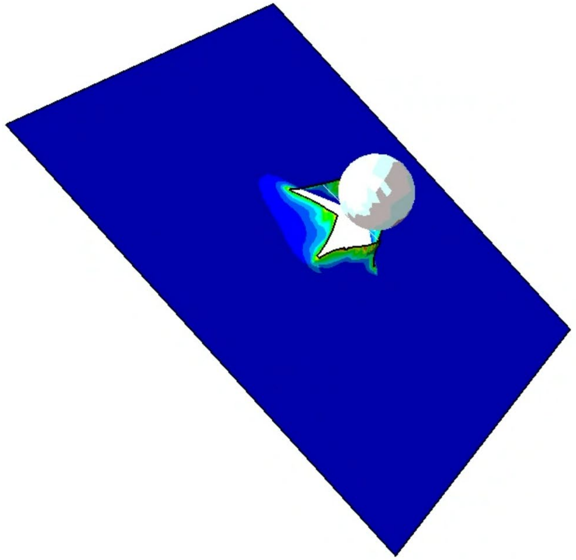
BUILDING VULNERABILITY FUNCTIONS

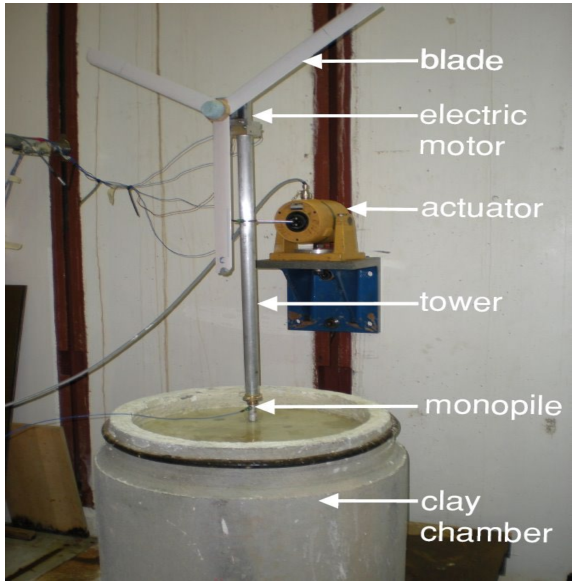




Damage State	*Labour Cost*	*Transportation Cost*	*Material Costs*	*Other Costs*	*Total*	*LossRatio*
DS1	86	0	119,741	0	119,828	**0.005**
DS2	365	5,188	211,319	0	216,871	**0.008**
DS3	723	5,188	552,100	0	558,010	**0.021**
DS4	1,784	5,188	2,210,996	0	2,217,967	**0.085**
DS5	8,695	9,387	4,365,907	0	4,383,989	**0.168**
DS6	29,122	642,265	22,406,734	3,010,733	26,088,854	**1.000**

Step: Step-1 Frame:
Total Time: 0.008100



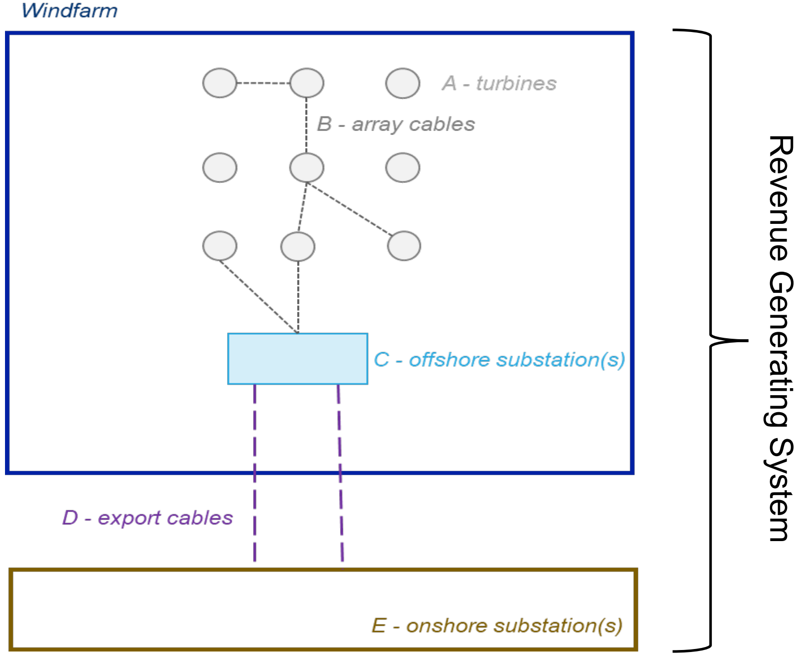


Approach	Pros	Cons	Use Cases
Empirical	Good data volume & quality	Bias, event-specific, limited	Pricing, portfolio loss
Engineering	Works when data is limited	Costly, assumption-sensitive	New designs, hypotheticals
Judgment	Flexible, fills data gaps	Biased, needs expert input	Rare assets, low-data areas

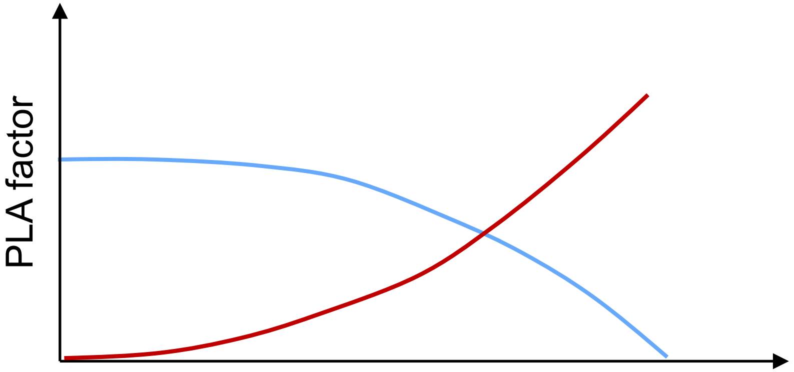
VULNERABILITY DOES NOT STOP HERE!

