SAPIENZA
UNIVERSITÀ DI ROMA

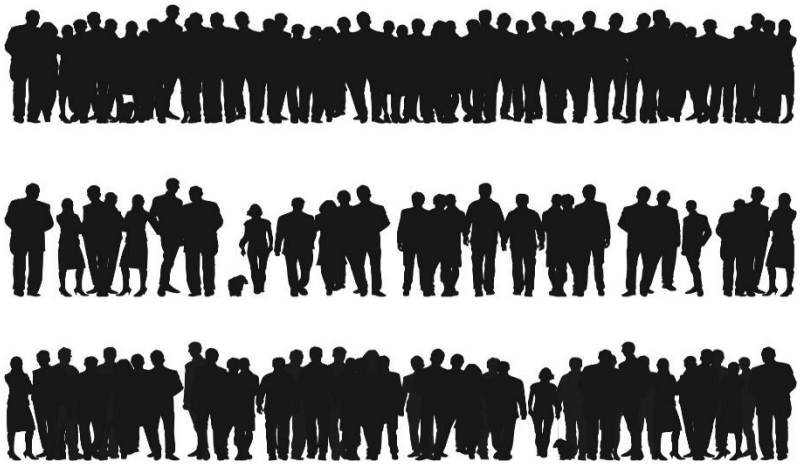
THESSALONIKI
16TH EUROPEAN CONFERENCE ON
EARTHQUAKE
ENGINEERING
18 - 21 JUNE 2018
www.16ecee.org

Research needs towards resilient communities

Paolo Franchin

2018, June 18th – Thessaloniki, Greece

Community



People → Infrastructure

Users → **System**

Engineering → **System**

Obstacles to achieving resilience

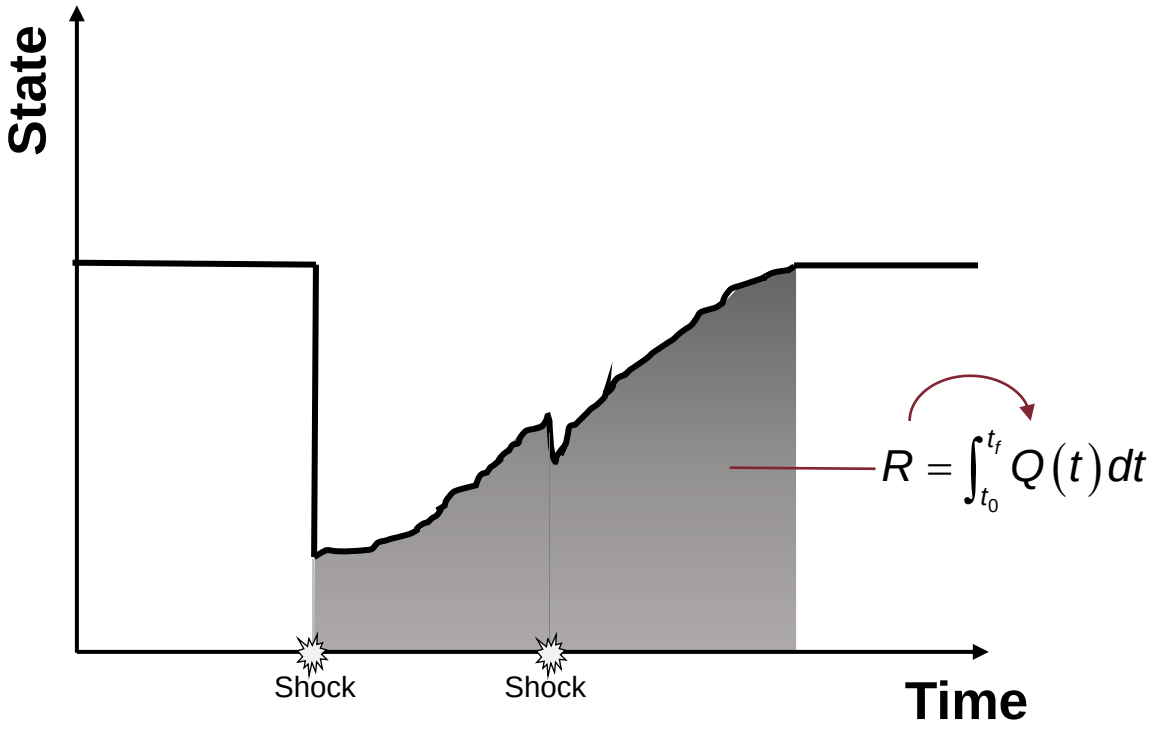
Political, economical, cultural

Methods, tools (quantitative)

Research needs

Resilience

Resilience is difficult to quantify because it is a systemic metric...

