Geneva, 27-28 June 2018

1st IAVCEI/GVM Workshop
From Volcanic Hazard to Risk Assessment

PHYSICAL VULNERABILITY FOR QUANTITATIVE RISK ASSESSMENT

PLINIVS Study Centre

for Hydrogeological, Volcanic and Seismic Engineering

National Competence Centre for Italian Civil Protection Department

Interdepartmental Centre of Research
Laboratory of Urban and Territorial Planning
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Risk Assessment: Definitions

Risk [Scenario] = Hazard x Exposure x Vulnerability

Risk analyses

*The **RISK** is the probability that a predetermined level of damage (to people, buildings, infrastructure, economy, etc.) caused by natural events occurring in a given period of time and in a certain geographical area. The risk should be understood as a cumulative assessment, which assesses the potential total damage generated by all events (of same type) that can occur in a given area in a predetermined time period.*

$$\text{Risk}_l = \int_m q_m \left[\int_i (H_i) \cdot (V_{l,i,m}) \right]$$

***BENEFIT:** Comparative evaluations of areas subjected to planning for:*

- *decisions regarding **intervention strategies** (for example, evacuation priorities, etc.),*
- *definition of **damage mitigation strategies**.*

Scenario analyses

*The SCENARIO is the probabilistic distribution of the damage caused by **a single event of intensity "i"** with probability of occurrence assigned (**reference scenario**), in a given geographical area.*

$$\text{Scenario}_{l,i} = \int_m q_m [(H_i) \cdot (V_{l,i,m})]$$

BENEFIT: Identification of the area of interest and assessment of the territorial impact for:

- quantify the resources needed for emergency planning
- organization of the operational intervention.

- ✓ **Hi** probability of occurrence of the event characterized by magnitude "i", in a given time and in a given site;
- ✓ **$V_{l,i,m}$** probability to reach the damage level "l" for a vulnerability class "m";
- ✓ **qm** percentage of element exposed of class "m".

Risk Assessment: Exposure

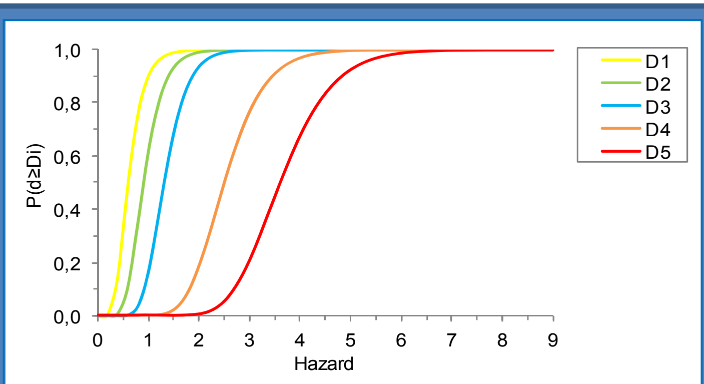
Exposure in terms of vulnerability classes

1. Identification of structural- typological features: Census and survey in situ

- Identification of Vulnerability classes

Exposure is the extension, the quantity and the quality of different elements that characterize the examined area (**people, buildings, infrastructures, economy, environment, etc.**), whose conditions and/ or functioning can be damaged, altered or destroyed by the event.

On the territory investigated, for each Minimum Reference Unit (MRU), the analysis of exposure should be carried out by grouping the elements exposed with similar vulnerability under effect of individual hazard Hk, in categories called "vulnerability classes".



VULNERABILITY CURVES express the probability that a given "vulnerability class" exceeds a certain level of damage , given a level of hazard magnitude.

DAMAGE LEVEL	DESCRIPTION OF PHYSICAL DAMAGE ON ELEMENT EXPOSED OR ALTERATION OF FUNCTIONALITY FOR GRIDS
D0	No damage on element exposed
D1	Slight damage
D2	Moderate damage
D3	Heavy damage
D4	Partial crisis
D5	Total crisis

Risk Assessment: Exposure

Exposure in terms of vulnerability classes

1. Identification of structural- typological features: Census and survey in situ

- Identification of Vulnerability classes

PLINIVS FORM

general information	type
	destination
	use
	exposure
condition	age
	conservation state
	finishes typology
descriptive characteristics	number of floors
	number of apartments
	basement
	residential basement
	height of first storey
	minimum height
	maximum height
	fence with h>2m
	orientation
	position in the aggregate
structural characteristics	main typology
	main vertical structures
	main horizontal structures
	roof shape
	roof structure
	walls thickness
	cladding thickness
	cladding typology
openings	percentage of openings on the façade
	number of small windows
	number of medium windows
	number of large windows
	material of small windows
	material of medium windows
	material of large windows
	protection system of small windows
	protection system of medium windows
	protection system of large windows
	conditions of windows
interventions	type of intervention
	age of intervention
regularity	plan regularity
	vertical regularity
	distribution of in plane claddings
	distribution of in elevation claddings
	structure type (RC)
	soft storey
	stocky elements

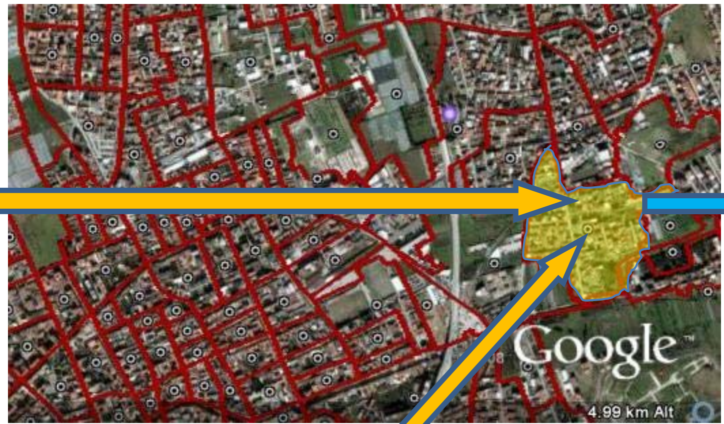
→ **VULNERABILITY CLASSES**

Risk Assessment: Exposure

Exposure in terms of vulnerability classes

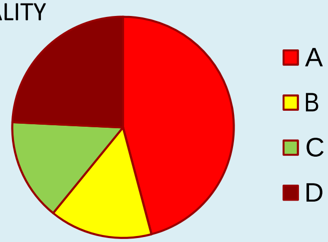
1. Identification of structural- typological features: Census and survey in situ

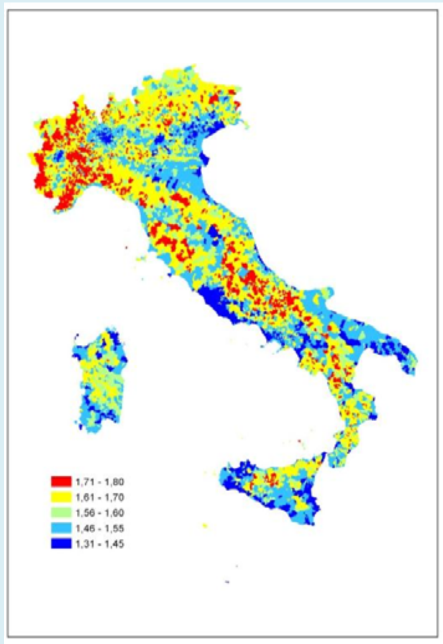
- Building inventory



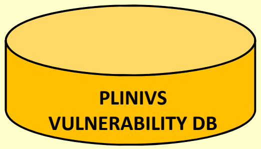
VULNERABILITY CLASSES DISTRIBUTIONS FOR CENSUS SECTION

APPLICATION OF THE STATISTICAL CORRELATIONS TO ISTAT DATA AND ASSESSMENT OF THE VULNERABILITY DISTRIBUTION FOR EACH MUNICIPALITY



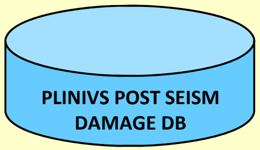


SURVEYED DATA: PLINIVS DB



BUILDING SURVEY IN "PEACETIME" FOR INVENTORY
(about 95.000 buildings, in about 250 towns)

- *typological characteristics*



POST DAMAGE SURVEY
(about 170.000 buildings, in about 500 towns)

- *typological characteristics*
- *damage description*

Risk Assessment: Exposure

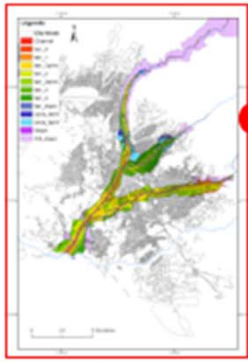
Exposure in terms of vulnerability classes