Contents

Business Interruption



Post-Loss Amplification (PLA)



CONCLUSION

- Vulnerability is the susceptibility of a structure to damage from hazard
- Represented by a 2-D damage ratio curve
    - Set capturing variations in characteristics
    - Quantifying unknowns: Inventory, Uncertainty, Correlations
- Modelling Strategies include empirical, engineering, and judgment-based approaches
- Business Interruption, PLA
- Key and adaptable component of a cat model with significant potential for improvements, curve porting, quality assurance

“All models are wrong, but some are useful.”

Box, G. E. P. (1976). ***Science and Statistics****. Journal of the American Statistical Association,* ***71****(356), 791–799.*

Vulnerability: Current and Future Trends

Prof. Tiziana Rossetto, FREng, FICE

OASIS Insight Conference- London 1st May 2025

Delft University of Technology

ucl.ac.uk/EPICentre

Topics

- State of play
- Current research directions in fragility/vulnerability
- Future needs and directions
- Barriers to Innovation

Fragility and Vulnerability Functions – current state of play

- Once called damage probability matrices – first one in Whitman et al. (1973)
- Nowadays many different fragility and vulnerability functions exist for different hazards
- Past dominance of empirical FF and VF, now dominance of those based on numerical simulations
- The field of earthquake engineering is still leading the field both in number and sophistication of models

Hazard	Individual Vulnerability /Fragility curves
Earthquake	3277
Wind	769
Landslides	650
Flood	178
Tsunami	118

Table: Current status of CATASTROPHI database

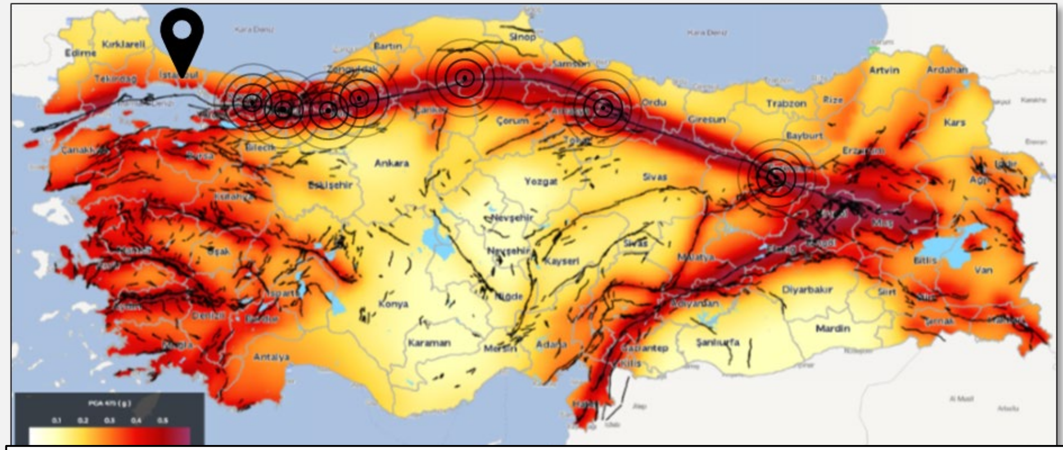
Whitman R.V. et al [1973] ''Earthquake damage probability matrices“, Proc. 5th World Conf. on EQ Eng.g, Rome, Italy

Current directions

Engineered infrastructure has a significant life (50-100 years), but structures degrade and can be affected by several hazards in this time

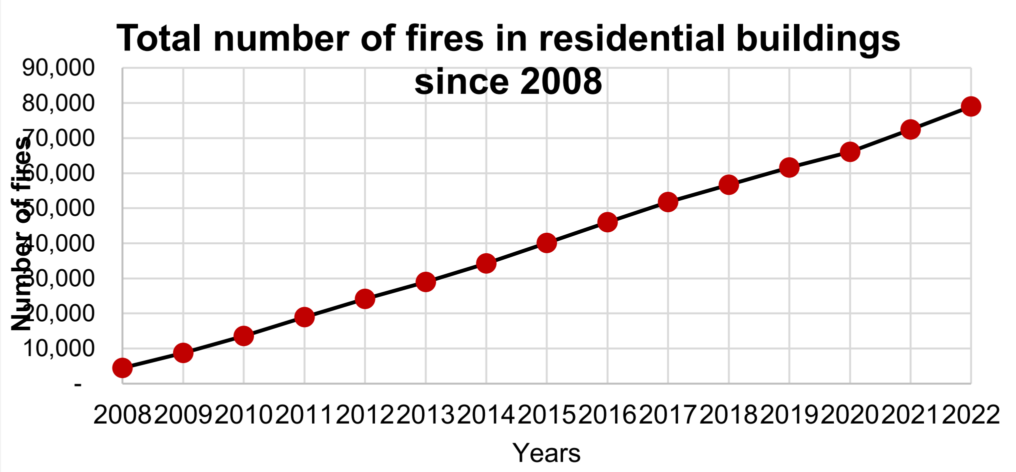
- Fragility functions accounting for degradation
- Fragility for sequential hazards
- Fragility for multiple (same or different) hazards

