SDGEE
Research Unit of Soil Dynamics and Geotechnical Earthquake Engineering

UGA Université Grenoble Alpes

Evaluation of Systemic Risk and Vulnerability of Critical Infrastructures

Astha Poudel[1,2], Kyriazis Pitilakis[1], Vitor Silva[3]
1) Aristotle University of Thessaloniki, Greece
2) Université Grenoble Alpes, France
3) GEM Foundation, Italy

URBASIS-EU

14.06.2023

Critical Infrastructures

“Assets and systems that are vital for the society, and whose damage or destruction can lead to serious consequences to the health, safety, and socio-economic well-being of the population”

INFRASTRUCTURES ARE AT RISK

Kobe Earthquake

Source: National Geographic
https://education.nationalgeographic.org/resource/kobe-earthquake/

Source: JR East
https://transweb.sjsu.edu/sites/default/files/1225-great-east-japan-earthquake-lessons-for-California-HSR.pdf

- About a million of Kobe's 1.4 million residents lost their electricity, gas and water supplies due to damaged pipes and transmission lines. Underground pipes were so badly damaged that thousands of people were still without gas, three months after the disaster. Phones in twisted and toppled phone booths continued to work.

Source: Facts and Details
https://factsanddetails.com/japan/cat26/sub160/item863.html

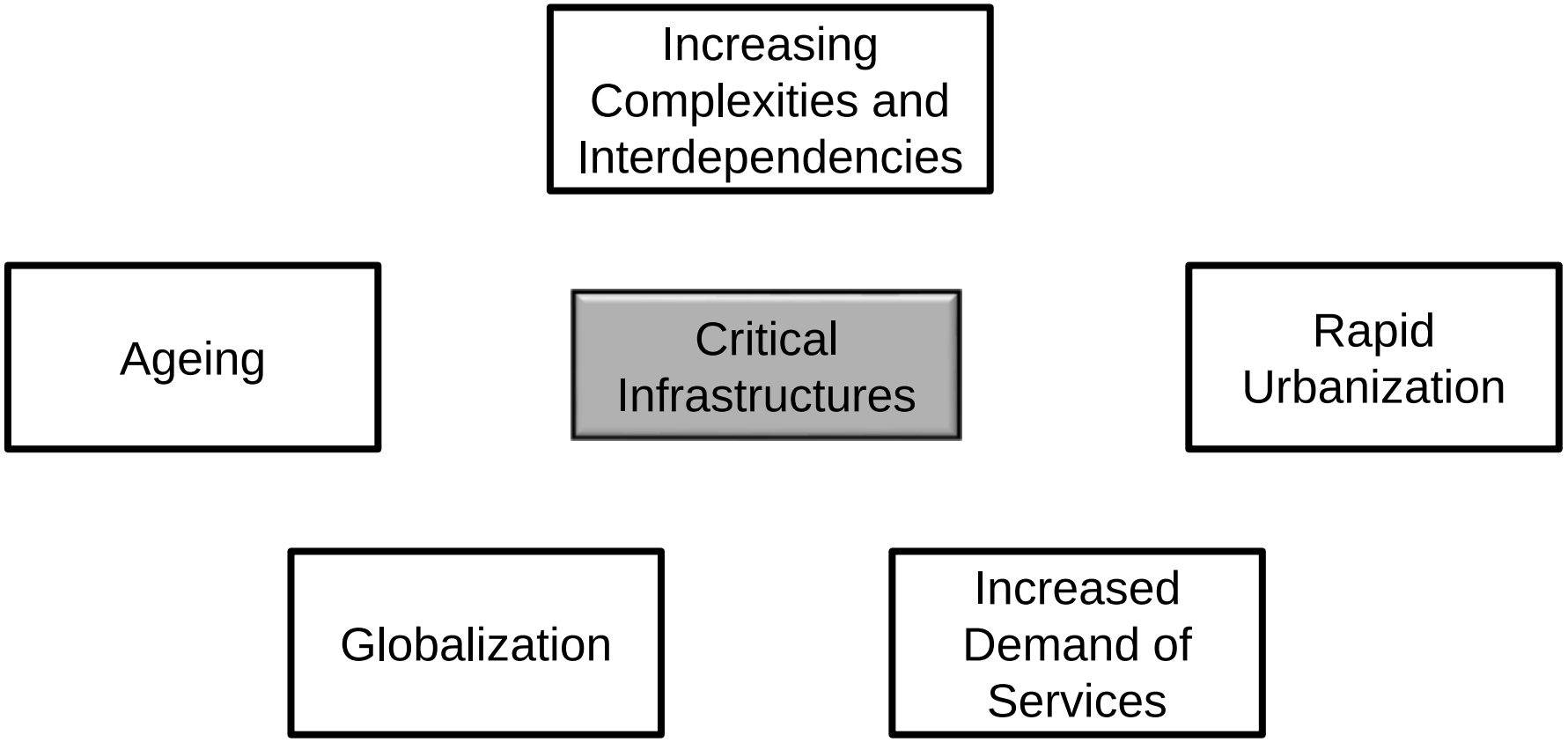
Christchurch Earthquake




Source: Eidinger and Tang (2012)

Kumamoto Earthquake

Source: Moya et al 2020


Increasing Complexities and Interdependencies
Ageing
Critical Infrastructures
Rapid Urbanization
Globalization
Increased Demand of Services

If infrastructure risk assessment is so important, why is it still limited in risk assessment studies around the globe???