1. Identification of structural- typological features: Census and survey in situ

Models customization (Arequipa, Perù)

Urban areas vulnerability carachterization

Vulnerability of recurring building components



Customized GIS data

Type	A	B	C	D	E	F	G	H	I	J	K	L
Roof slope	Pitched or rounded roof	One and two pitched roof	Flat roof	Flat roof	Flat roof	Rounded and flat	Flat roof	One and two pitched roof	Flat roof	Flat roof	Flat roof	Flat roof
Materials	Cement, concrete block	Tile, brick	Cement, concrete block	Ignimbrite	Cement, concrete block	Ignimbrite	Metal	Metal	Metal	Cement, concrete block	Tile, zinc, adobe	Tent
Size	Long and large: 300 to 1000 m² (modern church, water tank governmental buildings)	Medium size: 100 to 300 m² (houses, building of variable age)	Medium size: 100 to 300 m² (houses, building of variable age)	Medium size : 100 to 300 m² (old building)	Large size: 300 to 1000 m² (governmental buildings, large buildings, hotels)	Large size 300 to 1000 m² (Church or large, old buildings)	Very large: > 1000m² (large shed or modern supermarkets)	Medium to large (industrial or commercial buildings of variable age)	Medium: 100 to 300 m² (industrial or commercial buildings of variable age)	Medium: 100 to 300 m² (houses, buildings of several periods)	Small: < 100 m² (small houses and poor quality buildings)	Large : 300 to 1000 m² (School, restaurant)
Maintenance	Finished and well maintained	Finished and very well maintained	Finished and well maintained	Finished and relatively well maintained	Finished and well maintained	Finished and very well maintained	Finished and very well	Finished and relatively to well maintained	Finished and relatively well maintained	Unfinished and unmaintained: poor conditions	Unfinished and unmaintained: poor conditions	Finished

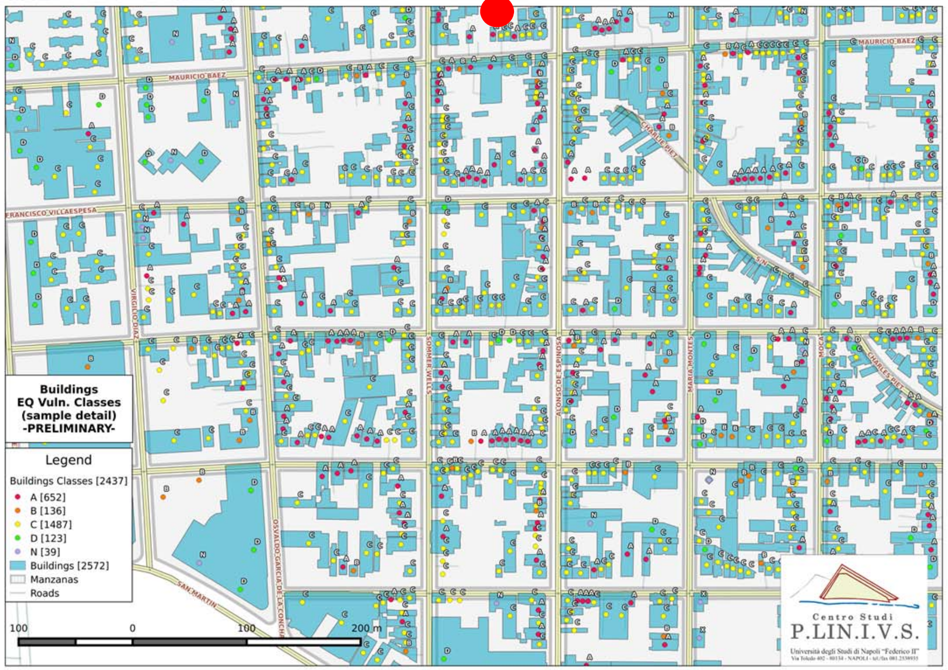
Risk Assessment: Exposure

Exposure in terms of vulnerability classes

1. Identification of structural- typological features: Census and survey in situ

Models customization (Santo Domingo, Dominican Rep.)

Vulnerability distribution at municipal level

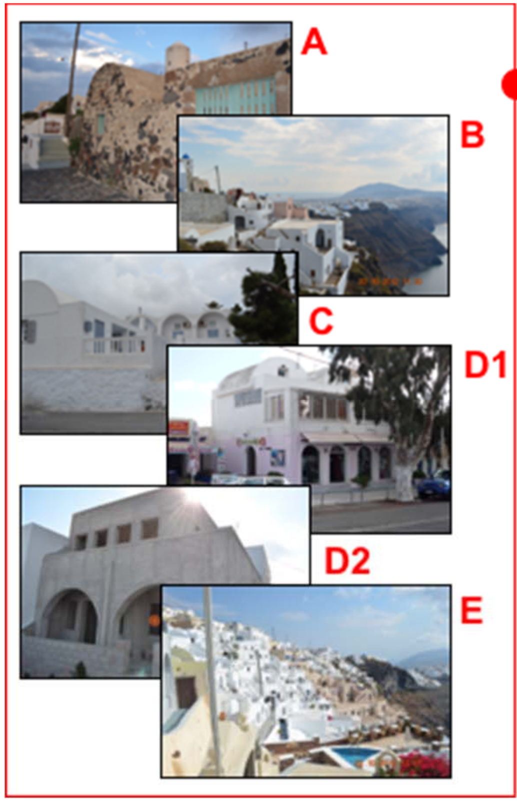


Risk Assessment: Exposure

Exposure in terms of vulnerability classes

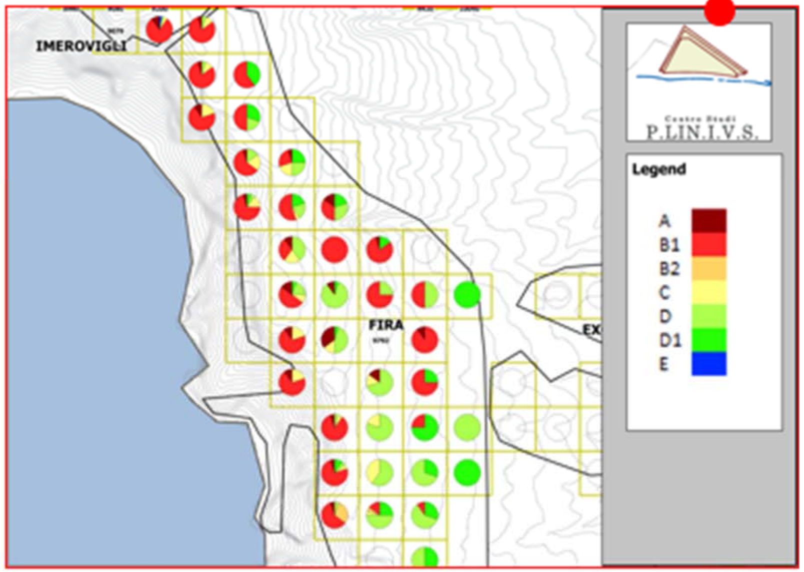
1. Identification of structural- typological features: Census and survey in situ

Models customization (Santorini, Greece)



Surveys on site and building vulnerability classes identification

Vulnerability distribution at municipal level



Risk Assessment: Vulnerability

Earthquake (EQ)

- Vulnerability of buildings

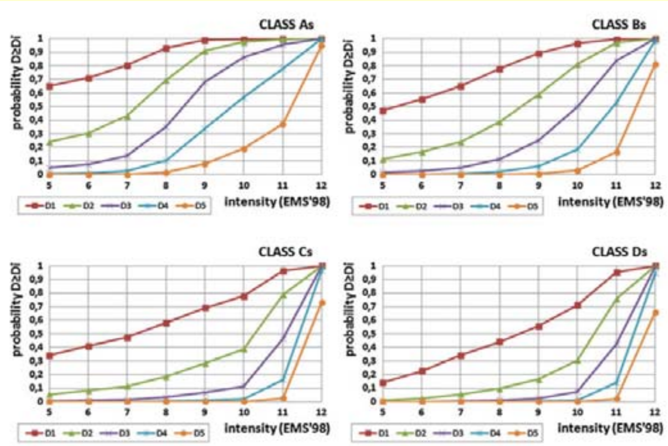
VULNERABILITY CLASSES

	HORIZONTAL STRUCTURES				
VERTICAL STRUCTURES	Poor stiffness Metal sheet, vaults and/or wooden floor (without ties)	Poor technology (e.g. "SAP" floor*)	Medium stiffness Vaults and/or wooden floor (without ties)	Medium high stiffness Iron beam floor	High stiffness Reinforced concrete and steel floors
Weak masonry Rubble masonry neglected	As	As	As	As	As
Medium quality Rubble masonry maintained	As	As	Bs	Bs	Bs
Good masonry Squared masonry	As	As	Bs	Bs	Cs
Framed structures (RC or steel)	-	Bs	-	-	Ds

* SAP floor (self- supporting floor) is a typical Italian horizontal structure, made of clay/cement mix with smooth bars at intrados. This technology is considered very dangerous because of the cement casting superior slab does not cover the reinforcement bars inserted in the hollow tile.