Example 1: Multiple (different) hazards – fire followed by earthquakes



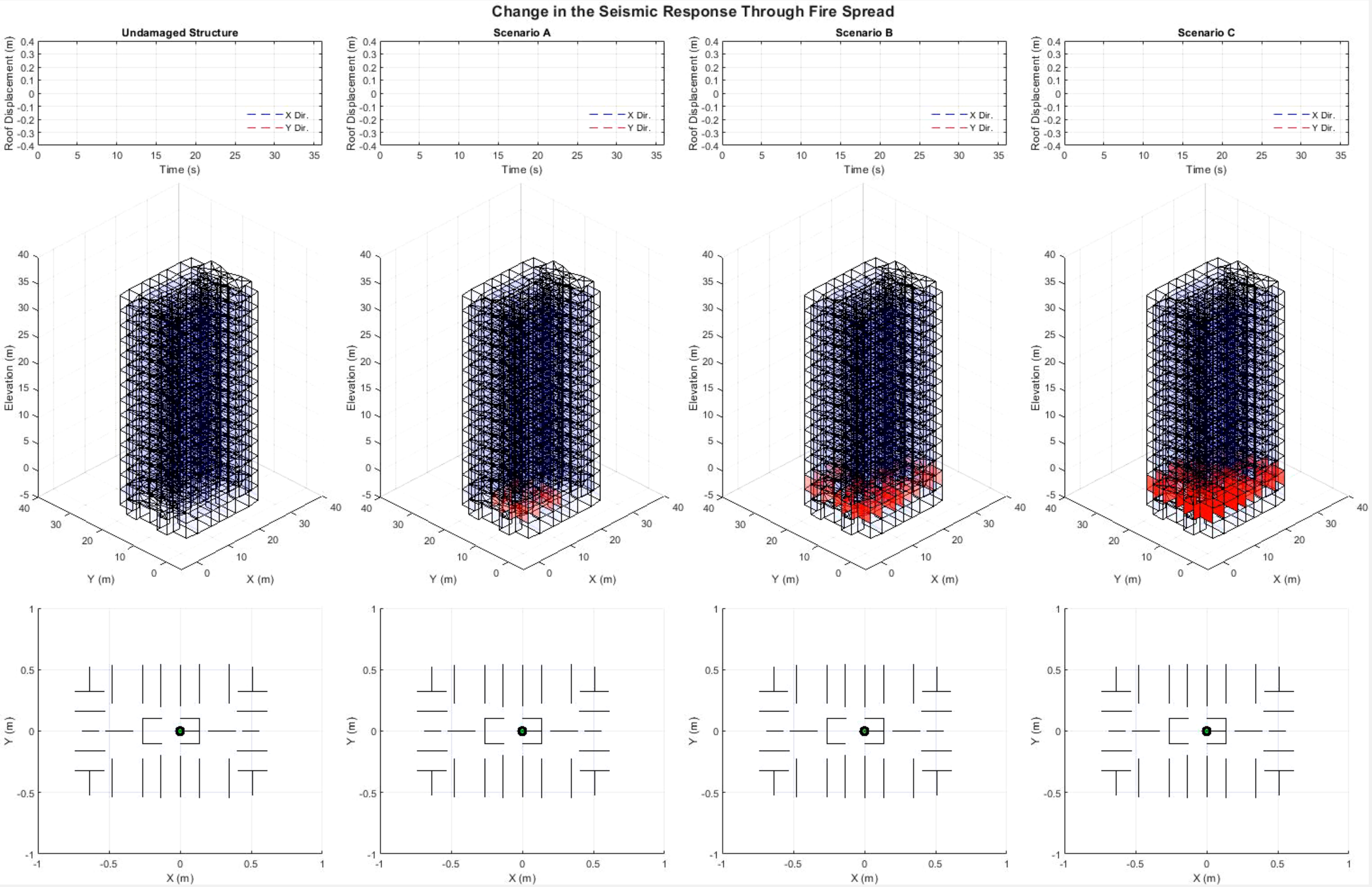
The case of Istanbul: How do fire-damaged buildings perform under earthquakes?

- No post-fire engineering investigation
- Only cosmetic repair conducted
- Hidden unrepaired damage



Source: Dede, S. et al. (2023). Seismic performance of fire damaged structures: preliminary analysis of a 14-story case study structure. Proc. Of the SECED Conference, Cambridge, UK.

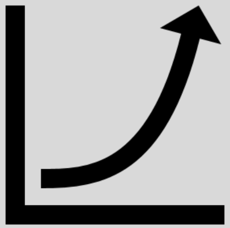
Example 1: Multiple (different) hazards – fire followed by earthquakes



- A fire of just 30mins duration can affect the collapse probability under earthquake
- Spread of fire affects collapse mechanism

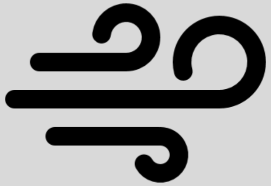
Video care of Sahin Dede, UCL

Current to future directions – green economy, hazards & climate change



Renewable energy technologies: significant uptake in the **last decade** (Lloyd's, 2020).