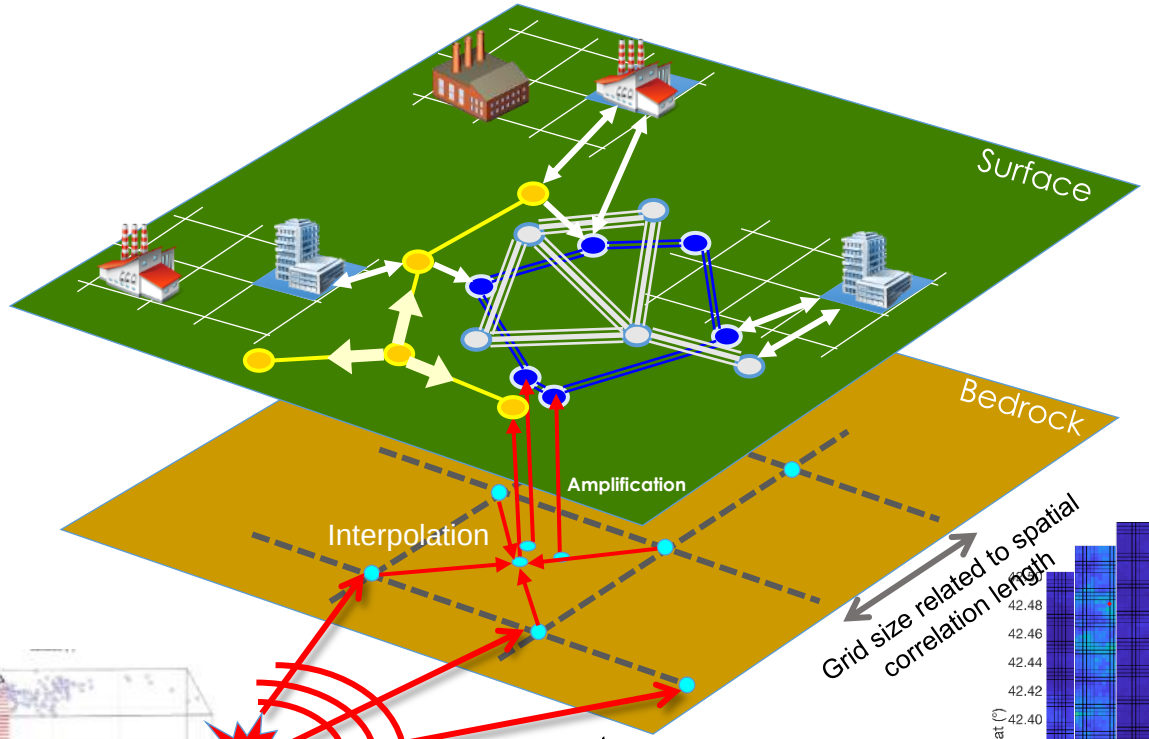


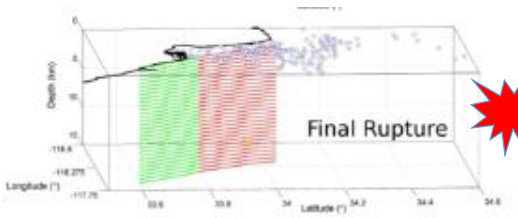
(Bruneau et al 2003)

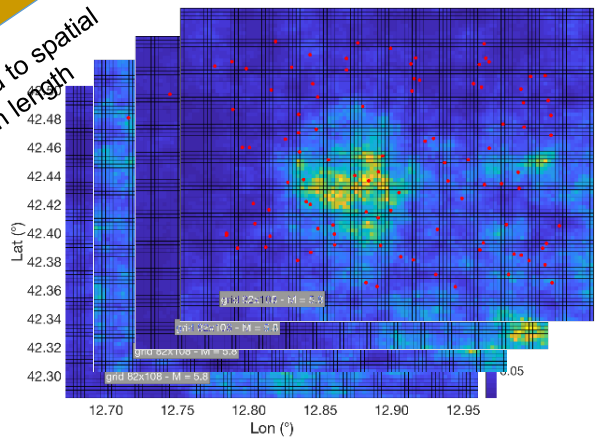
System

Resilience is difficult to quantify because it is a systemic metric...

…and system is complex





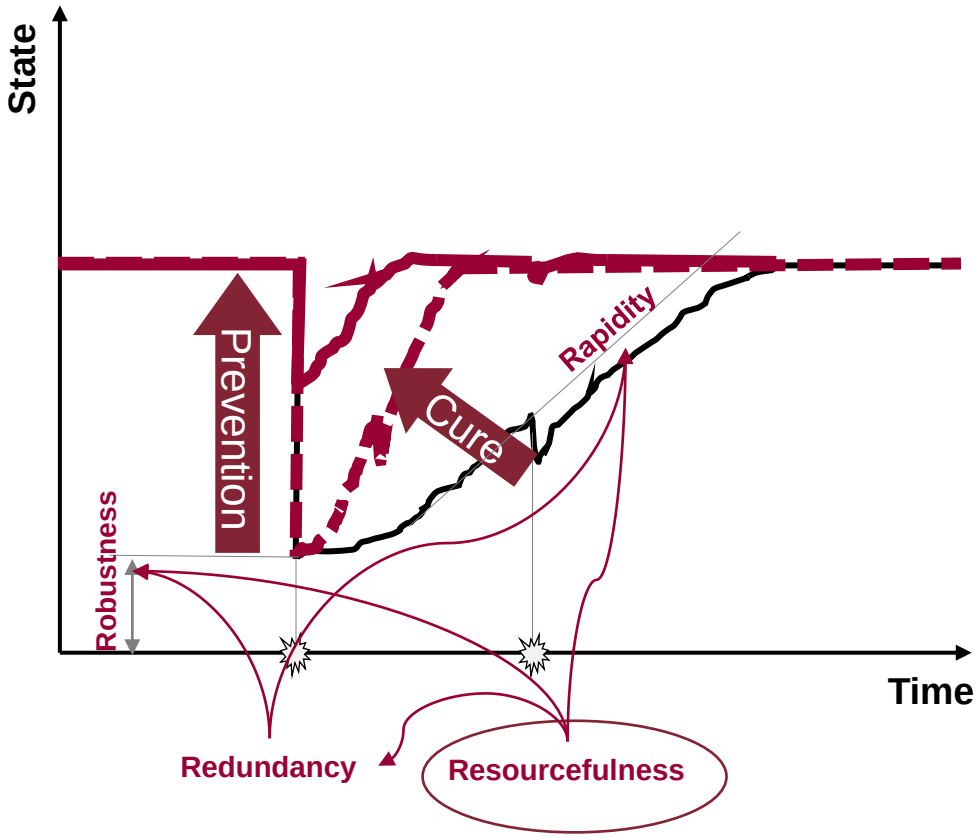


(Franchin 2014)(SYNERG, 2009-2013)

Resilience assessment → Resilience design

Assessing resilience is a difficult task,
Designing/building it into the system is even more