VULNERABILITY CURVES (empirical approach)

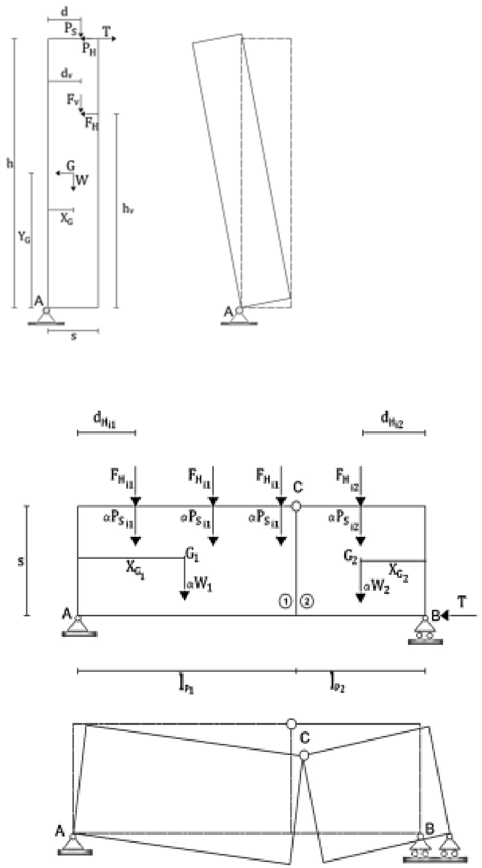
Probabilistic observational approach based on statistical calculation on numerous in situ damage distribution surveys related to past tectonic events

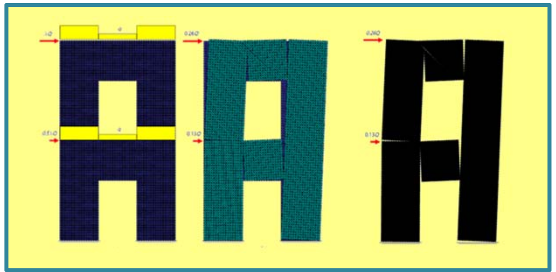


Risk Assessment: Vulnerability

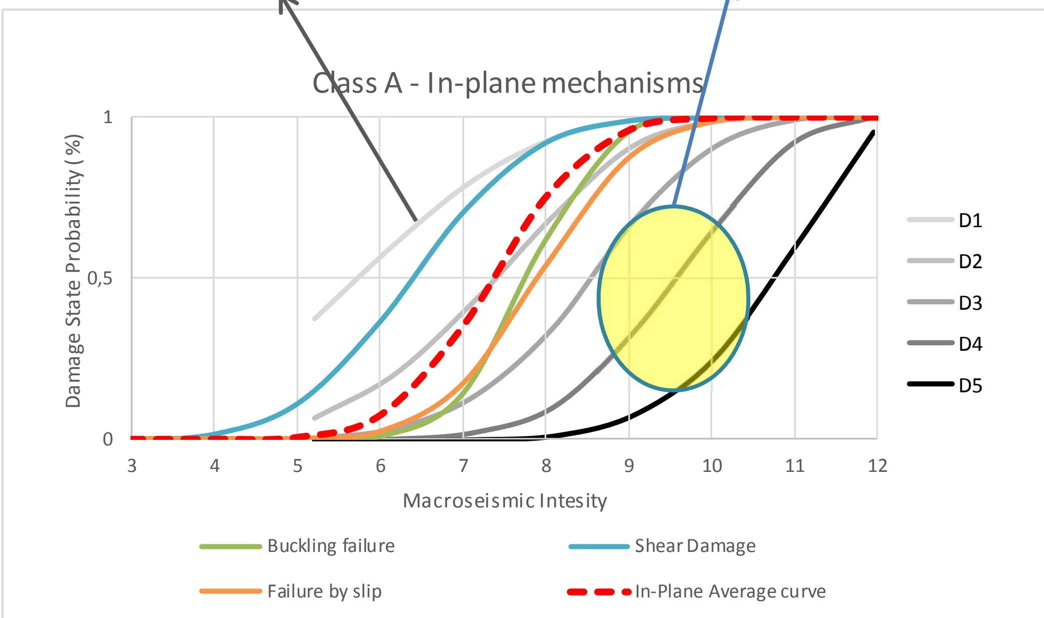
Earthquake (EQ)

- Collapse mechanisms in masonry buildings





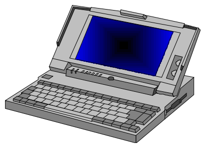
DPM Zuccaro



Risk Assessment: Vulnerability

Monte Carlo approach

- Vulnerability of buildings



Column steel bars (%) of the section

Column section incr. every 2 storeys (cm)

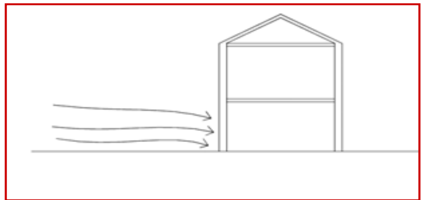
M_0 (tm)

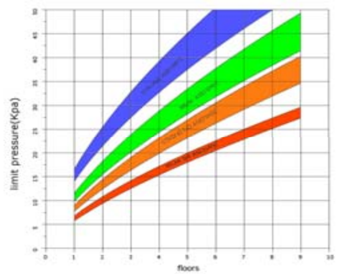
Strong-asesimic	1,5	10(15)	15	7,5	15
Weak-asesimic	1	10	15	7,5	10
Strong not asesimic	0,5	10	15	7,5	5
Weak not asesimic	0,5	5	10	5	5

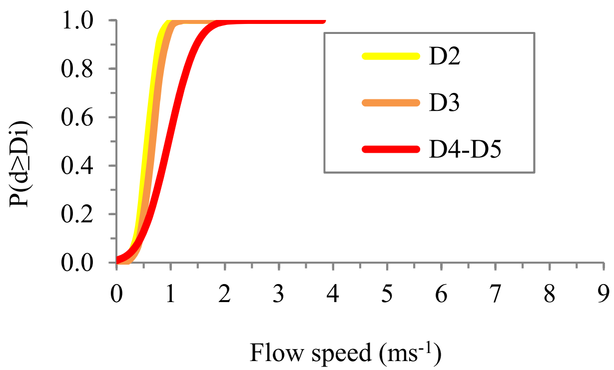
Beams type

R.c. building type

Beams M_0 increment every 2 storeys (tm)







Risk Assessment: Vulnerability

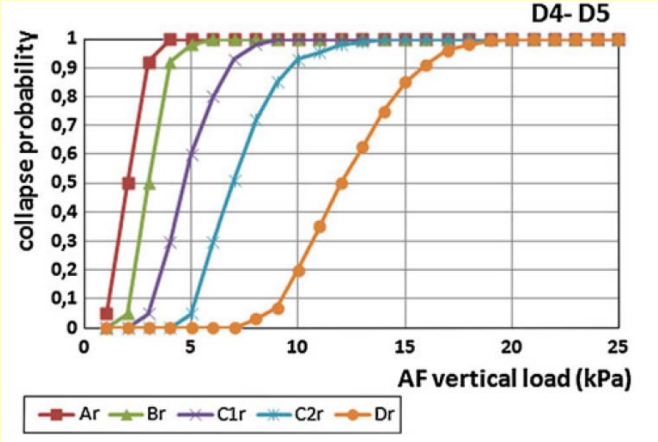
Ash fall (AF)

- Vulnerability of buildings

VULNERABILITY CLASSES

Type	Description
Ar	Weak pitched wooden roof
Br	Flat standard wooden roof
	Reinforced concrete flat roof- SAP type
	Weak steel flat roof
C1r	Old flat RC roof
	Weak pitched steel roof
C2r	Recent flat RC roof
	Recent flat steel roof
Dr	Recent pitched RC roof
	Recent pitched steel roof