Four-fold decrease in **costs** (Lloyd's, 2020).



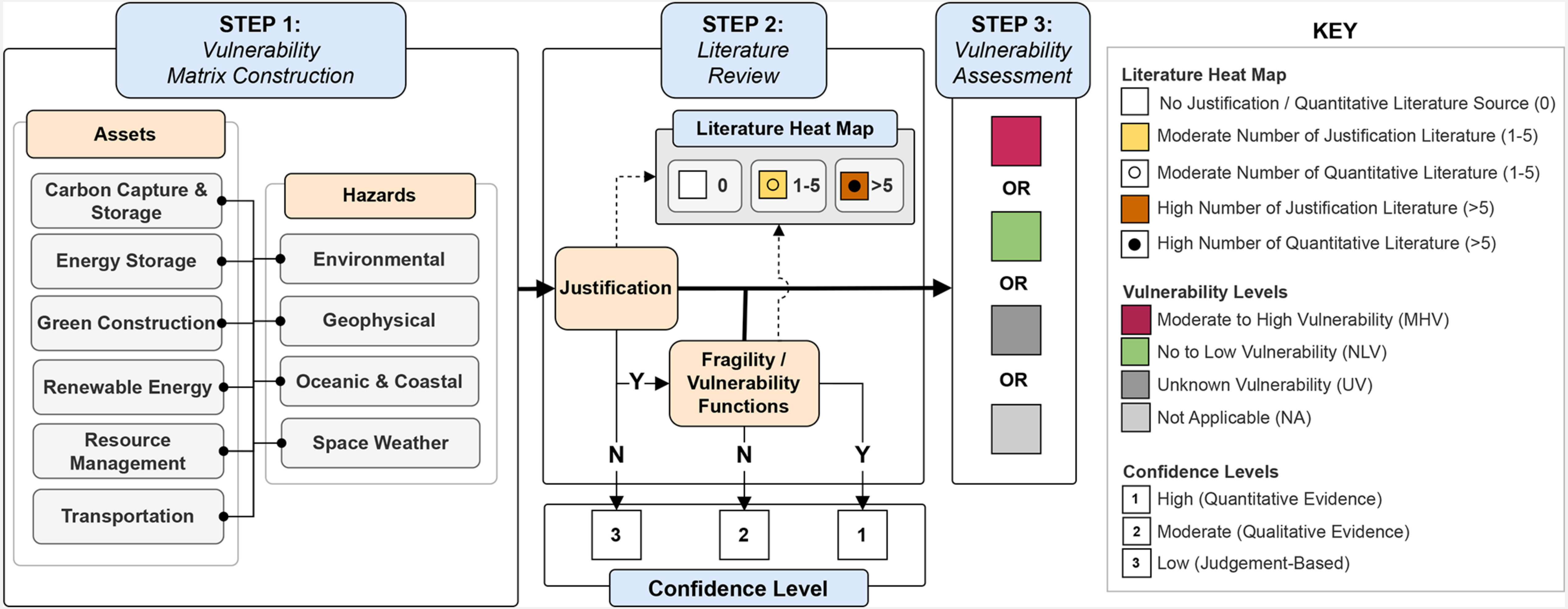
Green energy systems are **prone to disruption:** (Bett and Thornton, 2016; Lloyd's, 2020)

- Environmental conditions
- Size
- Location Constraints

Comprise **relatively new** assets – including nature-based

Data scarcity due to limited exposure time

Current to future directions – green economy, hazards & climate change



Source: Baskaran, et al. (2025) ‘Review article: Insuring the green economy against natural hazards – charting research frontiers in vulnerability assessment’, Nat. Haz.& Earth Syst. Sci., 25(1), 49–76. doi:10.5194/nhess-25-49-2025

Recall :