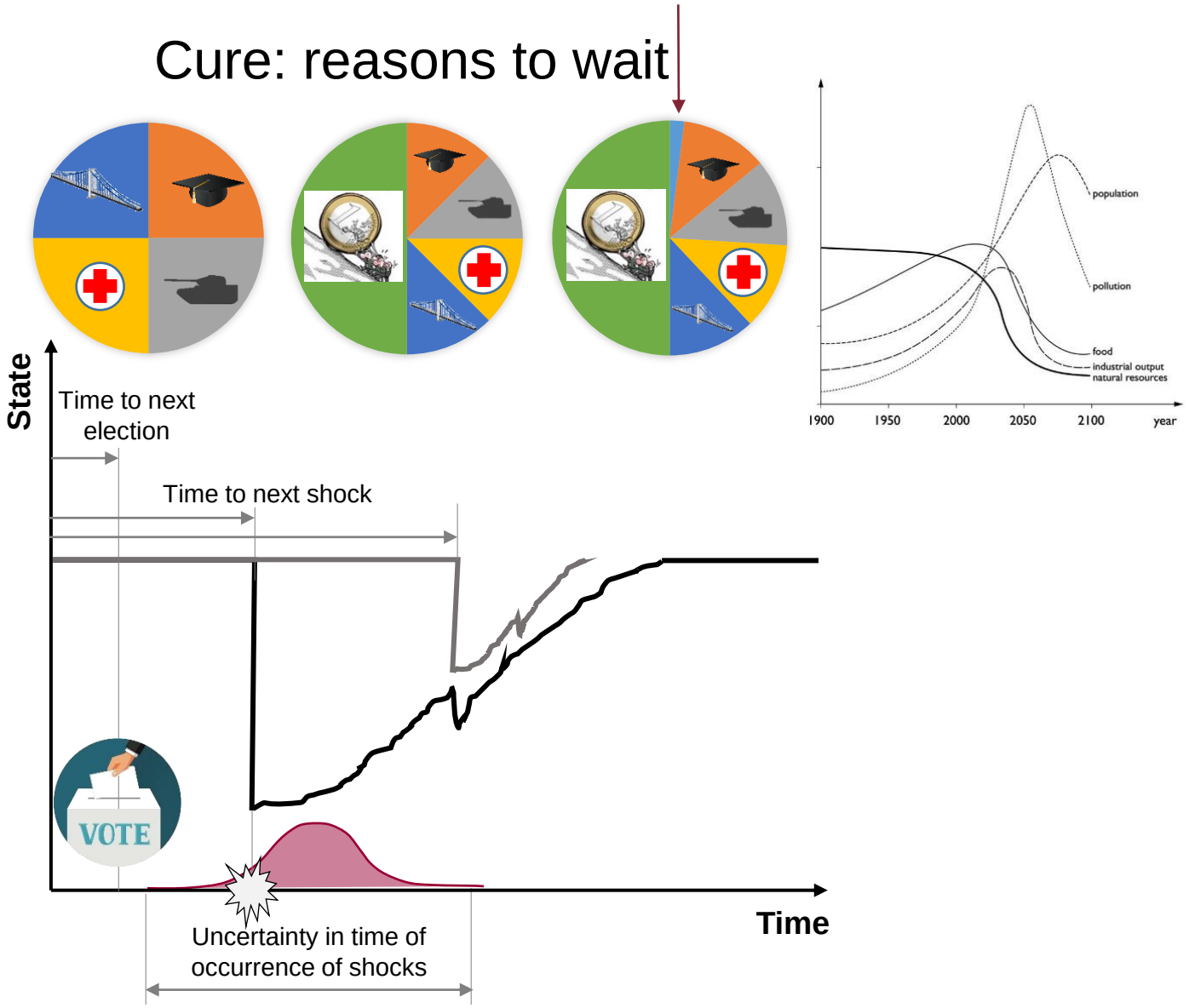
Two, non mutually exclusive strategies to invest resources



(Bruneau et al 2003)

Prevention or cure?

Cure: reasons to wait



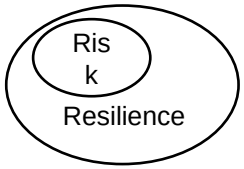
(Meadows et al 2004)

Prevention or cure?

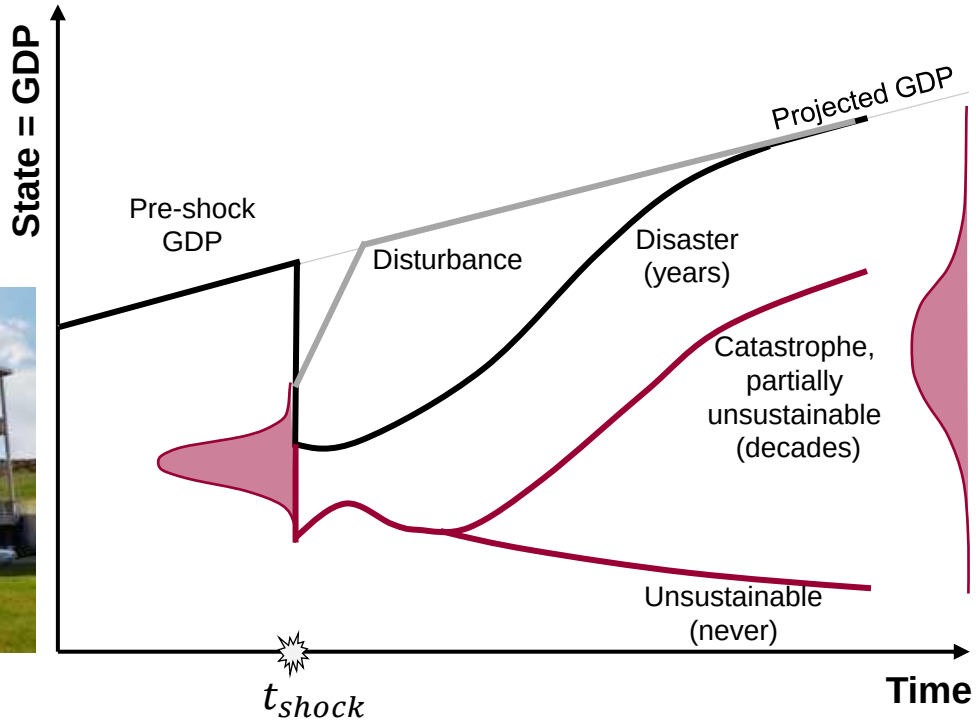
In praise of prevention

Uncertainty for $t > t_{shock}$ much larger

What if the shock is TOO LARGE?
Preventing the loss may be the only way

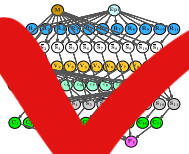


(Zio 2018)

