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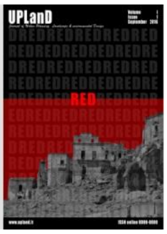

Research & experimentation
Ricerca e sperimentazione

SEISMIC AND ENERGY RETROFITTING OF RESIDENTIAL BUILDINGS: A SIMULATION-BASED APPROACH

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HIGHLIGHTS

- Cost-effectiveness of seismic retrofitting interventions for residential buildings can be improved by applying energy efficiency measures.
- Reliable simulations on seismic impact assessment enable decision makers to compare "what-if" scenarios.
- Mass retrofitting of existing housing stock needs to be tackled through advanced tools integrating multi-criteria and cost-benefit analyses.

ABSTRACT

The topic of the high seismic vulnerability of housing stock in Italy is back again at the center of political, economic, social and scientific-technical debate following the seismic crisis that struck Marche, Umbria and Lazio regions in 2016. These events have once again raised the need for a massive retrofitting program at National and Regional level, addressing the majority of the existing building stock, realized for 60% prior to the adoption of the first seismic code (Law 64/74), in a territory characterized north to south by high levels of seismic hazard. In recent years, different kinds of tools have been implemented to allow the simulation of natural hazards' impacts on the built environment and to support strategic choices both in the field of emergency management and resilience-based urban design and planning. Nevertheless, an integrated set of instruments for a quantitatively informed decision support is still missing.

Within EU-FP7 CRISMA project, an integrated DSS (Decision Support System) application has been developed, with a set of tools and functionalities addressing the main aspects involved in the decision-making processes for natural hazards preparedness and response.

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1. INTRODUCTION

The topic of the high seismic vulnerability of housing stock in Italy is back again at the center of political, economic, social and scientific-technical debate following the seismic crisis that struck Marche, Umbria and Lazio regions in 2016. The heavy damages produced by the main events of August 24 (magnitude 6.0 with epicentre in Accumoli), of 26 October (magnitude 5.9 with epicentre in Ussita) and 30 October (magnitude 6.5 with epicentre in Norcia and Preci), have once again raised the need for a massive retrofitting program at National and Regional level, addressing the majority of the existing building stock, realised for 60% prior to the adoption of the first seismic code (Law 64/74), in a territory characterized north to south by high levels of seismic hazard.

The need to undertake effective common strategy for disaster risk reduction is certainly well understood beyond the emergency contingencies by politicians, local administrators and decision-makers at various levels. The cost of emergencies, both in terms of assistance to affected populations, both of direct and indirect economic impacts related to the complexity of reconstruction processes, has been the subject of in-depth studies following L'Aquila earthquake in 2009, returning a complete picture of economic and technical data which can help to measure the effectiveness of preventive actions to reduce the seismic impact, in particular on housing stock. Despite the growing awareness about the effectiveness of seismic improvement and upgrading measures in relation to the potential damage reduction according to the reference magnitude in the various areas of the country, the National Plan for Risk Prevention Seismic provisions introduced by Law 77/2009 remains however largely not implemented for what concerns the spread of technological retrofitting actions for public and private buildings.

A recent report (ANCE/CRESME, 2012) highlights the extent of the socio-economical factors connected to the vulnerability of Italian territory to natural hazards, especially to seismic and hydrogeological risk. Since 1944, the total cost of the damage caused by earthquake, landslides and floods is more than 240 billion €, about 3.5 billion per year. The figure takes into account the costs of emergency and first aid needed to face hazardous event, the post-event reconstruction of infrastructure and building stock damaged or destroyed, as well as contributions aimed at the reprise of economic activities disrupted and the development of the territory and in some cases the charges related to the tax and social contribution benefits. This huge amount is also almost doubled if we consider only the last four years, reaching an annual share of 6.8 billion (mostly due to the earthquakes in Abruzzo and Emilia-Romagna regions and to floods in Liguria and Toscana regions).

It is a topic of extreme importance also in the international context where, while in the field of energy efficiency and environmental quality the important framework of building codes and regulations, incentives for public and private investments set up in the last decades, especially within EU countries, has allowed an increase of national retrofitting programs, the same cannot be said for what concern the introduction of measures for the mitigation of natural hazards. In fact, even if the regulatory environment has often been adequately improved at national level to face risk factors connected to local conditions, the efforts in this direction didn't produce a leverage effect in the construction sector for what concerns public/private investments and "safety oriented" retrofitting programs.