3 = low confidence in evaluation

Red = Med-high vulnerability
Dark grey = unknown vuln.y

RENEWABLE ENERGY SOURCES	ENVIRONMENTAL															
	CLIMATE CHANGE / UNSEASONAL PATTERNS	DROUGHT	DUST OR SAND STORM	EXTREME COLD (FREEZE)	GLACIAL MELT	HAILSTORM	EXTREME HEAT: HEATWAVE	LIGHTNING	PLUVIAL FLOODING	RIVERINE FLOODING	SNOW AVALANCHE	SUDDEN TEMPERATURE VARIATION (SHORT-	EXTREME WINDS: TROPICAL CYCLONES	WILDFIRE	WINTER STORM	EXTREME WINDS: EXTRATROPICAL CYCLONES
BIOFUEL – CROPS	2	1	2	2	2	2	2	3	1	1	2	2	1	2	2	2
BIOFUEL – INDUSTRIAL FACILITIES	3	3	3	3	3	3	3	3	1	2	3	3	3	3	3	3
BIOGAS – INDUSTRIAL FACILITIES – ANAEROBIC DIGESTER	3	2	3	2	3	3	2	2	2	2	3	3	2	3	2	2
BIOGAS – INDUSTRIAL FACILITIES – VALORISATION OF BIOGAS	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3
BIOMASS – INDUSTRIAL FACILITIES	3	3	3	3	3	3	2	3	2	2	3	3	3	3	3	3
BIOMASS – WOOD (FORESTRY)	2	2		2	3	2	3	3	2	2	2	3	2	2	2	2
E-FUELS (SYNTHETIC FUELS) STORAGE	3	3	3	3		3	3	3	3	3	3	3	2	3	3	2
GEOTHERMAL	2	2	3	2	3	2	2	2	2	2	3	3	1	3	3	2
HYDRO POWER – RESERVOIR	2	2	3	2	3	3	2	2	2	2	2	3	3	2	3	2
HYDRO POWER – RIVER-RUN-OFF	2	2	3	2	3	3	3	3	2	2	2	3	3	3	3	3
OCEAN – TIDAL ENERGY – TIDAL CURRENT STATIONS	3	3	3	3		3	3	3				3	2		3	3
OCEAN – TIDAL ENERGY – TIDAL RANGE STATIONS	3	3	3	3		3	3	3				3	3		3	3
OCEAN – WAVE ENERGY	2		3	3		3	3	3				3	3		3	3
OFFSHORE WIND – BED-FIXED	3	3	3	2		1	3	2				3	1	3	2	1
OFFSHORE WIND – FLOATING	3		3	3		3	3	3				3	1		3	2
ONSHORE WIND	3	3	2	2	3	1	3	2	2	2	3	3	1	2	2	1
SOLAR POWER – FLOATING PHOTOVOLTAICS (FPVS)	3	3	2	3		2	2	2		3		3	2	2	2	2
SOLAR POWER – LAND-BASED CSP FARMS	2	2	2	3			2	3	3	3		3	3	3		
SOLAR POWER – LAND-BASED PV FARMS	3	3	2	3		2	2	2	2	2	3	3	1	2	2	2
SOLAR POWER – ROOF PVS	3	3	2	3		2	2	2	3	3	3	3	1	2	2	2

Source: Baskaran, et al. (2025) doi:10.5194/nhess-25-49-2025

Recall :

Yellow = <5 sources of literature

Brown= 5-10 sources of lit.

○ = some quantitative data

● = significant quantitative data

RENEWABLE ENERGY SOURCES	ENVIRONMENTAL															
	CLIMATE CHANGE / UNSEASONAL PATTERNS	DROUGHT	DUST OR SAND STORM	EXTREME COLD (FREEZE)	GLACIAL MELT	HAILSTORM	EXTREME HEAT: HEATWAVE	LIGHTNING	PLUVIAL FLOODING	RIVERINE FLOODING	SNOW AVALANCHE	SUDDEN TEMPERATURE VARIATION (SHORT-	EXTREME WINDS: TROPICAL CYCLONES	WILDFIRE	WINTER STORM	EXTREME WINDS: EXTRATROPICAL CYCLONES
BIOFUEL – CROPS		○							○	○			○			
BIOFUEL – INDUSTRIAL FACILITIES									○							
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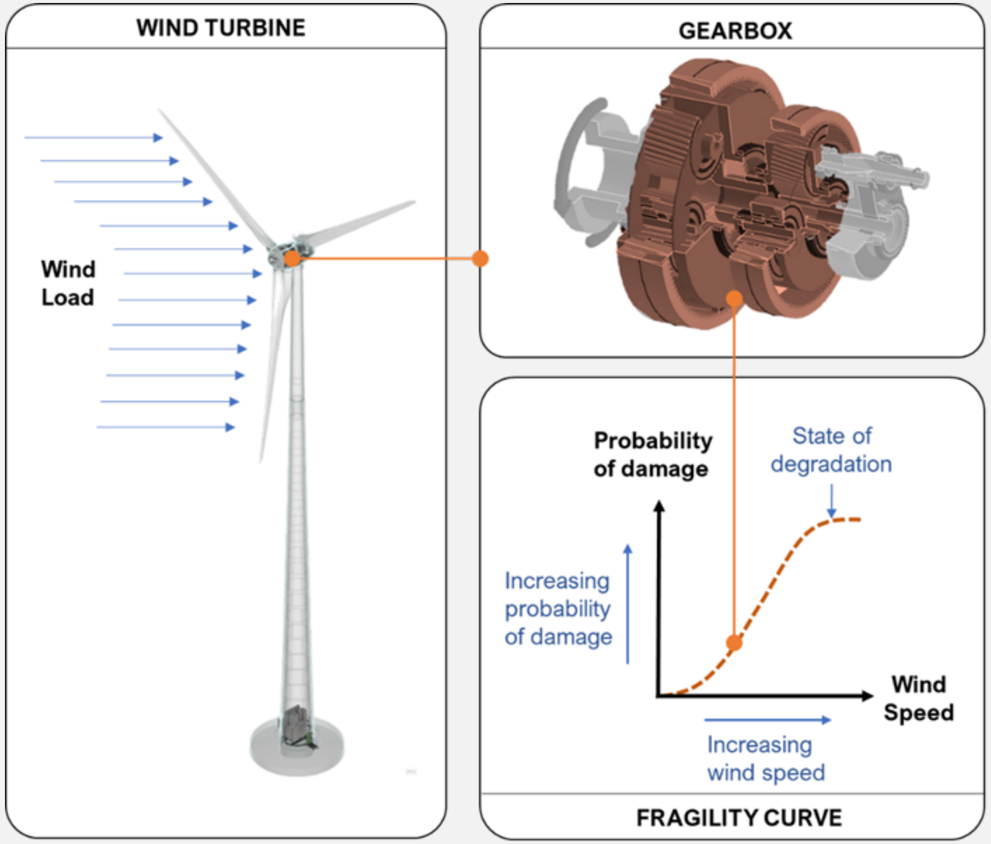
OCEAN – WAVE ENERGY																
OFFSHORE WIND – BED-FIXED						○							●			●
OFFSHORE WIND – FLOATING													○			
ONSHORE WIND						○							●			○
SOLAR POWER – FLOATING PHOTOVOLTAICS (FPVS)																
SOLAR POWER – LAND-BASED CSP FARMS																
SOLAR POWER – LAND-BASED PV FARMS													O			
SOLAR POWER – ROOF PVS													O			