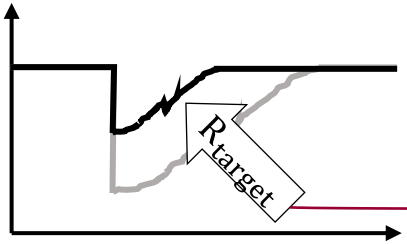


(Davis 2014)

Research needs



Decision Support System
Using system simulation to inform decision making



Resilience

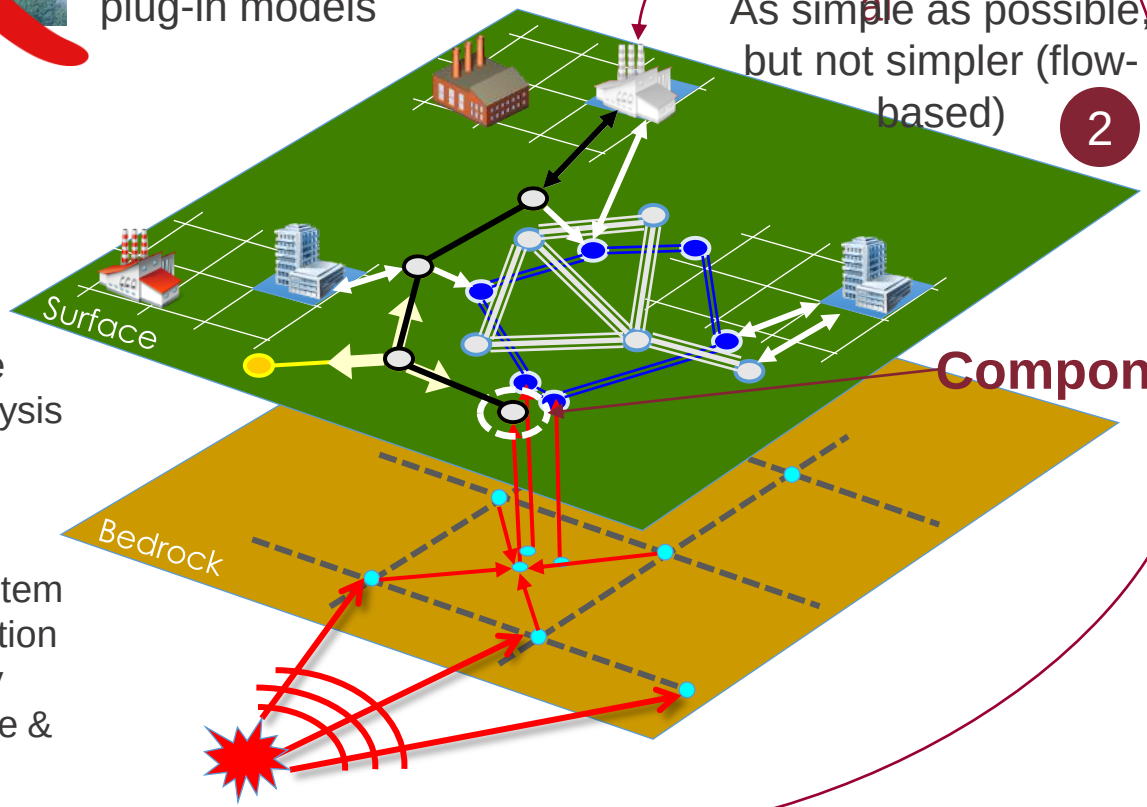
Resilience-based design (RBD) 1

Validation
Sensitivity to plug-in models

System|Consequences

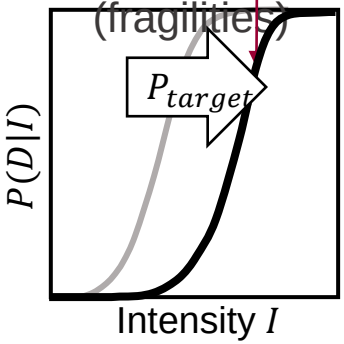
Physical/Function

As simple as possible, but not simpler (flow-based) 2



Component|Damage

3 Improve surrogate models (fragilities)



Hazard

Simulation at the base of risk analysis since the '70s because:

- Rare events
- Complex system
- Experimentation economically unsustainable & physically infeasible

+

Unprecedented

1: Resilience-based design

Resilience-based design: $R \rightarrow P$

i.e. Performance-based design with resilience-based targets

The question is how safe is safe enough?

Codes started with life safety, they're moving to damage control, will they end up with community resilience?

(Bisch 2015-18)

Resilience-based design: $R \rightarrow P$

Nuclear Power Plant

System level

Undesired outcome

Core damage

Radioactivity release

Vital plant functions

Reactivity control

Fuel cooling

Confinement

Frontline systems

Containment spray system

Support systems

Water

Electrical

TOP-DOWN

Component or sub-system level

Community

System level

Undesired outcome

Outmigration

Vital community functions

Housing

Employment

Education

Public services

Primary systems (bldgs)

Residen

Offices

Factories

Schools

Hospitals

Secondary systems (lifelines)