VULNERABILITY CURVES (Hybrid methods)



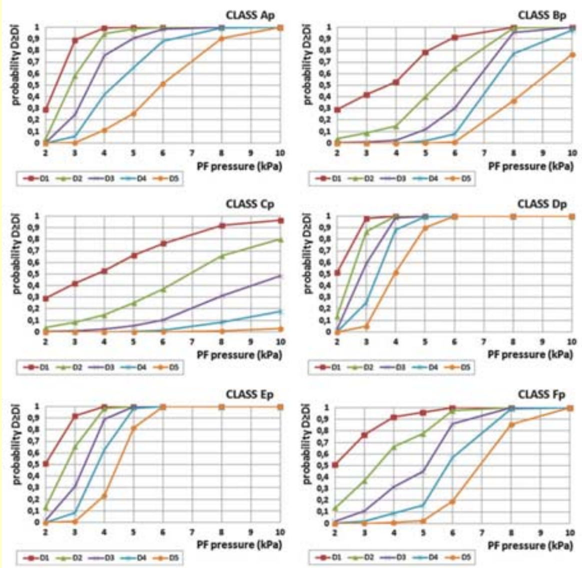
[Numerical analyses at limit state of collapse, experimental tests and statistical calculations]

Risk Assessment: Vulnerability

Pyroclastic flows (PF)

- Vulnerability of buildings

VULNERABILITY CURVES (hybrid approach)



VULNERABILITY CLASSES

STRUCTURAL ELEMENTS	
Type	Description
Ap	Weak masonry buildings of 3-4 storeys with deformable floor
	Weak or
Bp	Mediu
	Strong n
Cp	Strong n
Dp	Non- ase
Ep	Non- ase
Fp	Non- ase

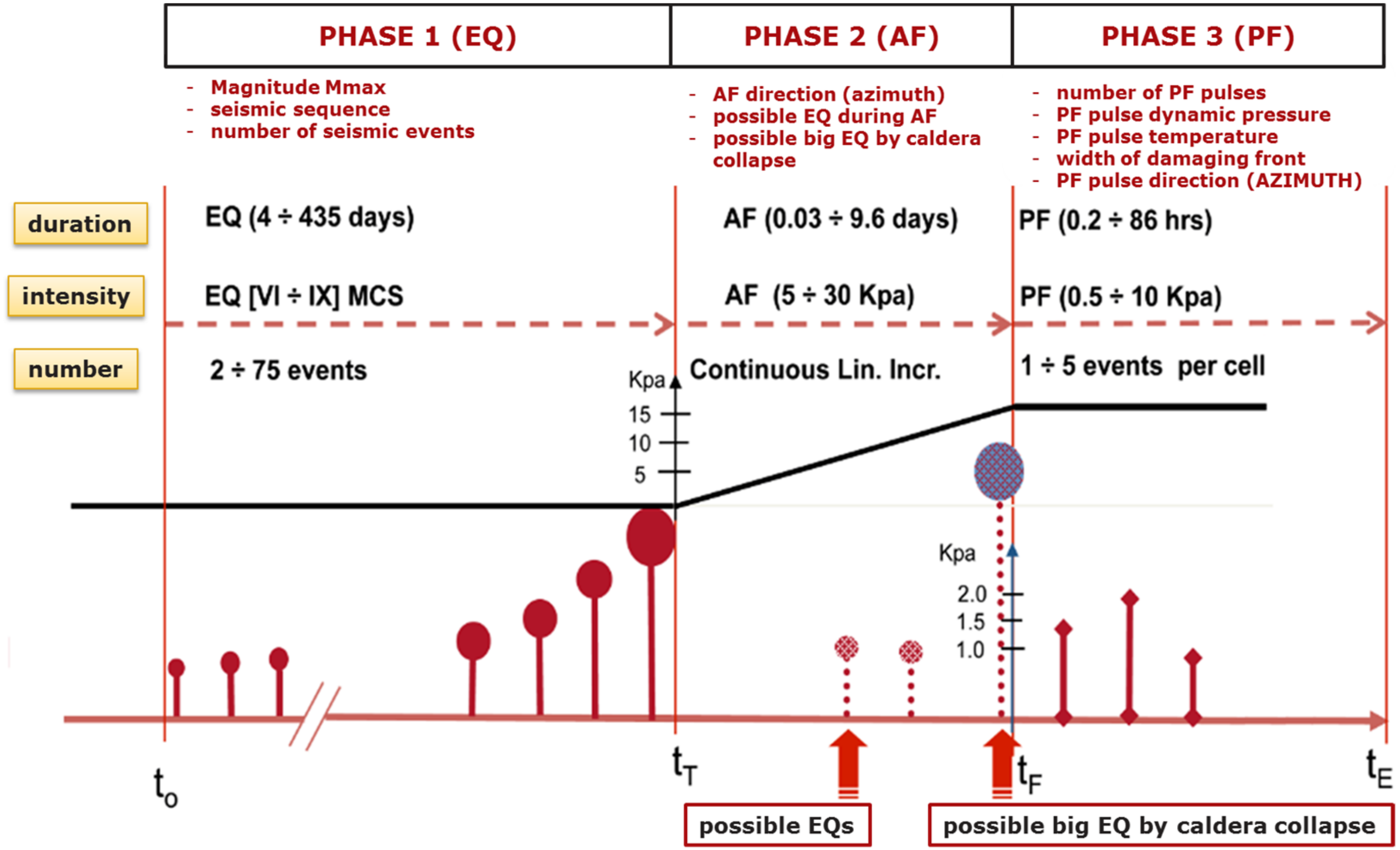
NOT STRUCTURAL ELEMENTS		
Type	Description	**COLLAPSE LOAD[kPa]**
Ap*	Windows glass of ordinary buildings	<1,5
Bp*	Aluminium window in bad condition	1,5
Cp*	Aluminium window in good condition	3,0
Dp*	Old wooden door	3,5
Ep*	Yellow tuff masonry wall	4,2-7,4
Fp*	Old wooden window	5,0
Gp*	Terra cotta tile in-fill panel without window	5,5
Hp*	Terra cotta tile in-fill panel with window	7,6-8,9

Risk Assessment: Scenario analyses

Vesuvius scenario analyses by cumulative damage

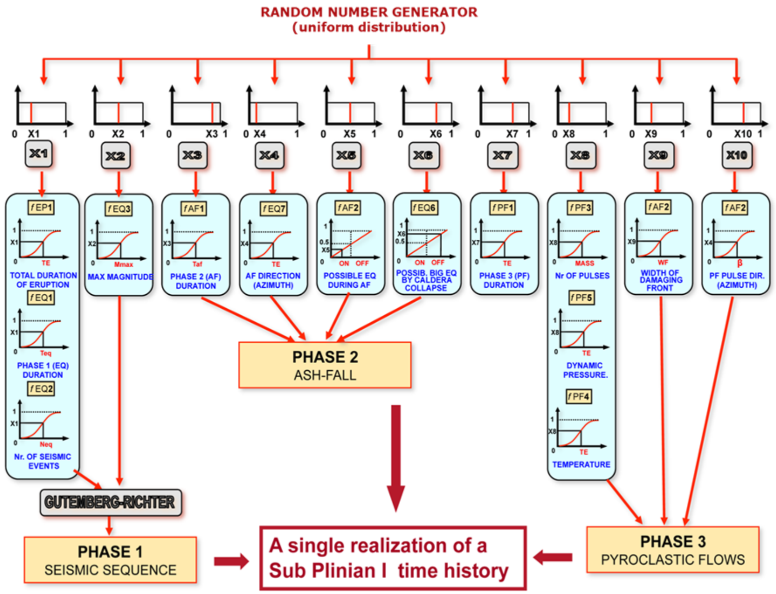
ASSESSING THE CUMULATIVE IMPACTS ON PEOPLE AND BUILT ENVIRONMENT FROM A SEQUENCE OF ERUPTIVE PHENOMENA ACCORDING TO TIME/SPACE DISTRIBUTIONS.