BIG GAPS!!

Source: Baskaran, et al. (2025) doi:10.5194/nhess-25-49-2025

Example 2: Onshore windfarm vulnerability to wind - gearboxes

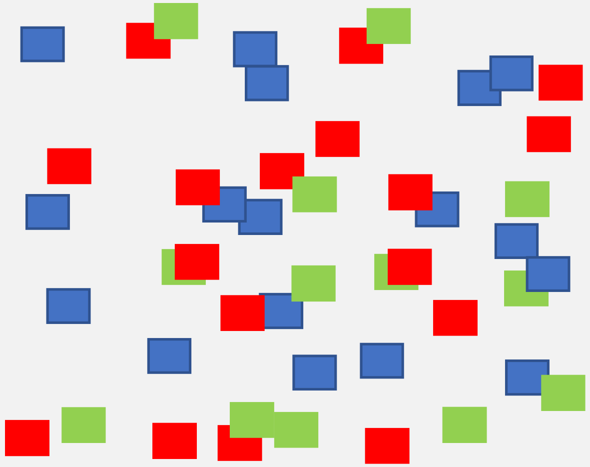
- There are no vulnerability functions for gearboxes in the nacelles of wind turbines
- We are using a Cooke's expert elicitation method to develop vulnerability functions for gearboxes under extreme winds
- Eliciting insurers, loss adjustors*, manufacturers, operators, utility providers
- Challenge: wind farm manufacturers and operators don't recognise wind as a significant hazard!



*Please speak with me if you are interested in being part of the elicitation!

Image care of Harikesan Baskaran, UCL

Barriers to Innovation (1)



- Lack of GOOD vulnerability data for certain asset types, hazards and hazard intensities
- But also too much data that is currently hard to use

Non-ideal hosting

- Scientific papers
- Private databases
- Duplicate effort

Unstructured data

- Uncategorised
- Overlaps
- Data gaps

Lack of standards

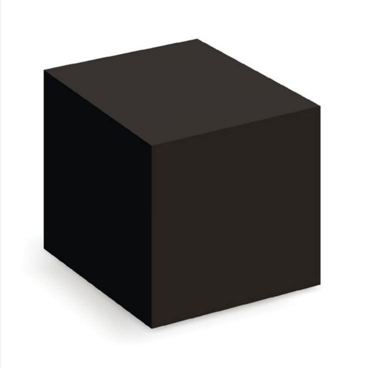
- Nomenclature followed loosely
- Only experts can decipher

Lack of quality control

- Data quality
- Function quality

Barriers to Innovation (2)

- No sharing by risk modellers and insurers of their data and needs with academics
- The regulatory need to use only recognized risk models – which are black box!
- Lack of a recognized QA approach to vulnerability models in industry – let's be honest, this is the fudge factor component
- Looking forwards to discussions!



www.ucl.ac.uk/EPICentre

THANK YOU!