Water

Waste

Energy

Commun ication

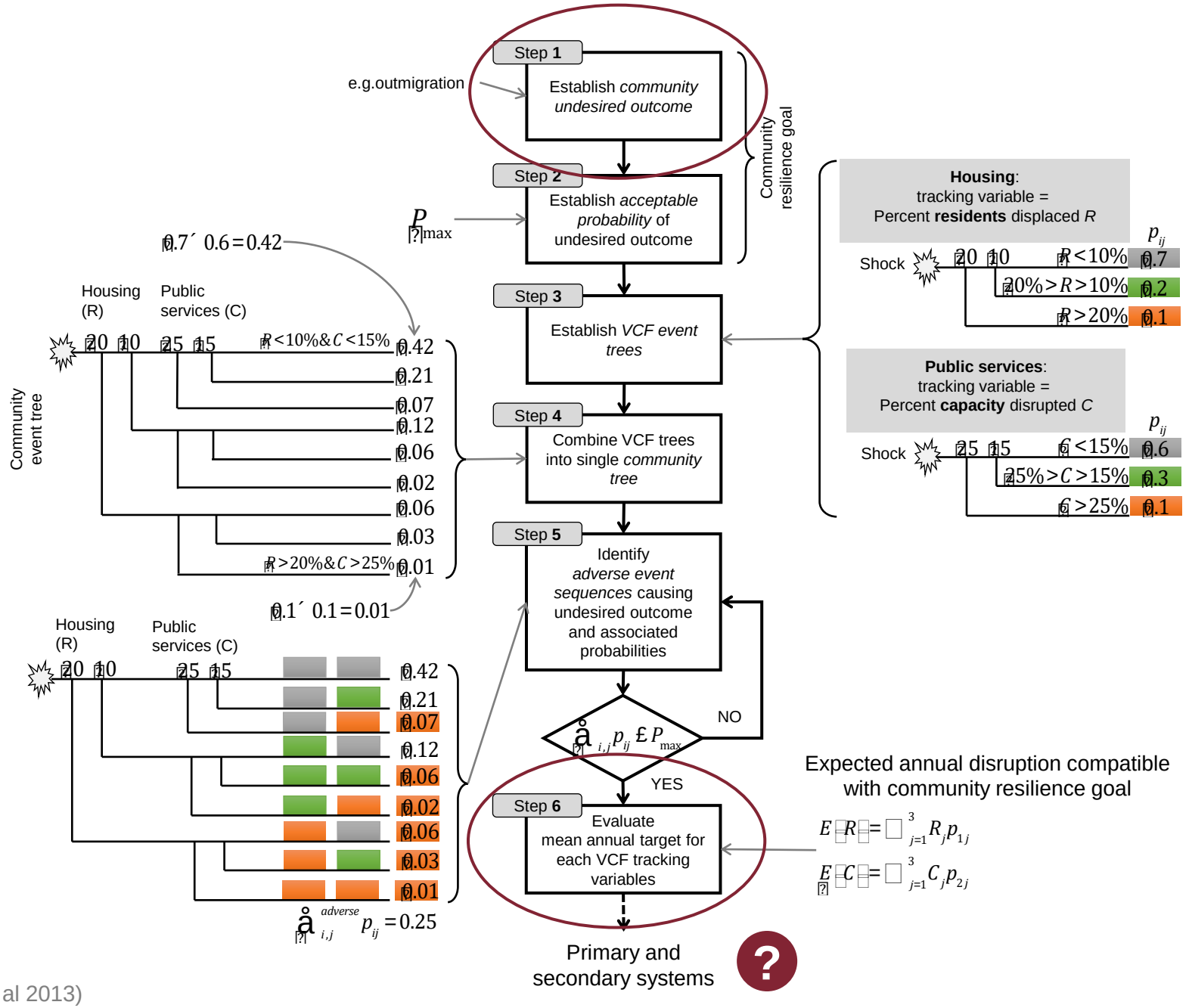
Transport

BOTTOM-UP

Component or sub-system level

(Mieler et al 2013)

Resilience-based design: $R \rightarrow P$



(Mieler et al 2013)

Resilience-based design: $R \rightarrow P$

Systemic analysis can fill this gap

Resilience-based performance target for a **new hospital**

Hospital ∈ Health-Care System ∈ Public Services VCF

Service importance matrix (1×n)

$\mathbf{I}_{service}$

	Service: Police	Health-care	Food
Public services	0.3	0.3	0.4

System importance matrix (n×m)

$\mathbf{I}_{system}$

		Systems: Primary: Police stations	Hospitals	Stores	Secondary: Water	Electric power	Fuel (oil)	Roads
Services	Police	0.4				0.2	0.2	0.2
	Health-care		0.5		0.1	0.2	0.1	0.1
	Food			0.5	0.1	0.1	0.1	0.2

$$D_{VCF} = \underbrace{\mathbf{I}_{service}}_{1\times n}\ \underbrace{\mathbf{I}_{system}}_{n\times m}\ \underbrace{\mathbf{D}_{system}}_{m\times 1} = \mathbf{I}_{service}\begin{bmatrix}\mathbf{I}_{system,1} & \mathbf{I}_{system,2}\end{bmatrix}\begin{bmatrix}D_{system,1}\\ \mathbf{D}_{system,2}\end{bmatrix} =$$

New hospital tolerable disruption (unknown)

$$= \underbrace{\mathbf{I}_{service}}_{1\times n}\ \underbrace{\mathbf{I}_{system,1}}_{n\times(m-1)}\ \underbrace{D_{system,1}}_{1\times 1} + \underbrace{\mathbf{I}_{service}}_{1\times n}\ \underbrace{\mathbf{I}_{system,2}}_{n\times(m-1)}\ \underbrace{\mathbf{D}_{system,2}}_{(m-1)\times 1}$$

Disruption to existing Buildings and lifelines (**from systemic analysis!**)

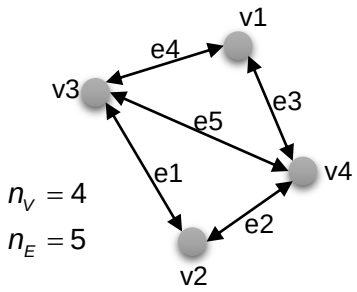
$$D_{system,1} = \frac{D_{VCF} - \mathbf{I}_{service}\mathbf{I}_{system,2}\mathbf{D}_{system,2}}{\mathbf{I}_{service}\mathbf{I}_{system,1}}$$

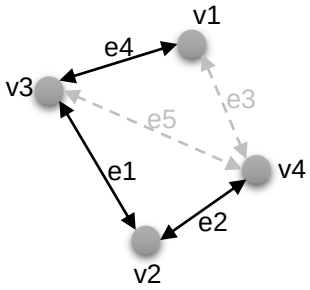
Still just an idea

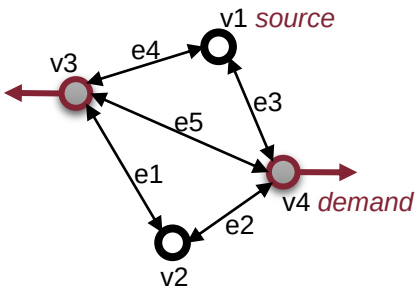
$$P_C = 2 \times 10^{-4} \div 10^{-5} 2$$