I tell you why…….

- Complexity of the system behavior that infrastructures possess
- Paucity and heterogeneity of the data, methods and metrics to properly characterize the system
- Insufficient knowledge about the relation between the different components and systems
- Lack of open source globally used tool that gives common platform from hazard modelling to infrastructure risk assessment at system level

Implementation of infrastructure risk to contemporary open tool - OpenQuake

Poudel A, Pitilakis K, Silva V, Rao A (2023) Infrastructure Seismic Risk Assessment: An Overview and Integration to Contemporary Open Tool Towards Global Usage, Bulletin of Earthquake Engineering, doi.org/10.1007/s10518-023-01693-z

Incorporation of Infrastructure Risk to OPENQUAKE: Prospect towards Global Usage

OpenQuake as contemporary, globally used, widely accepted, open tool

OpenQuake, so far, already possess a large hazard library with maximum number of GMPEs and has strong foundation to compute risk and vulnerability of the buildings which are the essential part of the built environment

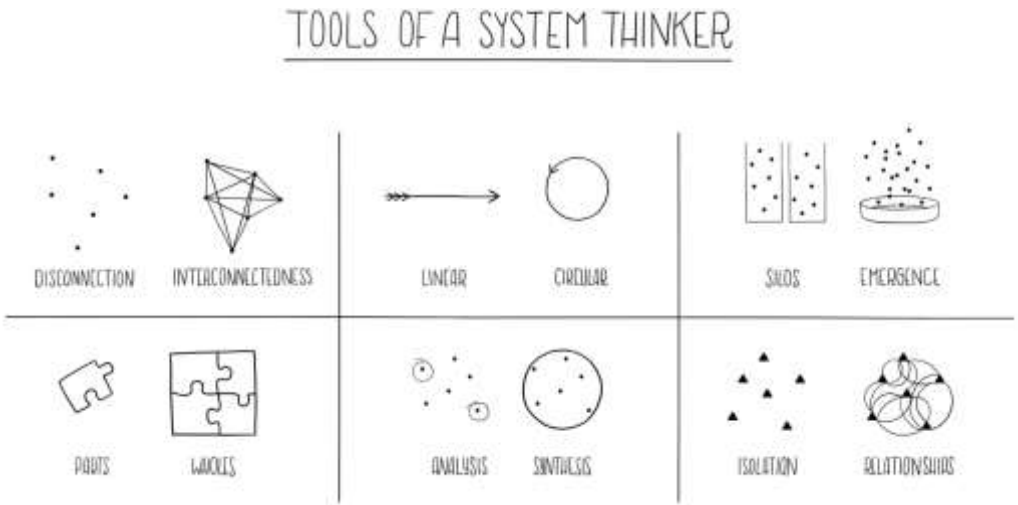
Combination of the capabilities of this powerful platform with infrastructure risk assessment is expected to gain wide and extensive application around the globe

Better mitigation plans or recovery models for COMMUNITY RESILIENCE

INFRASTRUCTURES BEHAVE AS A SYSTEM

Systemic Approach

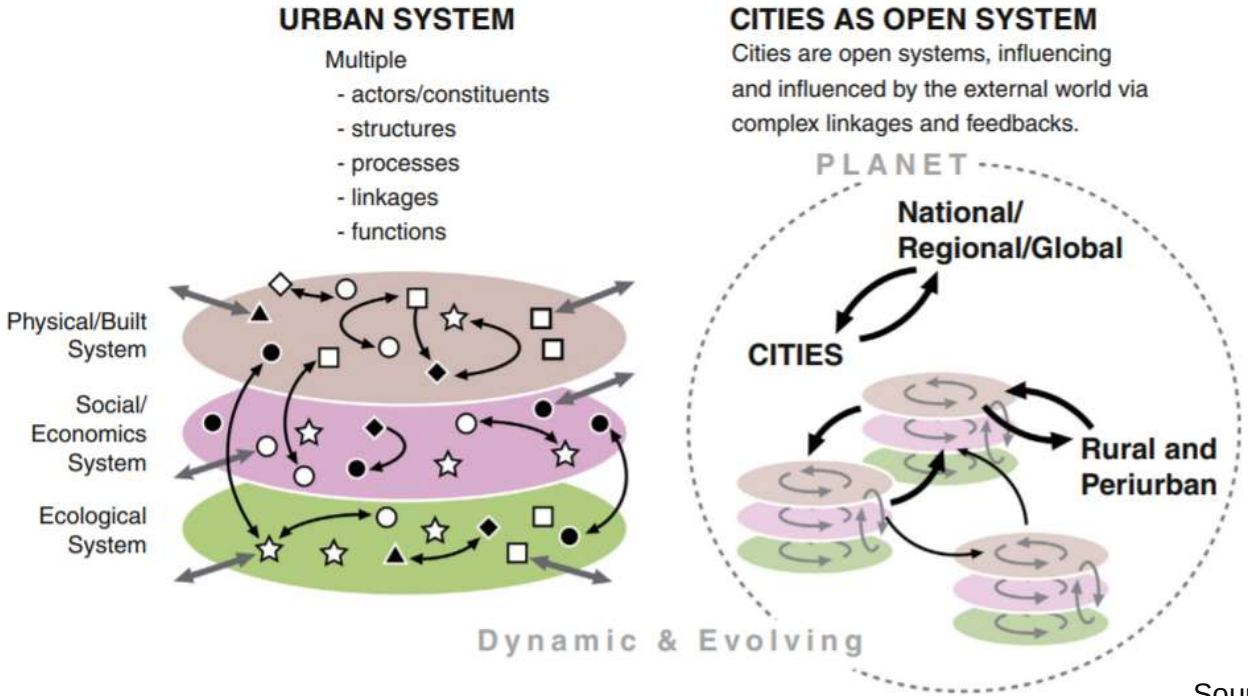
SYSTEMIC>>Relating or effecting the whole of a system rather than some parts of it