One of the reasons of this difficulty to put into practice the important achievements in terms of strategic guidelines and technical rules comes from the low cost-benefit ratio of this kind of interventions. Even if is widely demonstrated that investments on mitigation measures allow to reduce recovery costs after the event until 75% (MMC, 2005), the actual economic benefit is obtained only after the disastrous event is occurred and, until that moment, these kind of investments represent only an additional cost factor if compared with a “standard” refurbishment intervention.

On the other side, building retrofitting interventions aimed at improving energy efficiency and energy production from renewable sources are characterised by a rising level of cost effectiveness, with a constant reduction of payback times of different kind of actions on building envelope and HVAC systems, also thanks to the growing push from construction industry and the development of innovative “green” technologies.

In this sense, a combined approach to energy efficiency and disaster mitigation issues allows to improve cost effectiveness of retrofit interventions and introduce new perspectives for product and process technological innovation in the construction sector.

2. CRISMA-NH: A SIMULATION-BASED DECISION SUPPORT TOOL

In recent years, different kinds of tools have been implemented to allow the simulation of natural hazards’ impacts on the built environment and to support strategic choices both in the field of emergency management and resilience-based urban design and planning. Nevertheless, an integrated set of instruments for a quantitatively informed decision support is still missing. Within EU-FP7 CRISMA project (crismaproject.eu), an integrated DSS (Decision Support System) application has been developed, with a set of tools and functionalities addressing the main aspects involved in the decision-making processes for natural hazards preparedness and response, allowing the simulation of alternative hazard and impact scenarios, as well as the comparison and assessment of different strategic choices, to be made both in “hot” and “cold” phases. In particular, the tool CRISMA-NH developed at PLINIVS Study Centre, University of Napoli Federico II, with the contribution of cismet GmbH, enables crisis managers, decision makers, urban planners and economic operators to investigate the consequences of geophysical (earthquakes, volcanic eruptions, hydrogeological events) and weather-related (marine events) hazards on the urban environment.

Different software modules are dedicated to the physical and economic impact assessment, including damage/time-dependent vulnerability analysis (e.g. in case of cascading events), evaluation of long and short-term mitigation actions (e.g. building retrofitting in “cold” phase or population evacuation in “hot” phase), and customizable multi-criteria and cost-benefit analyses. CRISMA-NH has been tested through a pilot application addressing the seismic crisis that stroke L’Aquila region in the first months of 2009, where the main-shock of April 6th caused more than 300 victims, more than 3.000 buildings seriously damaged and over 6 billion € of economic losses.

The following sections show the results of the pilot application, based on the simulation of multiple earthquakes and their impacts on buildings and population (including economic impact). In case of a series of earthquakes, the cumulated damages on buildings and the related consequences on physical and economic impact are evaluated. Long-term mitigation strategies are modelled with dedicated tools which simulate the effect of the implementation of seismic and energy retrofitting options, and evaluated through multi-criteria and cost-benefit analyses, allowing the comparison and ranking of alternative solutions.

2.1 CRISMA framework and CRISMA-NH application

CRISMA project has developed a simulation-based decision support system aimed at supporting crisis management in the context of natural and man-made hazards, providing a set of customizable models and tools available through the CRISMA Framework, to strengthen preparedness and response capabilities of crisis managers and first responders.

CRISMA System allows the simulation and modelling of realistic crisis scenarios and the impacts of hazards, taking into account both the evolution of the crisis according to the expected magnitude and potential cascading effects, as well as the effect of preparedness actions implemented by decision makers and local authorities. CRISMA-NH represents an application of the CRISMA Framework, dedicated to Simulation and Decision Support in the context of natural hazards (earthquakes, volcanic eruptions, hydrogeological and marine events), assessing physical and economic impacts, time-dependent vulnerability, and evaluating the effectiveness of long and short-term mitigation actions through multi-criteria and cost-benefit analysis.