2: System model

System functional model







$$n_V = n_S + n_D$$

$$\underset{n_v \times n_v}{\mathbf{A}} = \begin{bmatrix} 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

$$\underset{n_e \times n_v}{\mathbf{I}} = \begin{bmatrix} 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$$

$$\underset{n_e \times n_v}{\mathbf{I}^*} = \left[\begin{array}{cc|cc} 0 & -1 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ -1 & 0 & 0 & 1 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 \end{array}\right] = \left[\begin{array}{c|c} \underset{n_e \times n_S}{\mathbf{I}^*_S} & \underset{n_e \times n_D}{\mathbf{I}^*_D} \end{array}\right]$$

$\underset{n_e \times 1}{\mathbf{q}}$ edge flows

$\underset{n_D \times 1}{\mathbf{Q}}$ node demands

$Q_i = 0$ if junction

Balance (flow continuity at nodes) $\mathbf{I}_D^{*T}\mathbf{q} - \mathbf{Q} = \mathbf{0}$

Resistance (line loss) $\Delta\mathbf{h} - \mathbf{r}(\mathbf{q}) = \left(\mathbf{I}_S^*\mathbf{h}_S + \mathbf{I}_D^*\mathbf{h}_D\right) - \mathbf{r}(\mathbf{q}) = \mathbf{0}$ with $\mathbf{r}(\mathbf{q}) = \mathbf{R}\mathbf{q} \circ |\mathbf{q}|$

Assessment problem, not design!

Head driven — Additional demands

$$\begin{cases} \mathbf{I}_D^{*T}\mathbf{q} - \mathbf{Q}\left(\mathbf{h}_D\right) - \mathbf{Q}_{seismic}\left(\mathbf{h}_D\right) = \mathbf{0} \\ \left(\mathbf{I}_S^*\mathbf{h}_S + \mathbf{I}_D^*\mathbf{h}_D\right) - \mathbf{r}(\mathbf{q}) = \mathbf{0} \end{cases}$$

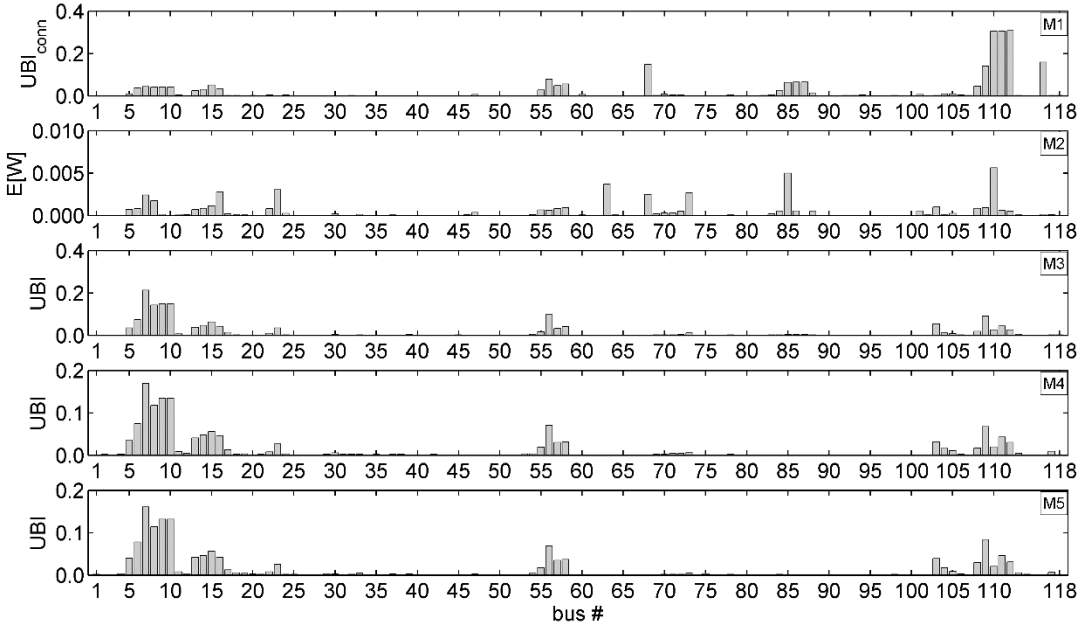
- Post-event demand model must be linked to systemic damage
- Done for water and gas
- Source capacity still missing

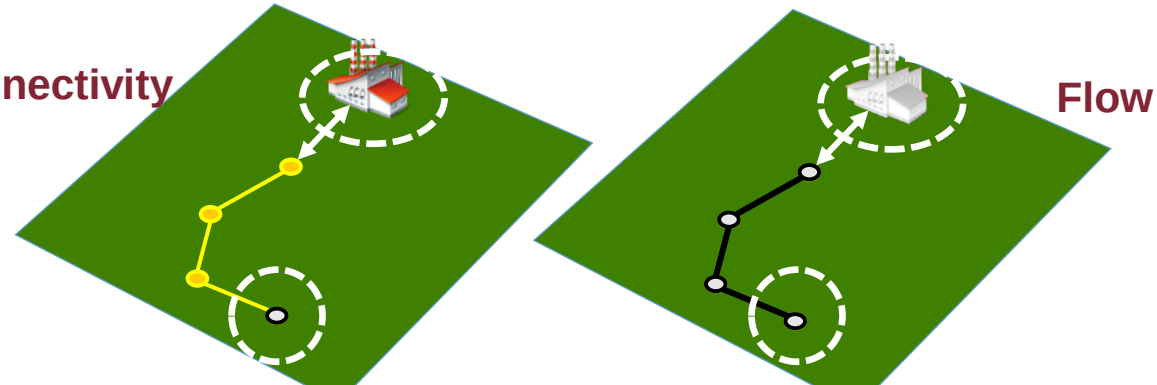
System functional model

Power networks

Power networks: much more difficult problem
(SECD formulated in 1955 still no fast/robust solution technique)