Source: Tools for system thinkers (Leyla Acaroglu)

https://www.leylaacaroglu.com/writing-by-leyla//tools-for-systems-thinkers-the-6-fundamental-concepts-of-systems-thinking

Urban system (Structure and Interlinkages)



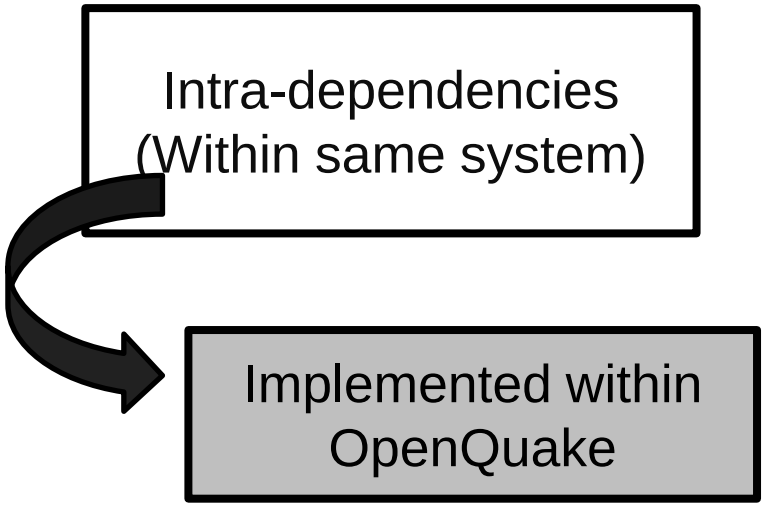
Source: Bai et.al (2016)

Systemic Approach

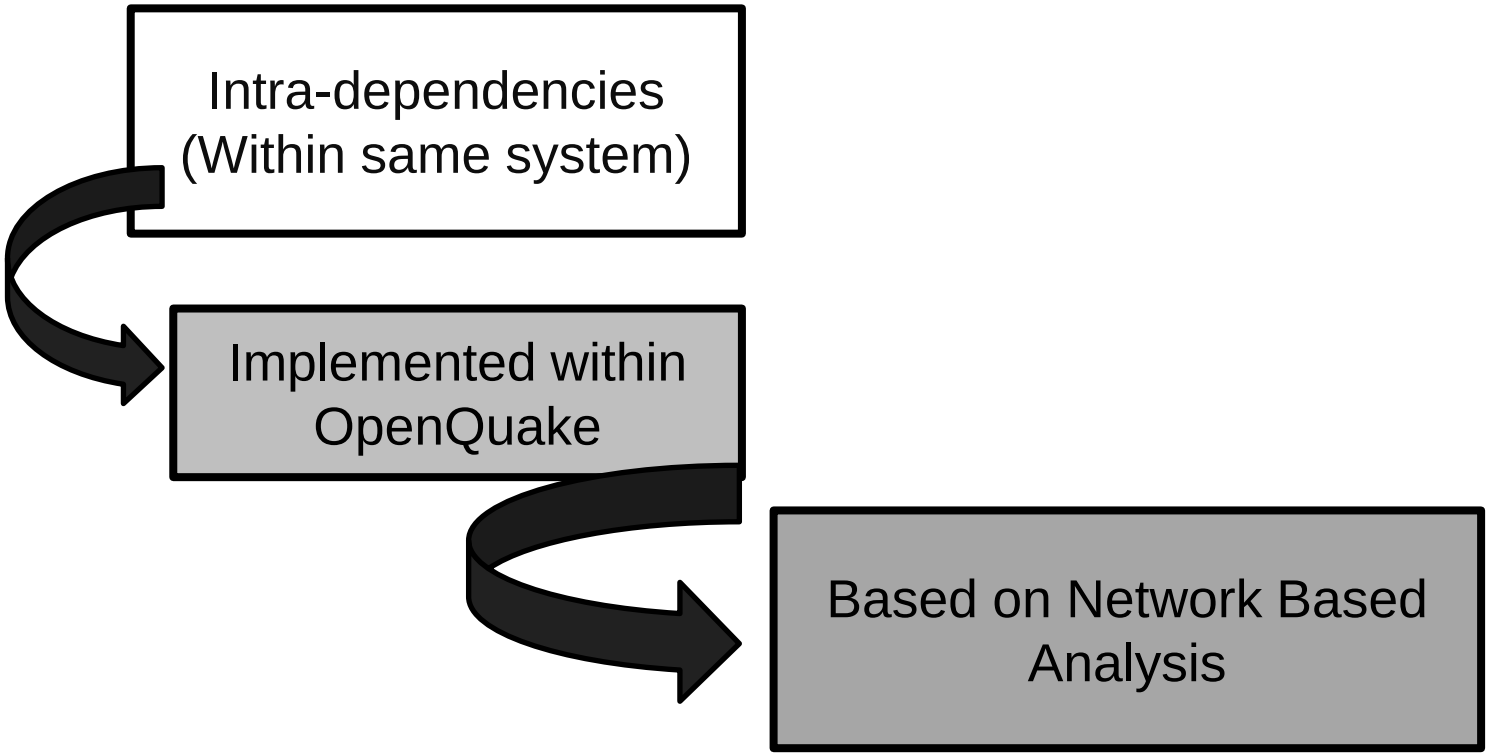
Intra-dependencies
(Within same system)