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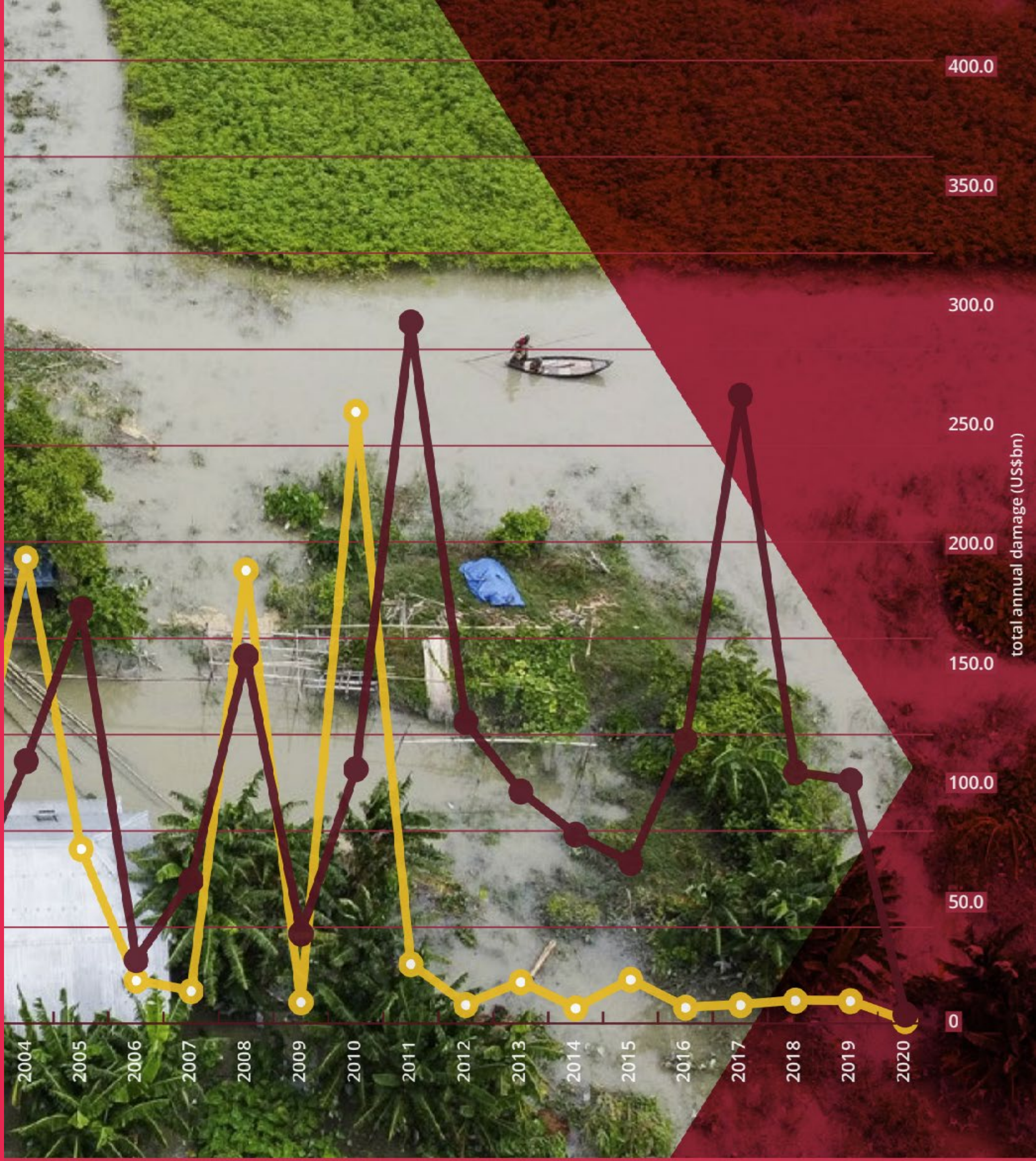
Vulnerability challenges and innovations in the development sector

Oasis Insight Conference - London

1 May 2025

Insurance Development Forum



Topics

- Challenges of assessing and representing vulnerability in development sector projects
- Project examples
  - GRMA Costa Rica
  - World Bank Central Asia
- Opportunities
  - Open data libraries, integration into open modelling
  - Research, collaboration, data sources

Vulnerability challenges in development sector projects

Project requirements

- Often multiple hazards and many different asset types
- Limited budget to develop new vulnerability curves

Understanding risk in generally data-scarce areas

- Absence of damage surveys / claims data to develop and validate local vulnerability information
- Loss data not correlated with damage level (e.g., consistent payment amounts)
- Limited information on local infrastructure and local materials
- Many studies using off-the-shelf curves from the region (or not!) as-is or adjusted to study area
- Often not using models with function sets included

Project example: GRMA Costa Rica

- Regional and national, multiple hazards
- Capability development (capacity building) throughout
- Range of vulnerability approaches used per hazard / asset type
- Sources: regional/national data, engineering judgement, project experience
  - “Locally adapted vulnerability models could improve assessments”
  - Collaborations: national/municipal engineers, Agriculture Ministry, civil protection

Hazard / Exposure	*Buildings*	*Infrastructure*	*Agriculture*	*Livestock*
Earthquake	Vulnerability Function	Component based Vulnerability Function		
River Flood	Component based vulnerability Function	Vulnerability Function	Agronomic crop response model / Vulnerability Function for flood depth	Animal feed model – required vs actual intake
Coastal Flood	Vulnerability Function			
Drought			Agronomic crop response model	Animal feed model
Volcanic Eruption		Vulnerability Function / Binary		
Landslides		Binary Vulnerability		
Tsunami	Vulnerability Function			

Project example: Central Asia
Background

"Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia"

gfdrr.org/en/program/SFRARR-Central-Asia

This project is funded by the European Union

Co-implemented by: GFDRR, World Bank Group, CESDRR ЦЧССРСБ

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Ташкентский государственный транспортный университет

- Regional probabilistic seismic and flood risk analysis, landslide scenarios
- Buildings, infrastructure, population, crops
- Capability development (capacity building) as major component at all stages

Project example: Central Asia
Flood vulnerability with regional variations

-Building-by-building empirical curves

- Accurate but requires empirical studies not feasible at regional scale / many asset types

Observed loss/damage fitting

- Requires a large amount of insurance claims data, which are not available in the target countries.