People are doing everything ranging from pure connectivity, to DC (linearized), to AC (nonlinear). Truth is that even AC is incomplete





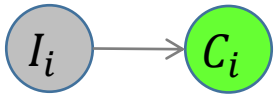
(Cavalieri et al 2014)

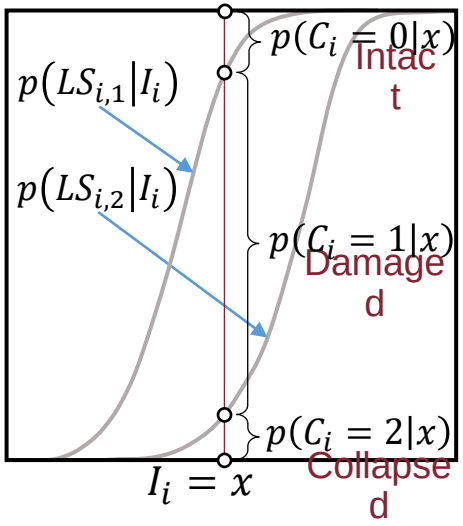
3: Components' models

Component damage model

Systemic analysis → 100s or 1000s of components → surrogate models

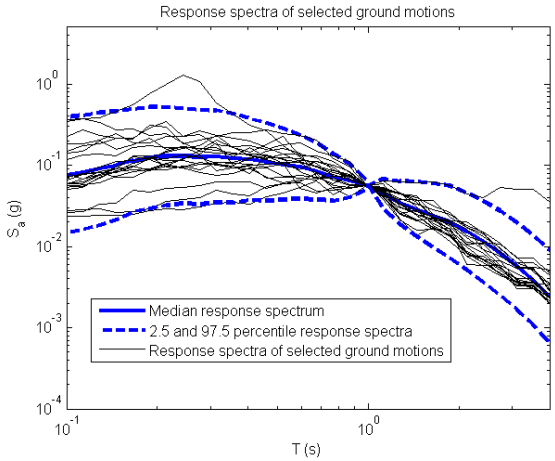
fragility $p(LS_{ij}|I_i)$ → damage given intensity $p(C_i|I_i)$





I_i is just <u>one</u> parameter of ground motion

$\boldsymbol{I}_i|I_i$ other GM parameters depend on site



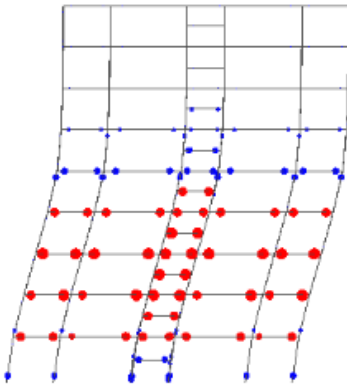
Fragility is structure & site-dependent

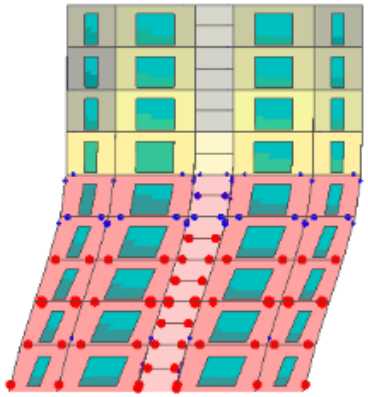
Fragility from field damage → difficult to generalize → numerical simulation

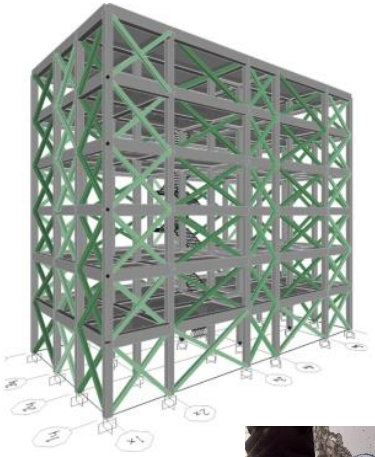
Calibrated models

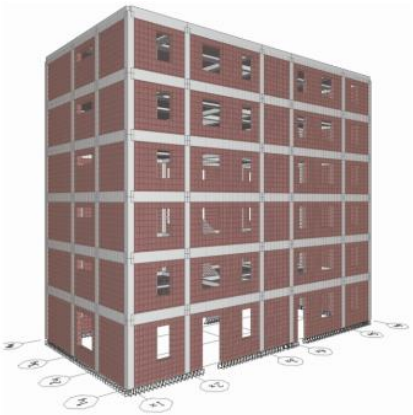
Component damage model

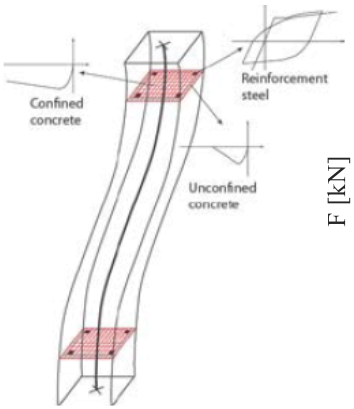
Fragility analysis via numerical simulation is a delicate business. Results depend on: ground motions, numerical model, analysis method, statistical method and modelled uncertainty