Inter-dependencies
(Between different systems)

Systemic Approach



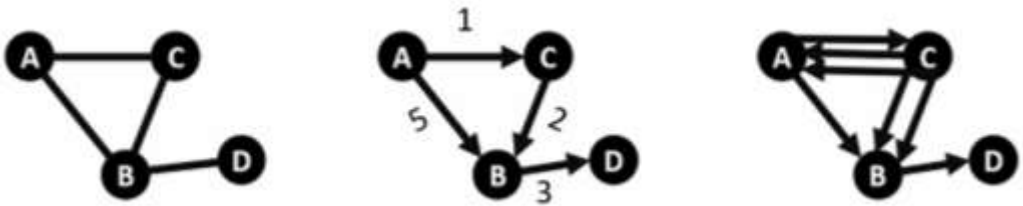
Systemic Approach



Network Based Analysis

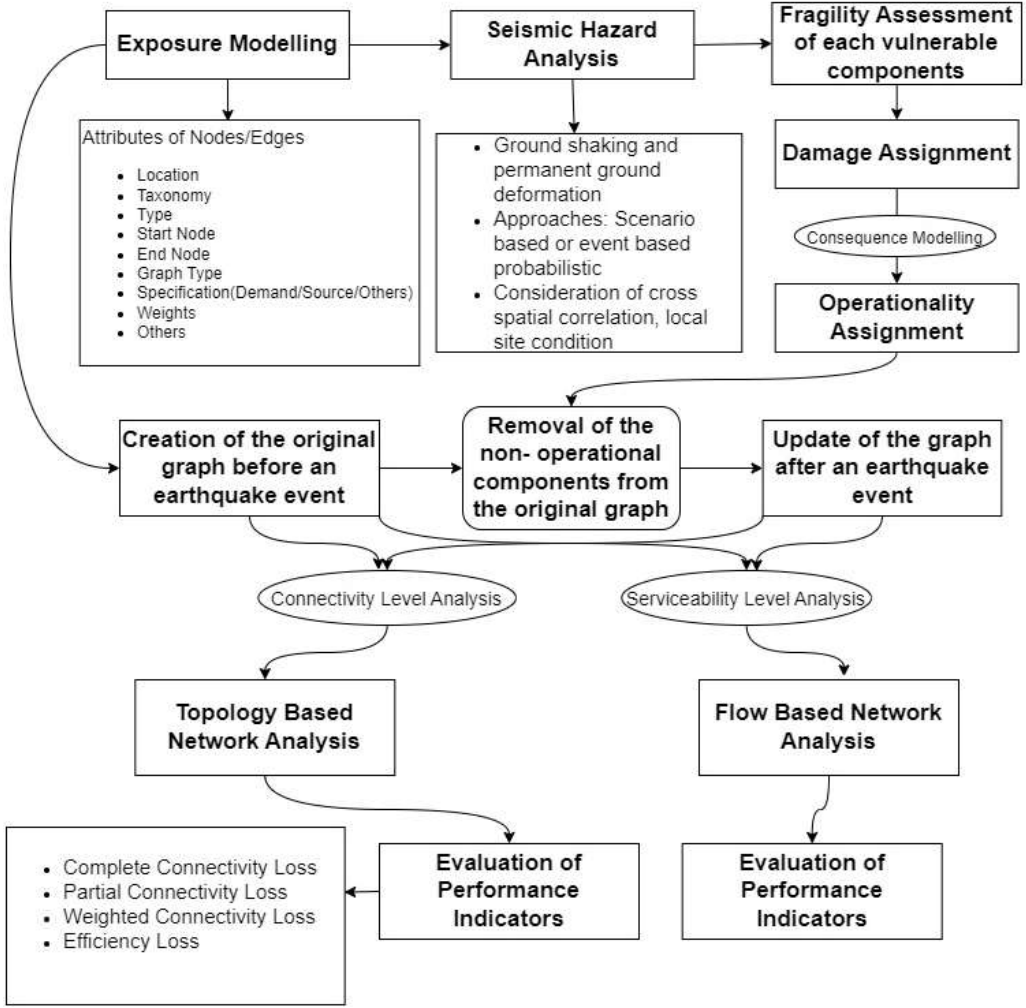
- Network-based analysis refers to the process of analyzing and studying complex systems using the framework of networks or graphs

- Graph is a composition of a set of nodes or vertices connected by edges or links.