Curves from literature

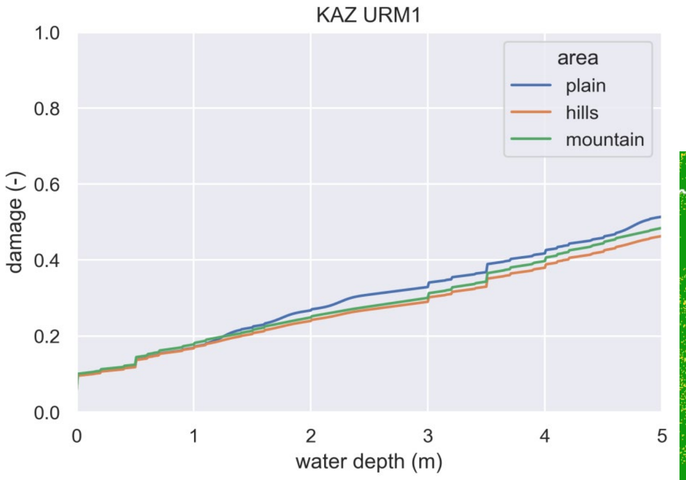
- Defined on generic building typologies, not tailored for the five Central Asia countries (typical situation).

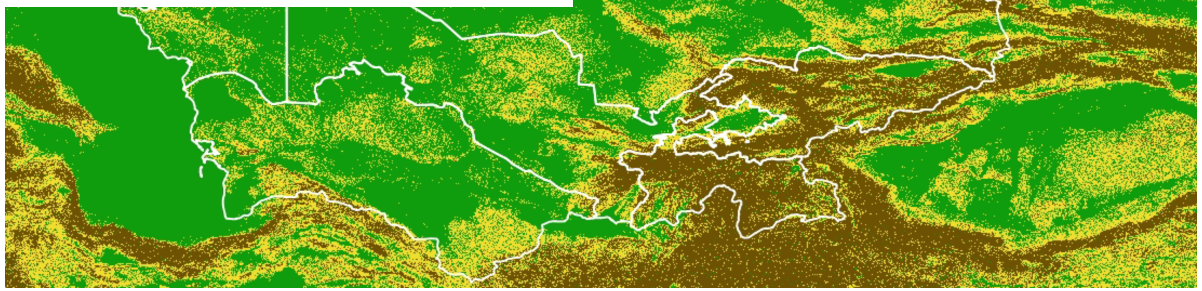
Component-based flood vulnerability models

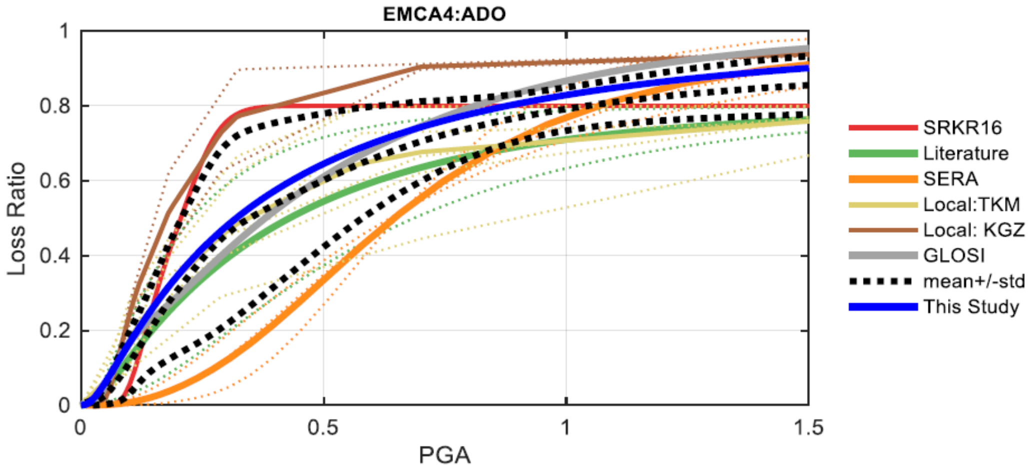
- Vulnerability of components (structural, non-structural, finishing, doors/windows, systems, basement, etc.) defined -> set of curves for each damage component (x 35).
- Combined depending on asset type
- Good for regional studies: can be automatised, flexible depending on asset types and input data.

Project example: Central Asia
Co-development of vulnerability information

- Dedicated workshops: H, E, V, R
  - > 50 people per session – incl. experienced and young engineers, scientists, students
- 4x half-day sessions on vulnerability
- Improve analysis with local expertise + share methods with local experts







- Capture variation in environments in vulnerability: influences duration and velocity
- Based on slope (derived from DEM)

Opportunities

- Efforts to provide greater access to vulnerability curves
  - GEM seismic vulnerability functions public on GitHub, CC-BY-NC licence
  - *OpenVulnerability* catalogue – open curves collated; limited sources but new resource
  - EPICentre: multi-hazard database populated, quality reviews can guide use
  - Open standards for risk metadata
    - Risk Data Library Standard, into World Bank Data Catalog
    - IDF integrating with OASIS; GRMA using open standards

- IDF / Oasis linking to and converting open curves into analysis-ready Oasis LMF files
  - Pull from GitHub, apply in new online modelling workflows

Opportunities

- Ongoing research
    - Vulnerability of specific building types, e.g. Bristol – Nepal schools, Malawi residential
    - Structured assessment of curves that might be suitable from one place to another
- More collaboration with local engineers to innovate at project level
    - Understand asset features, conditions and damage modes via local experience
- Maintained asset inventories
    - Pacific: PCRAFI / SPC asset data standards
    - Coalition for Disaster Resilient Infrastructure (GIRI 2.0)
- Encouraging more post-event (detailed) damage data collection against those inventories