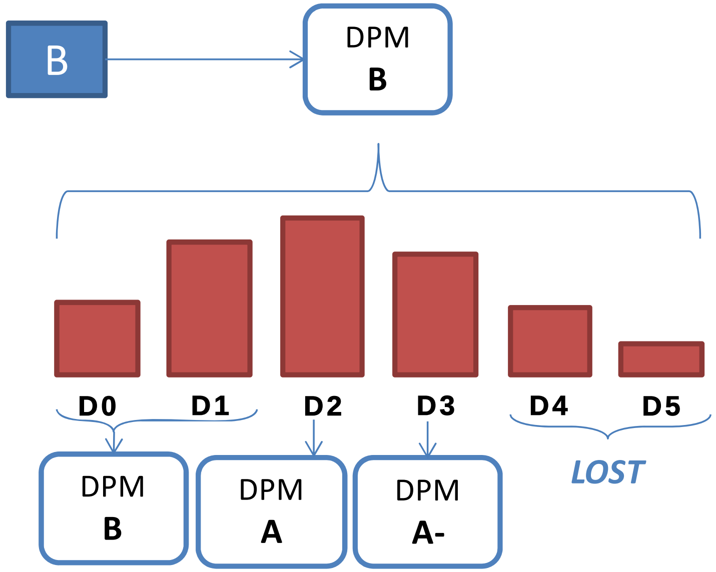
SUBPLINIAN ERUPTION TIMELINE

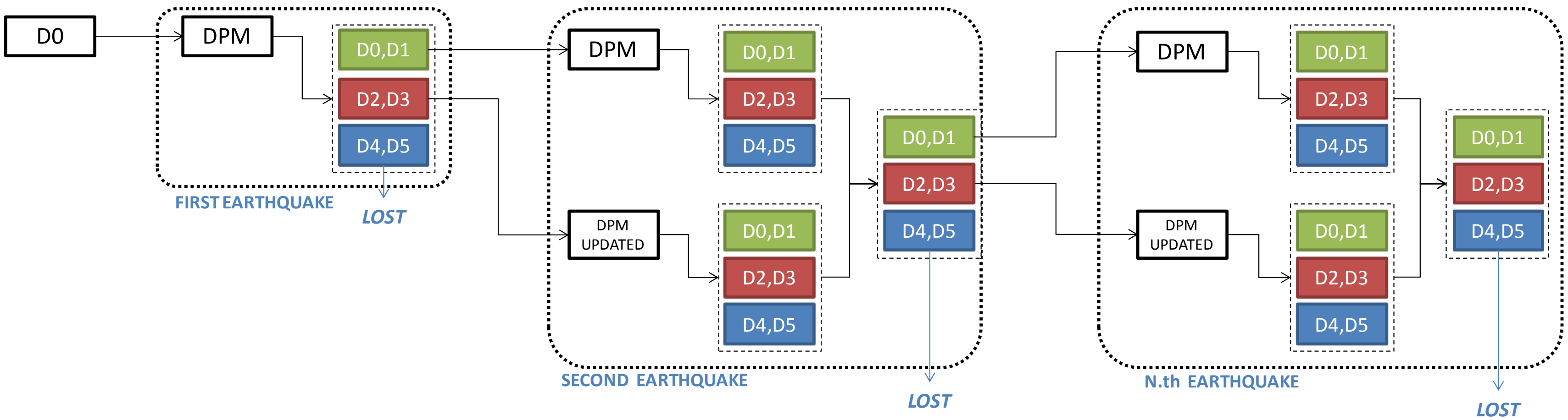


Risk Assessment: Scenario analyses

Vesuvius scenario analyses by cumulative damage





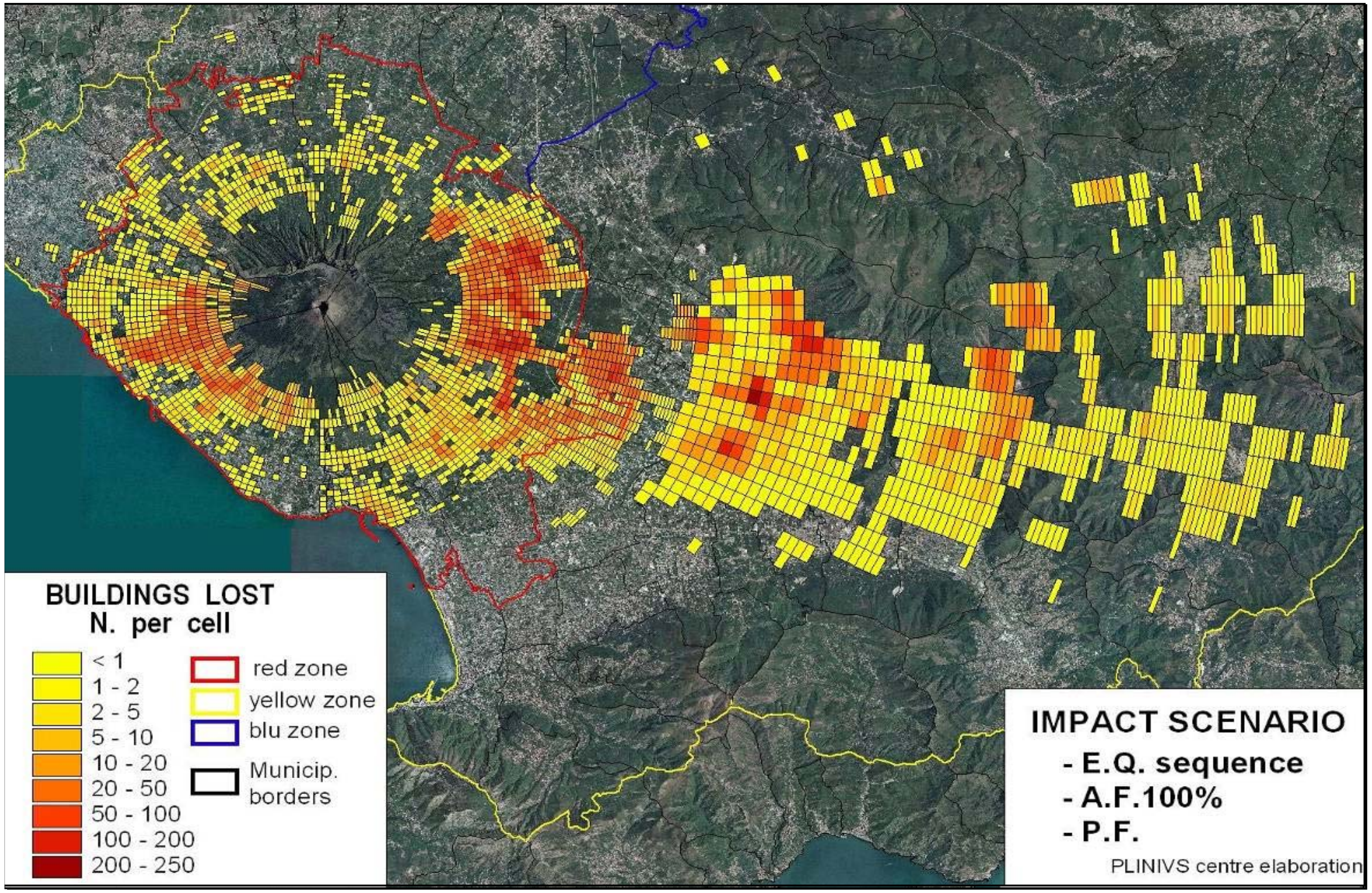


Risk Assessment: scenario by cumulative damage

Events	Buildings Lost (D4+D5+fired)				Casualties				
Sequence	By Step	Cumul	Fired	Total	Population in the Area (%)	Killed by Step	Killed (Cumulative)	Injuries by Step	Injuries Cumul.
PF	4351	28864	2850	31714	1.5%	3382	8440	2985	13456