Abstract Representation and Spatial Characterization of Infrastructure System

Infrastructure Risk Assessment (Methodological Framework)



Performance Indicators

Complete Connectivity Loss

- Quantifies the total loss of connection of demand nodes to source nodes
- Helpful to identify the worst-case scenario when the nodes could be completely isolated
- For example, identifying a settlement which will not have any access to hospitals or identify schools with no water supply at all after an earthquake event

Partial Connectivity Loss

- Quantifies the reduction of the redundancies of demand nodes with respect to the number of sources it is connected
- Measures the average reduction in the ability of demand nodes to receive flow from services
- Indirectly gives an insight of the quality of the service to each node too

Weighted Connectivity Loss

- Complements the partial connectivity loss by including the weights to the edges
- For example, beneficial in dense urban road where the distance covered, travel time is more crucial as complete connectivity loss might be rare

Efficiency Loss

- Popular metrics in network analysis that can handle all types of graphs
- Beneficial when distinguishing between demand and supply is difficult or incase of sparse data

Illustrative Example

(Case Study of Thessaloniki)

Case Study: Water Supply System of Thessaloniki

Scenario Based Seismic Hazard Analysis

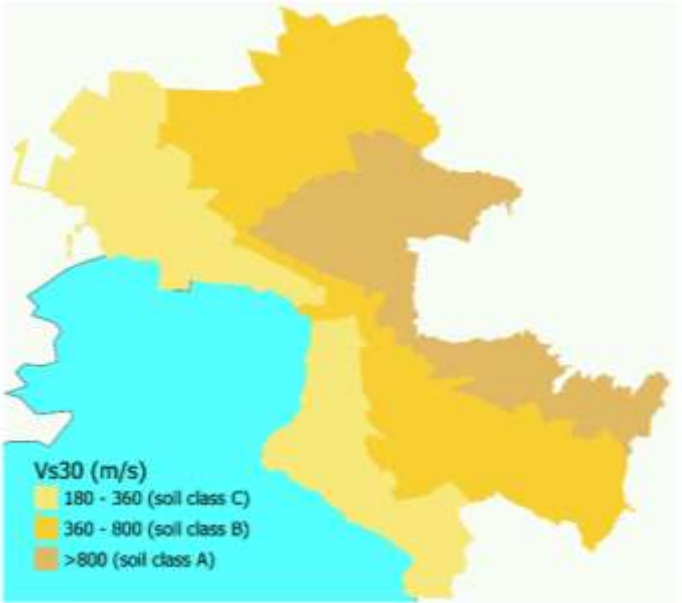
1978 Thessaloniki Earthquake considered for Scenario-based approach [Mw=6.5, R=20km]

Observed Damage for Buildings Portfolio	
Color Tag	**Post Earthquake Tagging (%)**
Green	74.50
Yellow	19.10
Red	6.40