Targeted decision-making activities that can be supported by CRISMA-NH can be resumed as follows:

- National/Regional Civil Protection willing to compare alternative scenarios and impacts on multiple elements at risk by varying hazards intensity and location parameters;
- National Civil Protection called to a decision on population’s evacuation in presence of a long-lasting seismic swarm or forecasting of other geophysical hazards (e.g. volcanic eruption, landslides);
- Public planning authorities called to optimal resources allocation for the implementation of mitigation measures (e.g. buildings retrofitting or transport network securing) in “peace time”;
- Insurance companies studying economic impact of geophysical hazards, comparing alternative scenarios by varying intensity and location parameters.

Within the CRISMA Project, a Pilot application of CRISMA-NH has been implemented, focusing on a specific type of seismic crisis, characterized by a long-lasting seismic swarm that is likely to produce a main shock with severe consequences on people, built environment and economy (Zuccaro et al., 2015). The reference scenario, defined as a baseline for the Pilot application, is the 2009 seismic crisis in L’Aquila (Italy). Inventory data, vulnerability distribution, location and magnitude of earthquakes have been defined according to the real crisis occurred. The CRISMA-NH application integrates the following models, developed in the last 20 years at PLINIVS Centre - University of Napoli Federico II (Zuccaro et al. 2015; Zuccaro et al. 2014; Zuccaro et al. 2013; Zuccaro and Cacace, 2011; Zuccaro and Cacace, 2010): Building impact model, Casualty model, Time Dependent Vulnerability model, Economic Impact Evaluation model, Building Retrofitting model (long-term mitigation).

The effectiveness of the proposed tool is strongly linked to the reliability of the seismic impact simulation both in terms of vulnerability analysis of the existing building stock, both in terms of level of damage expected following a given seismic scenario in terms of magnitude and location of the epicentre. The quality of the simulations produced through PLINIVS tools has been tested during the activities carried out as Competence Center of the Italian National Department of Civil Protection (established with the Decree of the Head of Department of Civil Protection n. 1922 May 15, 2006), through their application in supporting the emergency management operations, by applying as input of the model the real seismic events parameters, as in the case of L’Aquila 2009 and Centro Italia 2016 (August 24th event). Table 1 shows the comparison with actual data available from public repositories for the L’Aquila case, where only slight deviation (within the same order of magnitude) from the simulation output is registered.

Table 1: Comparison of building damage / casualty models output and real data from L’Aquila 2009 event (data limited to Municipality of L’Aquila)

Output	**Model**	**Real data**
Deads	249	272
Building losses (% of total buildings)	9.65%	12.5%

Source: PLINIVS-LUPT Study Centre

Data sources at national level for impact modelling are elaborated from the Italian National Institute of Statistics (ISTAT), calibrated through post-event direct surveys on site. Discrepancies between model output and real data can be explained by the differences in the total number of residential buildings (18.613 from direct surveys 2009 and 13.875 from ISTAT 2001), and especially by the variation in vulnerability classes distribution, especially for the weakest building typologies (class A and B), as shown in Figure 3.

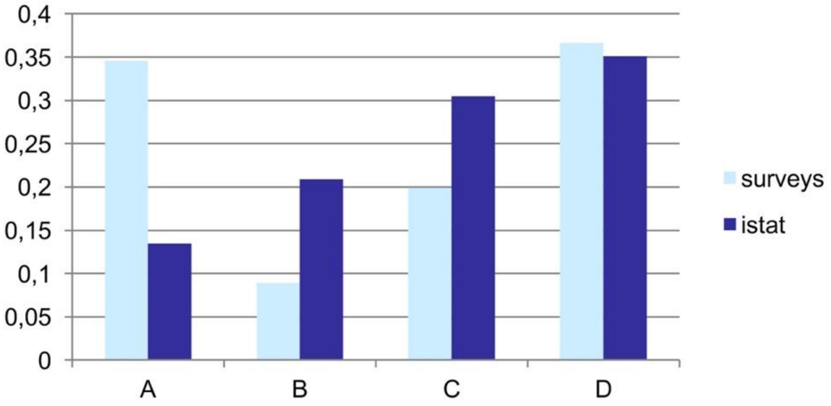

Figure 1: Comparison between vulnerability classes distribution in the Municipality of L'Aquila from direct surveys on site (2009) and ISTAT data (2001). *Source: PLINIVS-LUPT Study Centre*

For what concern the economic impact, the minor discrepancies observed between model and real data (see Table 3) are justified by the need of further calibrating back-office data during the process of customization of the general model to the L'Aquila application, where information related to e.g. average building surface area have been retrieved from surveys carried out at national level. A further refinement can be applied to rehabilitation and reconstruction unit cost.