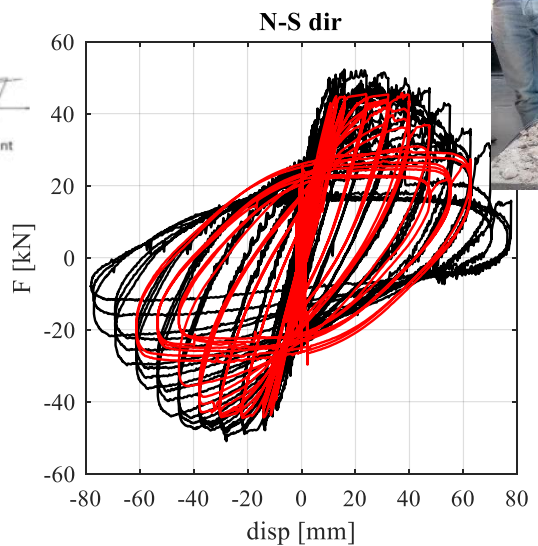


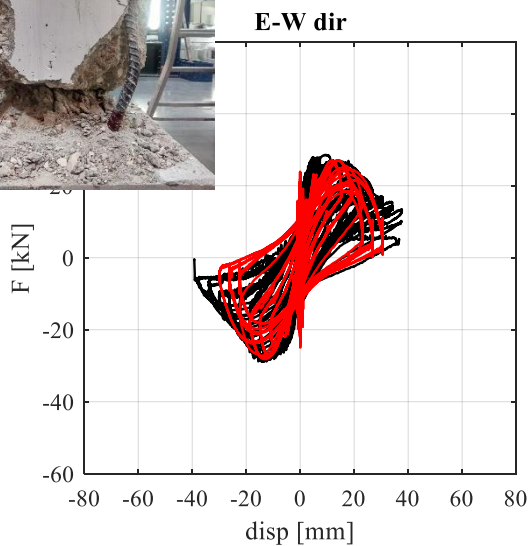








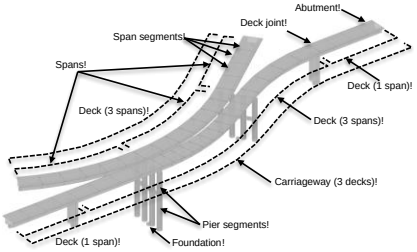


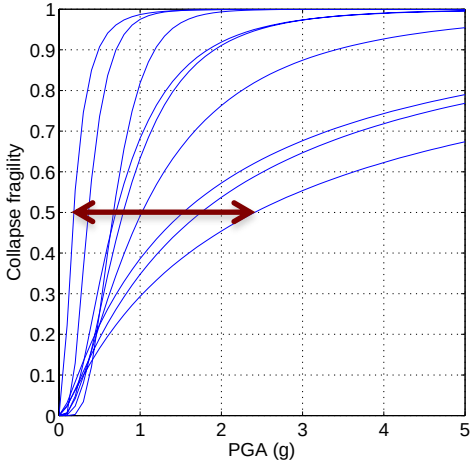


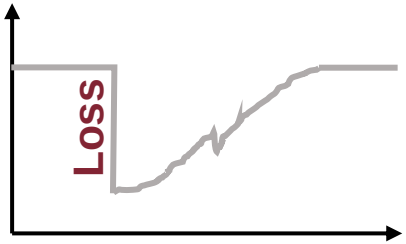
Component damage model

Refined fragility analysis of archetype buildings should not be used to support fragility functions for classes of assets!

D4 project 2009-2012 450+ bridges



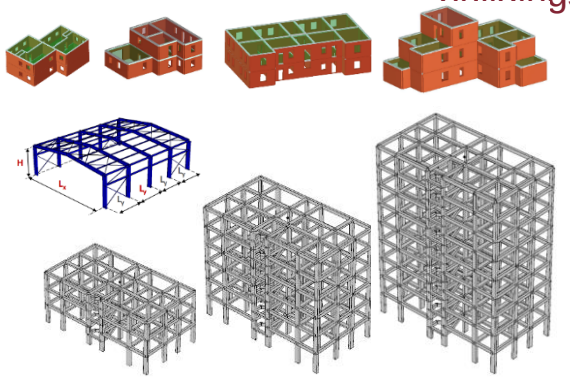




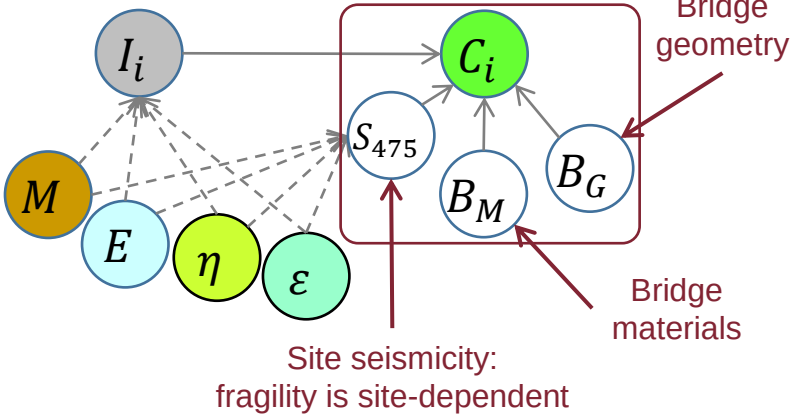
direct $L_D = \sum L_{Di}$

indirect $L_I = \sum L_{Ii} + \sum\sum L_{Iij}$

RINTC project 2015-2018
Tens of RC, PRC, URM, steel buildings



BN-based fragility



(Borzi et al 2015)(Franchin et al 2016)(RINTC Workgroup, 2018)

Conclusions

Conclusions

- Resilience is improved by reducing vulnerability and improving response/recovery
- Vulnerability reduction seems the most reliable, given the uncertainty in $t > t_{shock}$

- Components' damage: need **better surrogate models** Fundamental research in structural and geotechnical engineering is still needed
- Systems' behaviour: need **more realistic representation** (flow! Or enhanced/smart connectivity…)

- If former two are achieved, systemic analysis will be reliable enough to link performance of the components to global community resilience goals. This will provide:
  - A rational basis for performance targets in next generation codes
  - Support for building decision-support systems for use in real

Thank you!

Funding:

European Commission:
FP7 project **SYNER-G** – Systemic analysis framework

Italian Department of Civil Protection:
Reluis project **RINTC** – Seismic risk of Italian code-conforming buildings
Reluis project **RS6** – Seismic risk to lifelines
EUCENTRE project **d4** – Seismic vulnerability of Italian highway bridges

Contributors:

Francesco Cavalieri, Pierre Gehl
G. Weatherill, F. Noto, A. Lupoi, F. Mollaioli, S. Tesfamariam, S. Giovinazzi