Source: Kappos et al 2008, Riga et al 2021

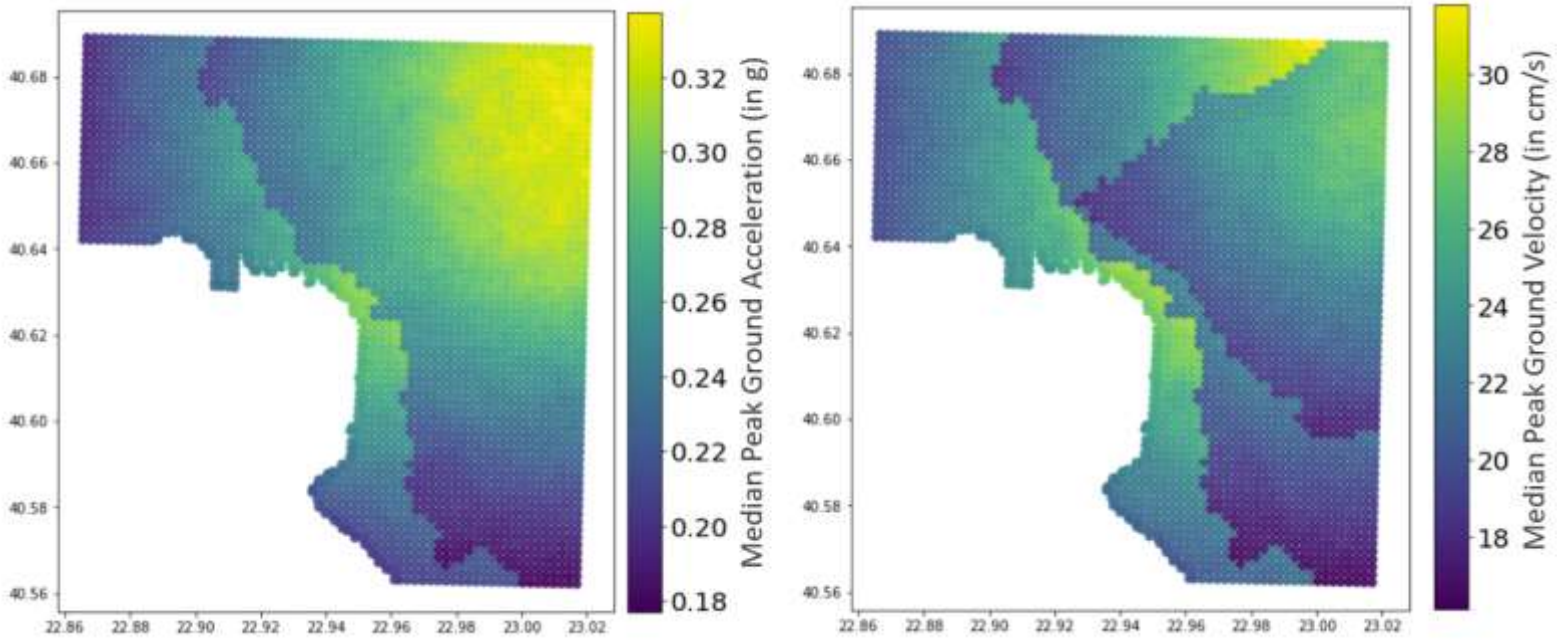
Scenario Based Seismic Hazard Analysis

- 6.5 Mw 1978 Thessaloniki earthquake
- Earthquake rupture>>Fault rupture model by Roumelioti et al 2007
- GMPE model for active shallow crustal regions >>Akkar & Bommer 2010
- Local soil conditions>> Microzonation study >>Anastasiadis et al 2001

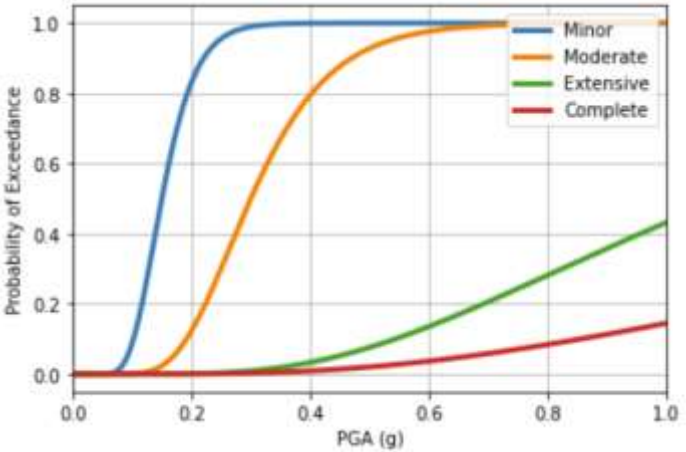


Spatial distribution of Vs30 models of Thessaloniki according to measured values

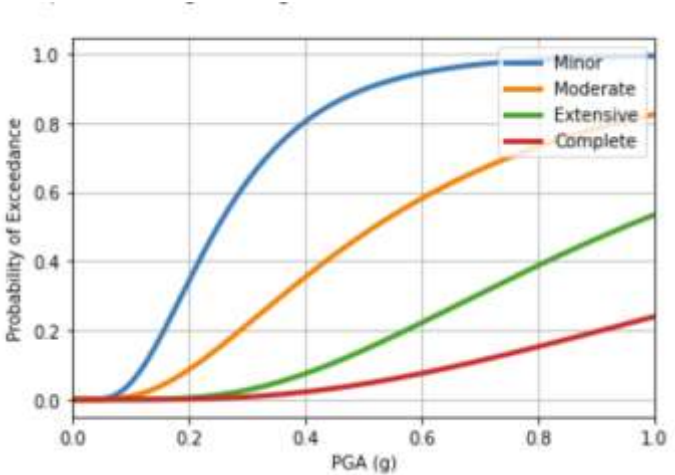
Scenario Based : Seismic Hazard Analysis



Representative Fragility Curves



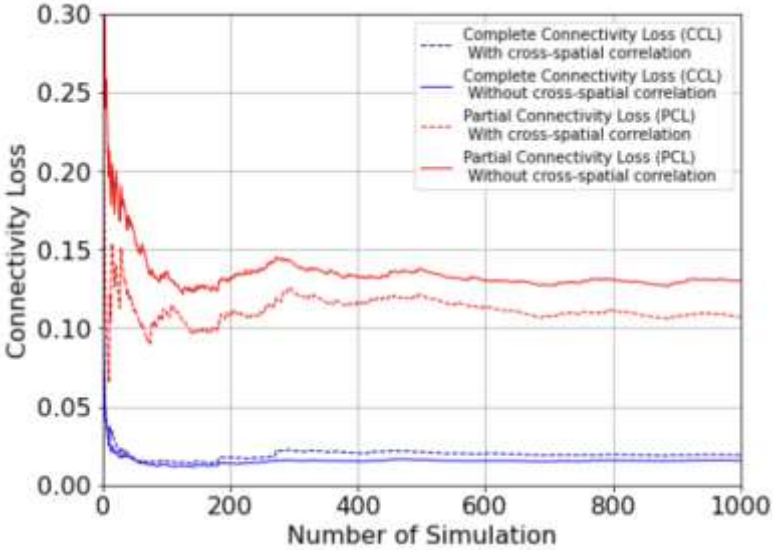
Fragility Curves for Pumping Stations (SRM-LIFE 2007)



Fragility Curves for Tanks (HAZUS)