Table 2: Comparison of economic model output and real data from L'Aquila 2009 event (data limited to Municipality of L'Aquila)

Output	Model	Real data
Emergency management	€ 794.806.611	€ 892.924.743
Reconstruction	€ 5.838.286.396	€ 5.254.571.840
Rumble clean-up	€ 28.241.574	€ 24.318.146
TOTAL ECONOMIC IMPACT	€ 6.661.334.581	€ 6.171.814.729

Source: PLINIVS-LUPT Study Centre

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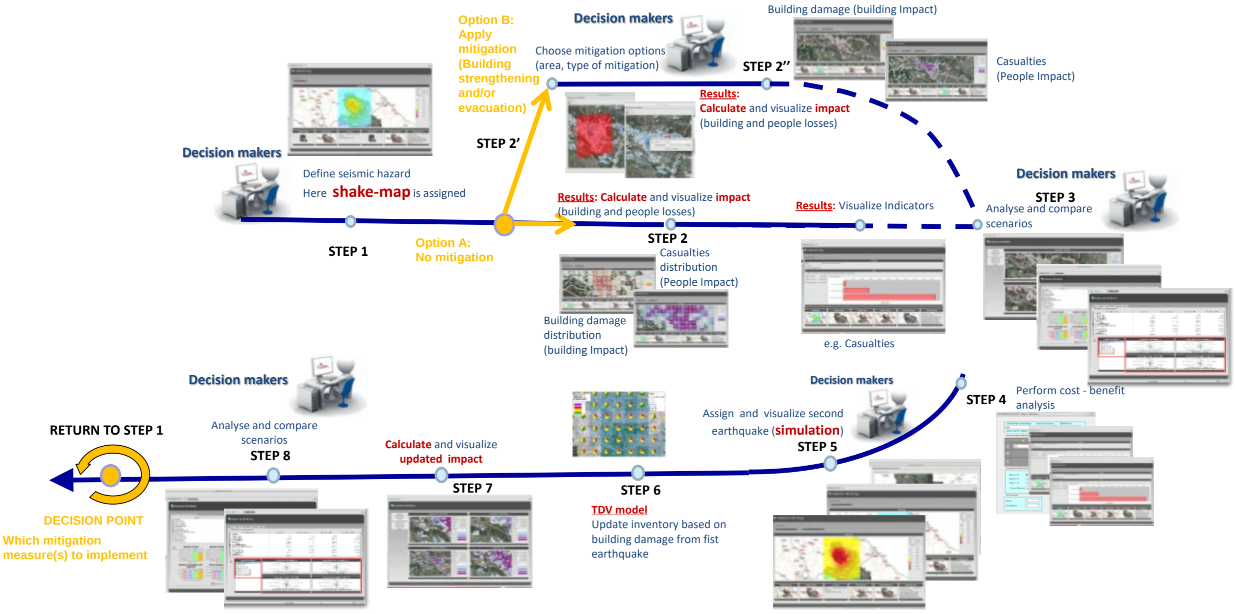
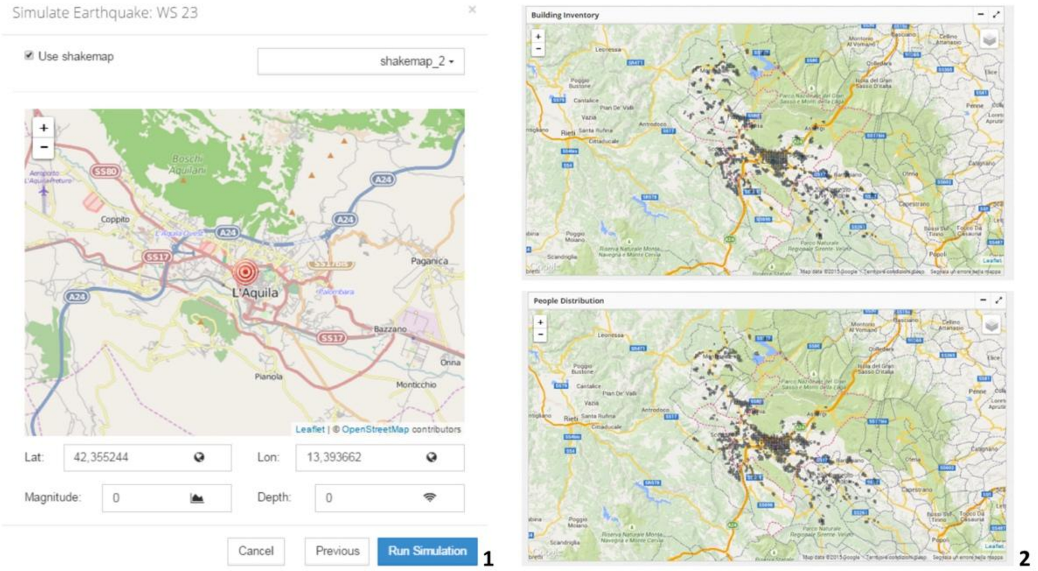