- AF+PF

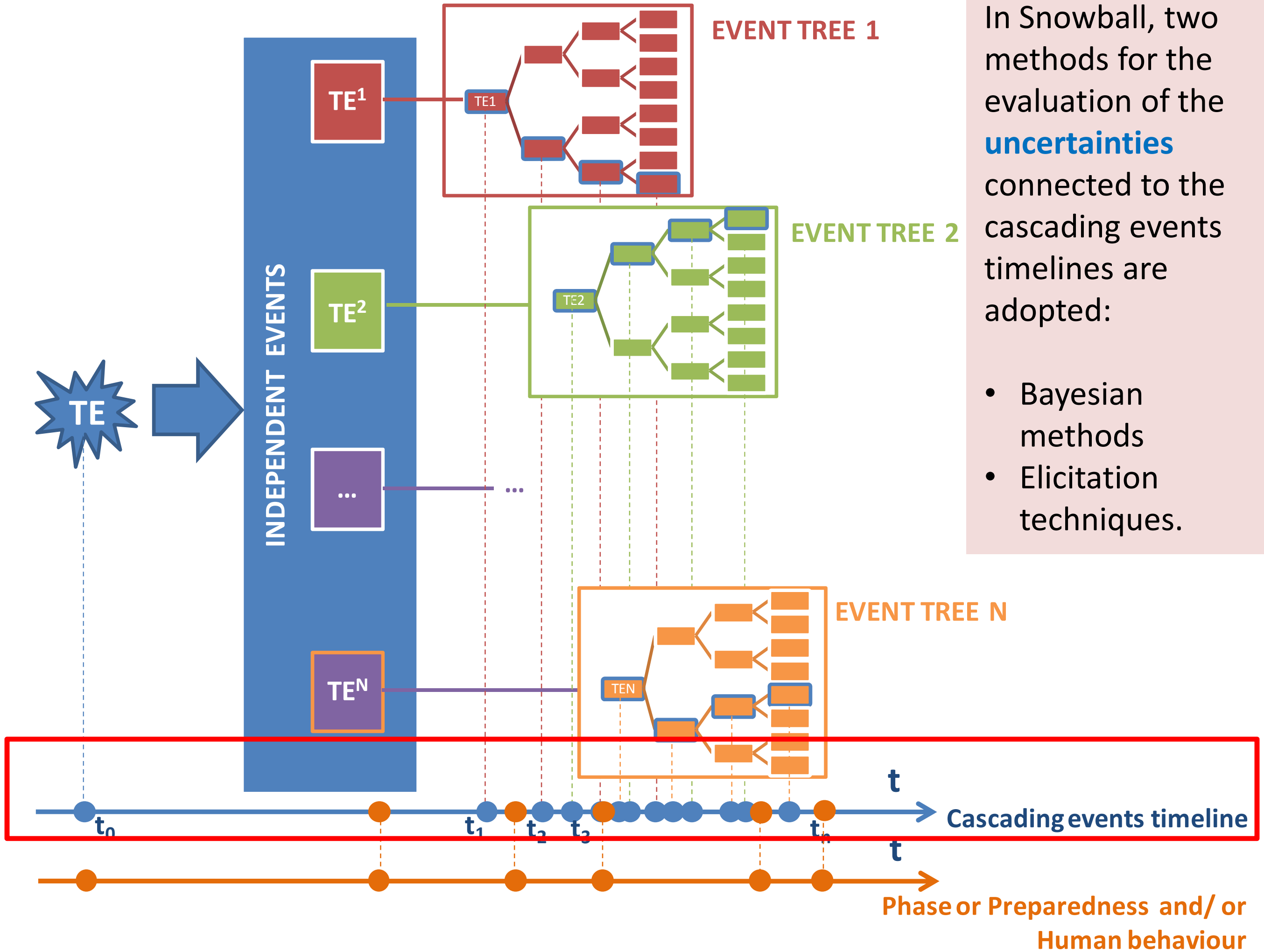
VESUVIUS



Risk Assessment: Multi- risk and Cascading effects

Cascading effects in Snowball project

Snowball methodology proposes to study the cascading effects like a typical **"SCENARIO ANALYSIS"**, through the assessment of damage induced on element exposed **by a single timeline of events** (called **cascading scenario time history**) **choices on the base of ad hoc criteria (i.e. probability of occurrence of time history, impact on specific element at risk, stakeholder interests, etc.).**

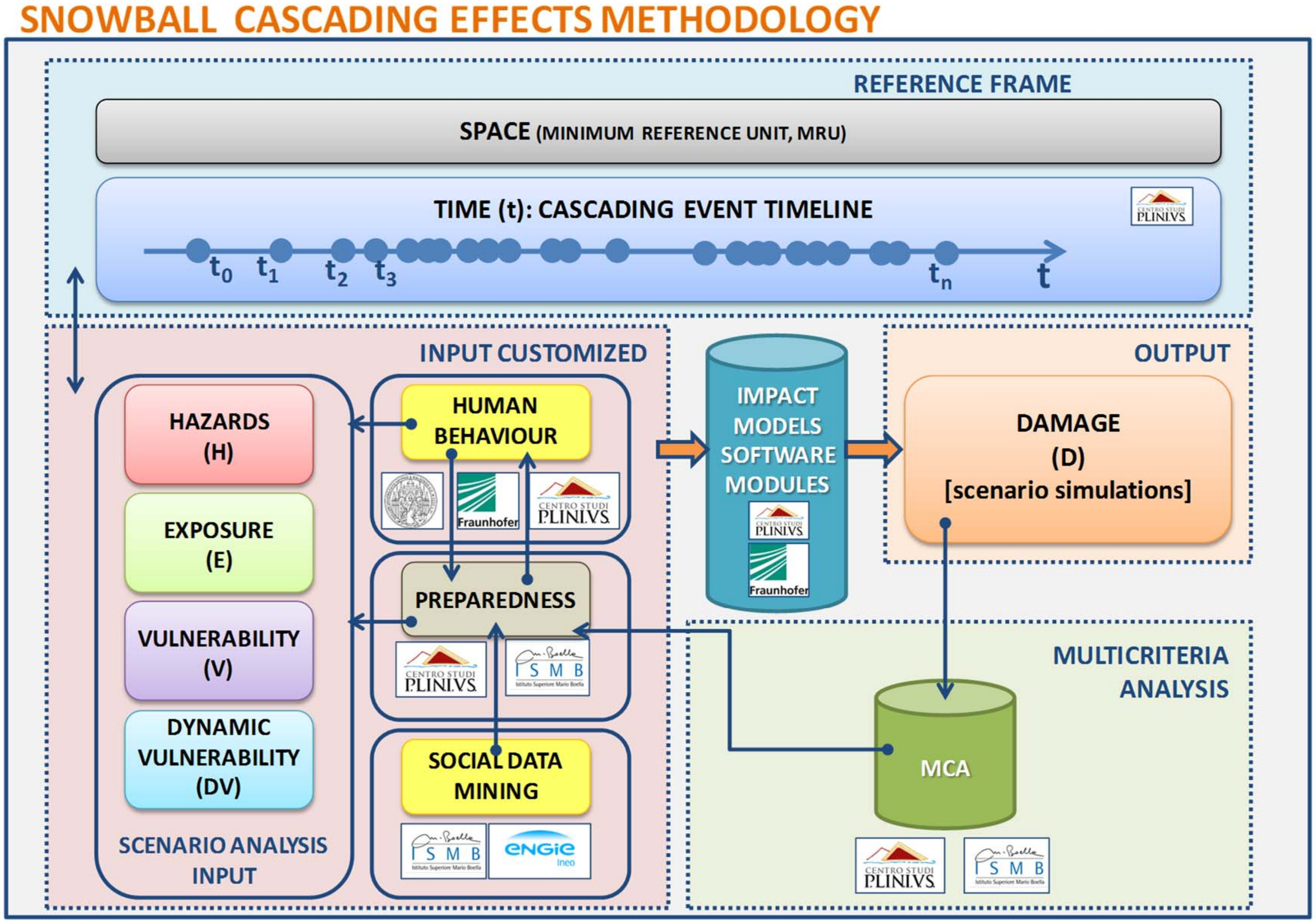


In Snowball, two methods for the evaluation of the **uncertainties** connected to the cascading events timelines are adopted:

- Bayesian methods
- Elicitation techniques.