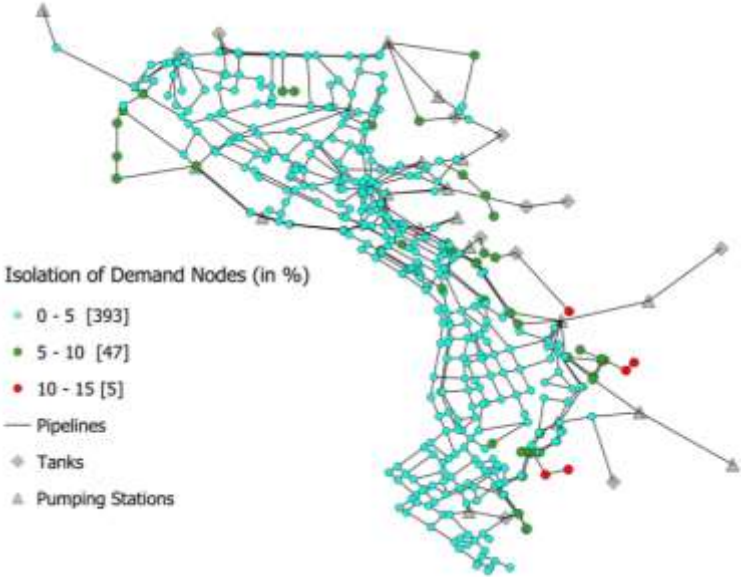
Pipelines: ALA(2001)

Results

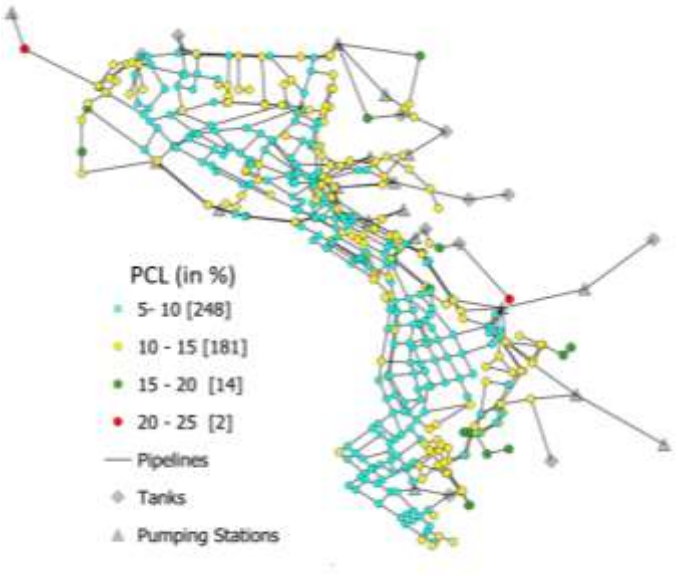


Scenario based analysis: Moving average for complete connectivity loss (CCL) and partial connectivity loss (PCL)

Results: At Nodal Level

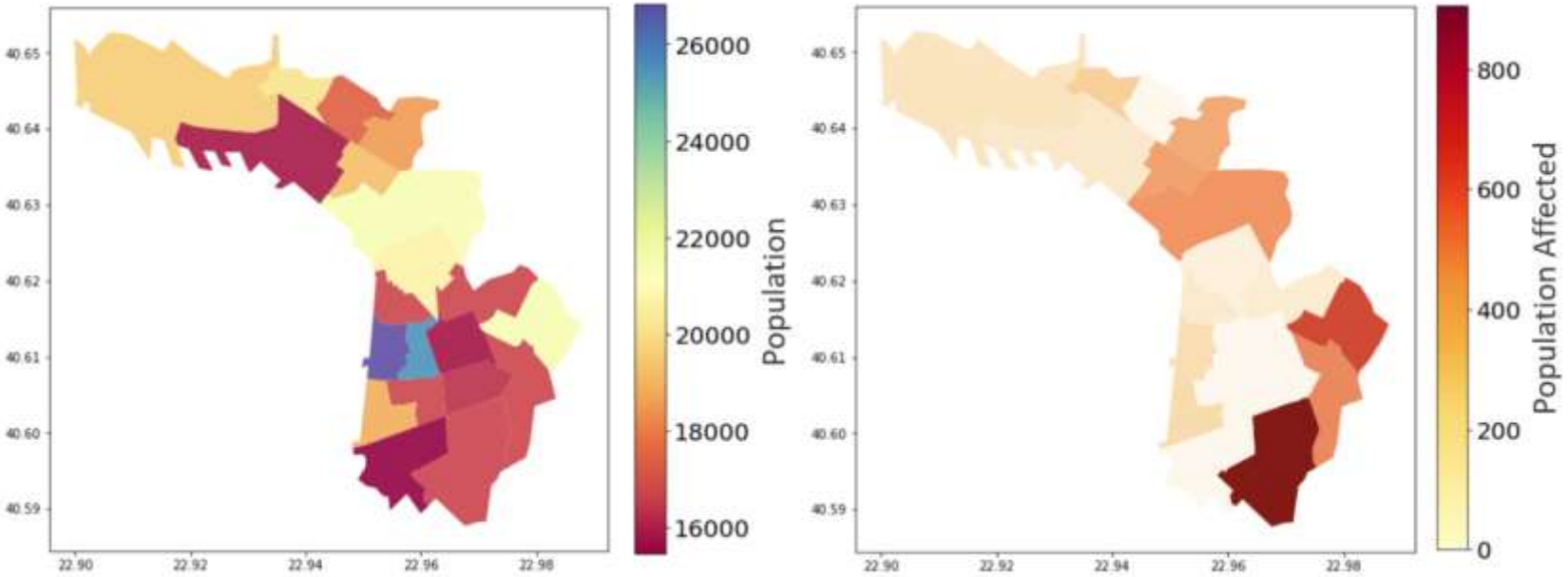


Isolation of each demand nodes for the scenario-based analysis



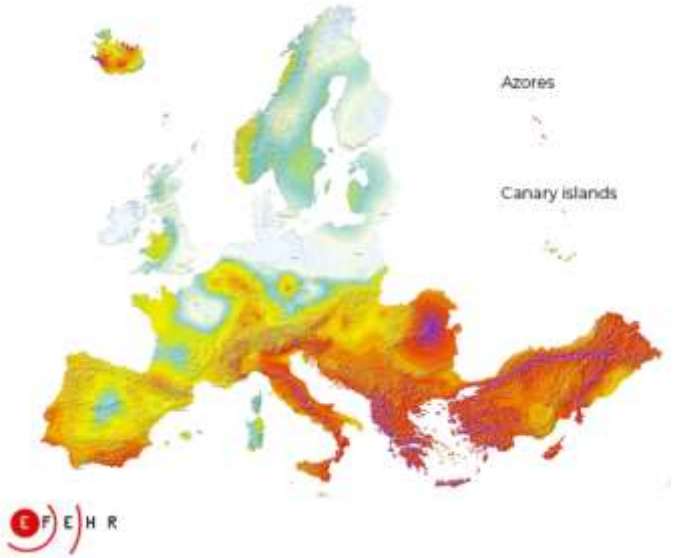
Partial connectivity loss (PCL) of each demand node considering scenario-based analysis

Population Affected



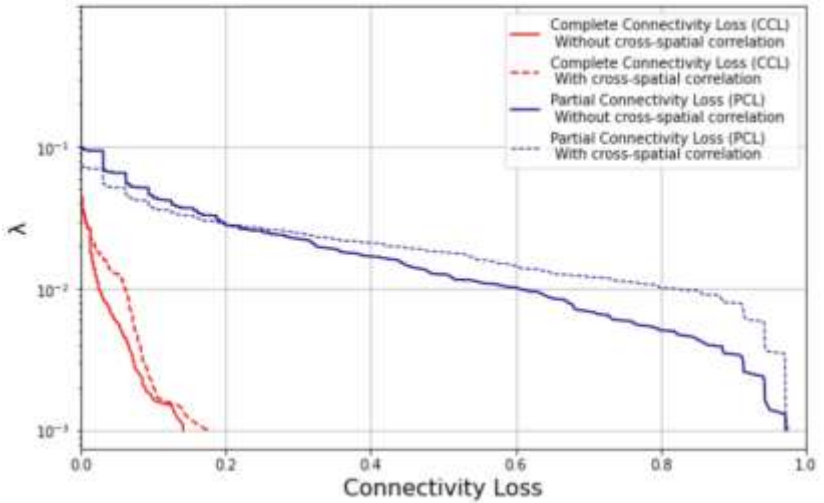
Population map at district level (left), Population affected with complete loss of water supply according to complete connectivity loss (CCL) considering scenario-based analysis at district level (right)

Event based Probabilistic Seismic Hazard Analysis



ESHM20 Hazard Model

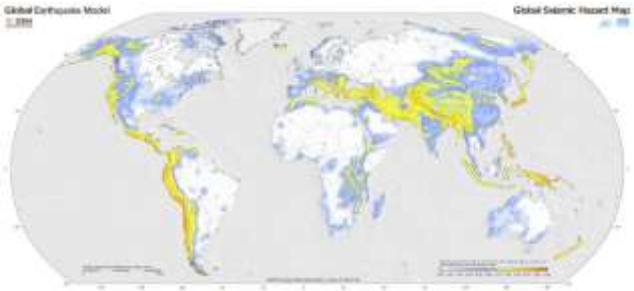
Source: Danciu et al. 2021



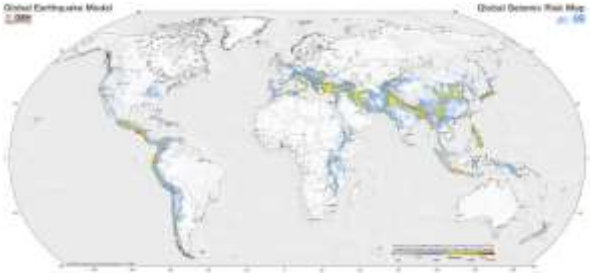
Mean Annual Frequency (MAF) curve for complete connectivity loss (CCL) and partial connectivity loss (PCL)

Some Final Thoughts ……

- Even though our infrastructures are at risk whose damage can lead to greater consequences, infrastructure risk assessment is still limited to only some places of a few countries!!
- Even at component level, the fragility curves are limited!!
- With the prospect of global usage, initiation of implementing infrastructure risk to OpenQuake has been carried out
- As our infrastructures are more and more interdependent, systemic approach considering different system would be the next step
- Infrastructure risk should be kept at higher priority by different stakeholders!!



Global Seismic Hazard Map



Global Seismic Risk Map

???

Global Seismic Infrastructure Risk Map (???)

https://www.globalquakemodel.org/gem-maps

Thank You
ευχαριστώ
धन्यवाद

apoudel@civil.auth.gr