Risk Assessment: Multi- risk and Cascading effects

Cascading effects in Snowball project



Risk Assessment: Multi- risk and Cascading effects

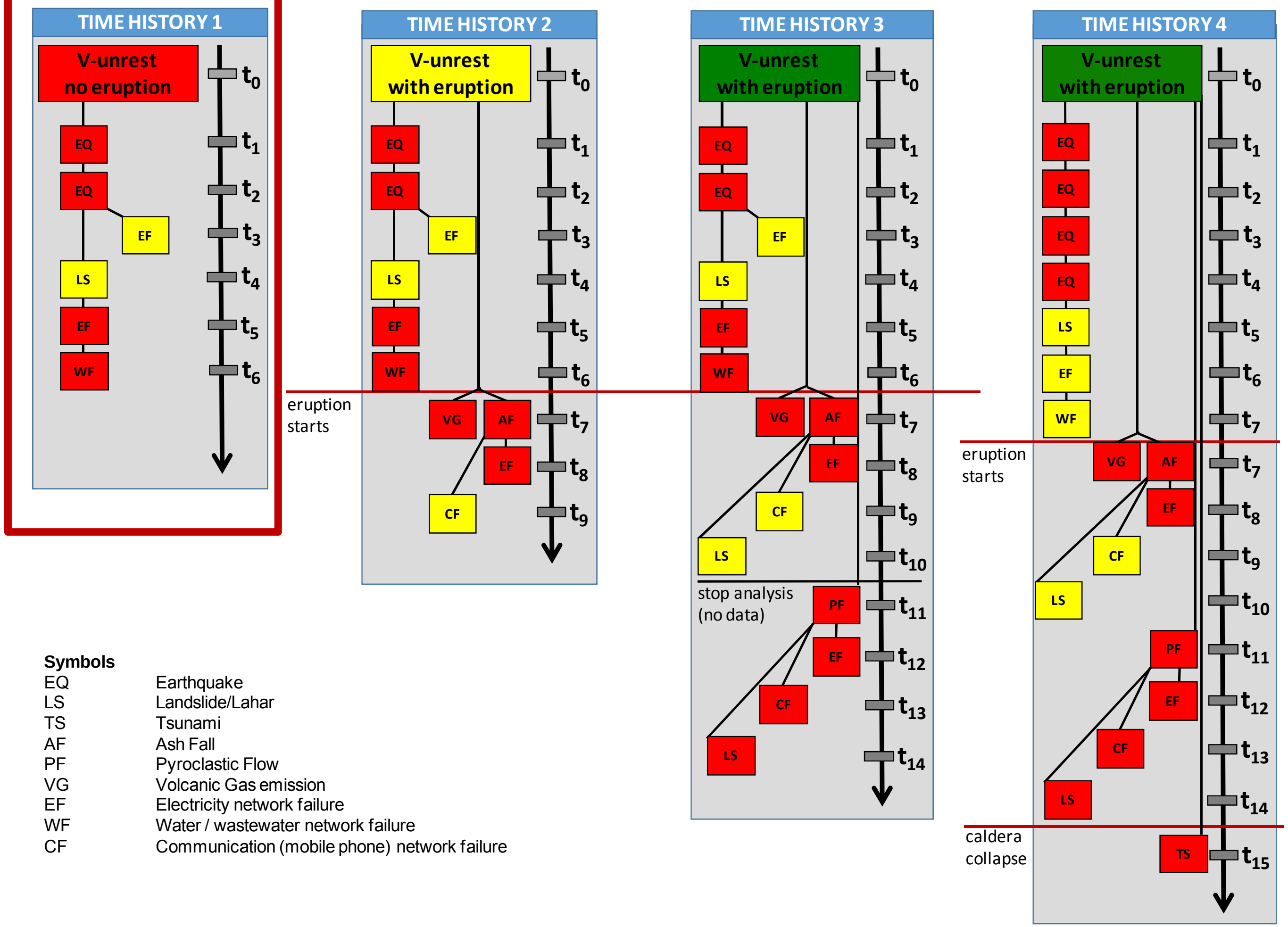
Cascading effects in Snowball project (Santorini case study)

Time History 1
Triggering Hazard
Volcanic unrest in Nea Kameni (high prob.)

Time History 2
Triggering Hazard
Vulcanian eruption
Nea Kameni (med prob.)

Time History 3
Triggering Hazard
Sub-Plinian eruption
Nea Kameni (low prob.)

Time History 4
Triggering Hazard
Sub-Plinian eruption
Coulumbo

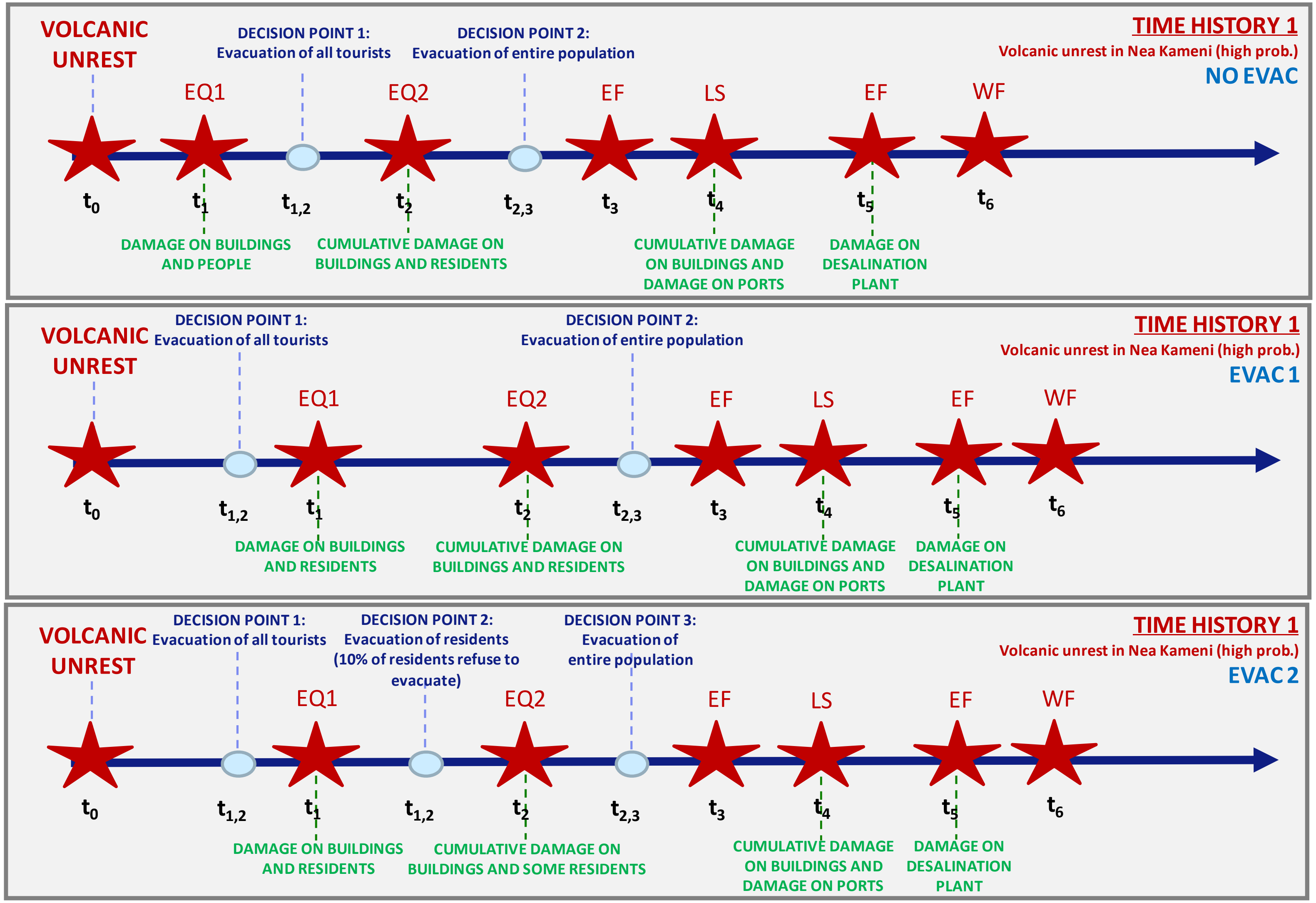


Symbols

EQ	Earthquake
LS	Landslide/Lahar
TS	Tsunami
AF	Ash Fall
PF	Pyroclastic Flow
VG	Volcanic Gas emission
EF	Electricity network failure
WF	Water / wastewater network failure
CF	Communication (mobile phone) network failure

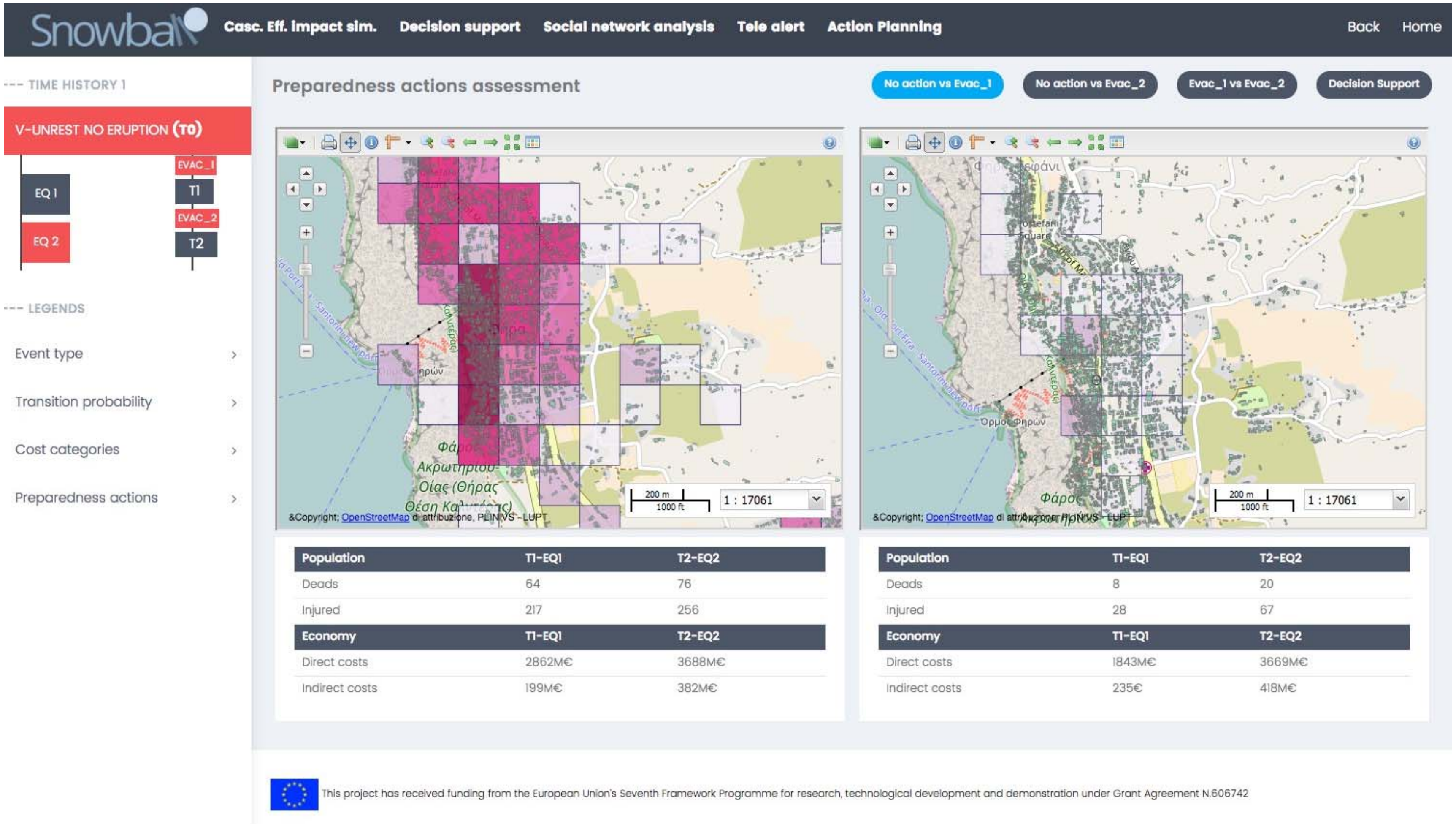
Risk Assessment: Multi- risk and Cascading effects

Influence of decision adopted to final impact



Risk Assessment: Multi- risk and Cascading effects

Cascading effects in Snowball project

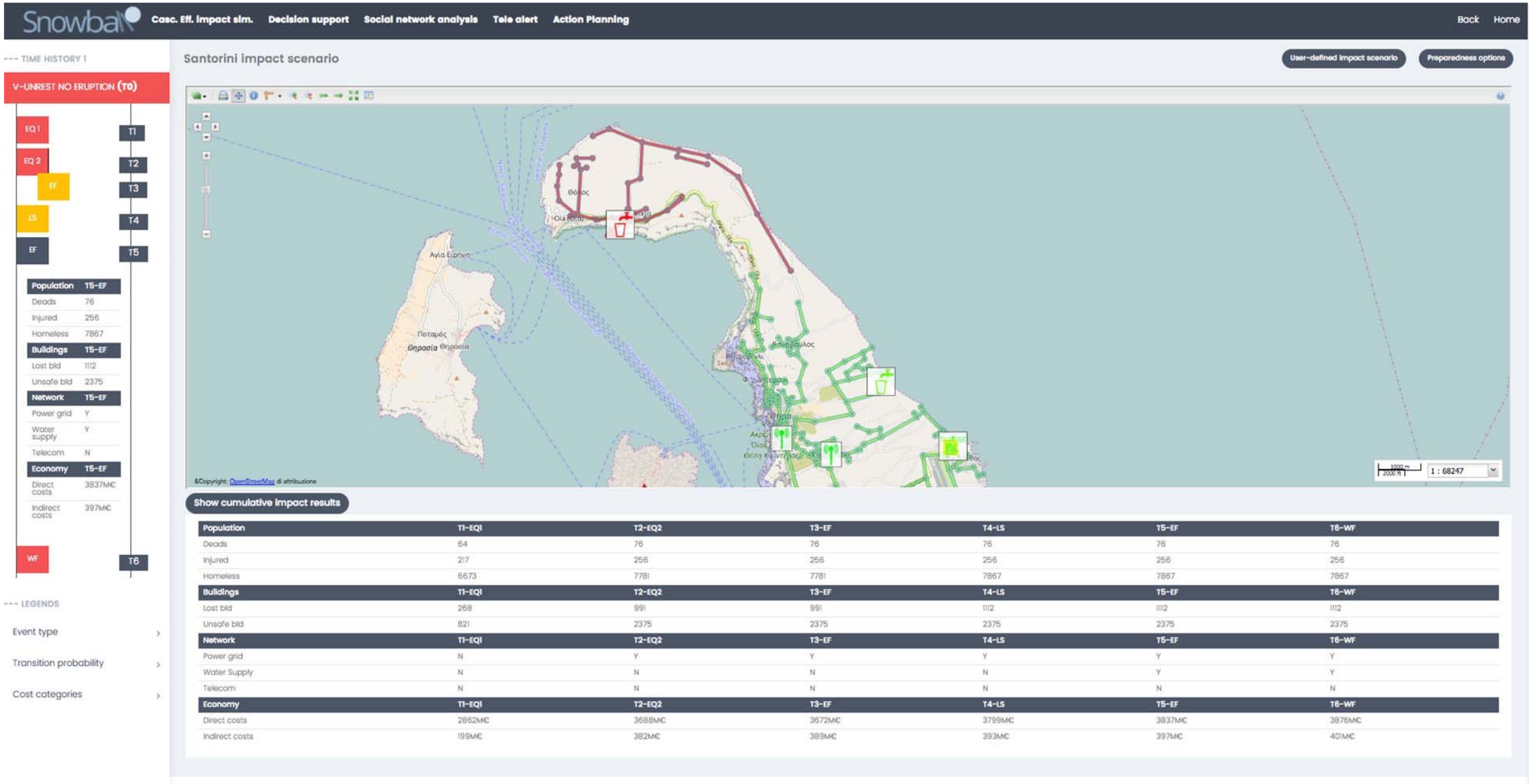


Population	T1-EQ1	T2-EQ2
Deads	64	76
Injured	217	256
Economy	**T1-EQ1**	**T2-EQ2**
Direct costs	2862M€	3688M€
Indirect costs	199M€	382M€

Population	T1-EQ1	T2-EQ2
Deads	8	20
Injured	28	67
Economy	**T1-EQ1**	**T2-EQ2**
Direct costs	1843M€	3669M€
Indirect costs	235€	418M€

Risk Assessment: Multi- risk and Cascading effects

Cascading effects in Snowball project



Current challanges in physical vulnerability assessment in the framework of volcanic risk

Purpose of vulnerability curves in risk analyses

	EMERGENCY PHASE	SCOPE
EARTHQUAKE	UNREST	Assessment of road safety in the management of the emergency
	POST EMERGENCY	Evaluation of economic impact and recovery times
ASH FALL	ALARM	Risk assessment with the aim to identify the areas interested by numerous collapse of roofs → evacuation areas
	POST EMERGENCY	Evaluation of economic impact and recovery times
PYROCLASTIC FLOWS	ALARM	• For ordinary buildings, the only defense for the population is the EVACUATION → It is sufficient the hazard map • For monumental buildings can be useful to identify mitigation strategies ad hoc.
	POST EMERGENCY	Evaluation of economic impact and recovery times

1. **Improvement in the evaluation of vulnerability curves of buildings and infrastructures under effect of single hazard (EQ, AF, PF, LS, LH, etc.).**

2. **Improvement in the evaluation of routine to assess the cumulative damage on element exposed due to multi-hazards or cascading effects.**

3. **Development of an ad hoc platform to collect the element exposed on the base of vulnerability features by volcanic hazard (volumes, materials, geometry and structure of roofs, infill panels an openings, etc.).**

Thanks for the attention