Figure 2: Sequential steps of a possible use case for Pilot D application allowing to evaluate the effects of possible mitigation actions (*source: Zuccaro et al., 2015*).

Figure 2 shows a possible sequence of steps related to the presented CRISMA Pilot application, aimed at understanding the effects of alternative mitigation options to reduce seismic risk, and the use of multi-criteria and cost-benefit analyses as decision support tools. It emphasizes the scope of comparing alternative crisis scenarios from simulations, corresponding to the application of different mitigation strategies (including no intervention), and supporting decision makers with the analysis of scenarios. The simulation of the cumulative damage on buildings when more seismic events strike the same area is addressed through the application of the Time Dependent Vulnerability model (Zuccaro et al., 2008; Polese et al. 2014).


Simulate Earthquake: WS 23

☑ Use shakemap — shakemap_2

Lat: 42,355244

Lon: 13,393662

Magnitude: 0

Depth: 0

Figure 3: Step 1 - Set up scenarios (define seismic hazard and exposure parameters). 1. GUI for selection of earthquake; 2. Building and population inventory.

At the first step (Figure 3), the hazard for the case study can be selected. Firstly, the number of Earthquake events is chosen, and the input mode for each seismic event in the series is selected (shake-map in terms of PGA or parameterization of the seismic hazard model with input of earthquake epicentre latitude and longitude, magnitude and depth). The chosen scenario may be developed at different levels, e.g. it can simply contain the initial data of the “world state” (e.g. inventory of vulnerable assets, lifelines, critical facilities, geographical data etc.), it may contain additional information (e.g. shake-map in terms of peak ground acceleration), or it may even be a pre-calculated impact scenario for the selected area. The tool allows the customization of the displayed information as typically done in GIS environments, e.g., overlapping geographical data with vulnerable assets or with the spatial distribution of the hazard parameters.

Once the reference scenario has been set up, the results of the impact simulation on selected elements at risk can be visualized. In particular, following option A, the impact is calculated without considering the application of possible mitigation actions. In the scope of L’Aquila pilot, PLINIVS models allow to estimate the impact of earthquakes on buildings (Building impact Model), on transport networks (Road Network Vulnerability model), on population (Earthquake casualty model) and on economy (Economic Impact model).

Figure 4 shows the scenario results, that can be visualized both in terms of maps showing the distribution of damage and casualties on the selected area (referred to geo-cells), and in terms of tables, showing the expected impacts according to indicators and criteria selected. The results are represented considering either average values of indicators, or values corresponding to 16% and 84% percentiles (labelled as AVG, MIN and MAX in the application).

In the pilot application, the following criteria have been set: n. of lost buildings; n. of unsafe buildings; n. of deaths; n. of injured; n. of homeless; direct damage costs; indirect damage costs; restoration costs.

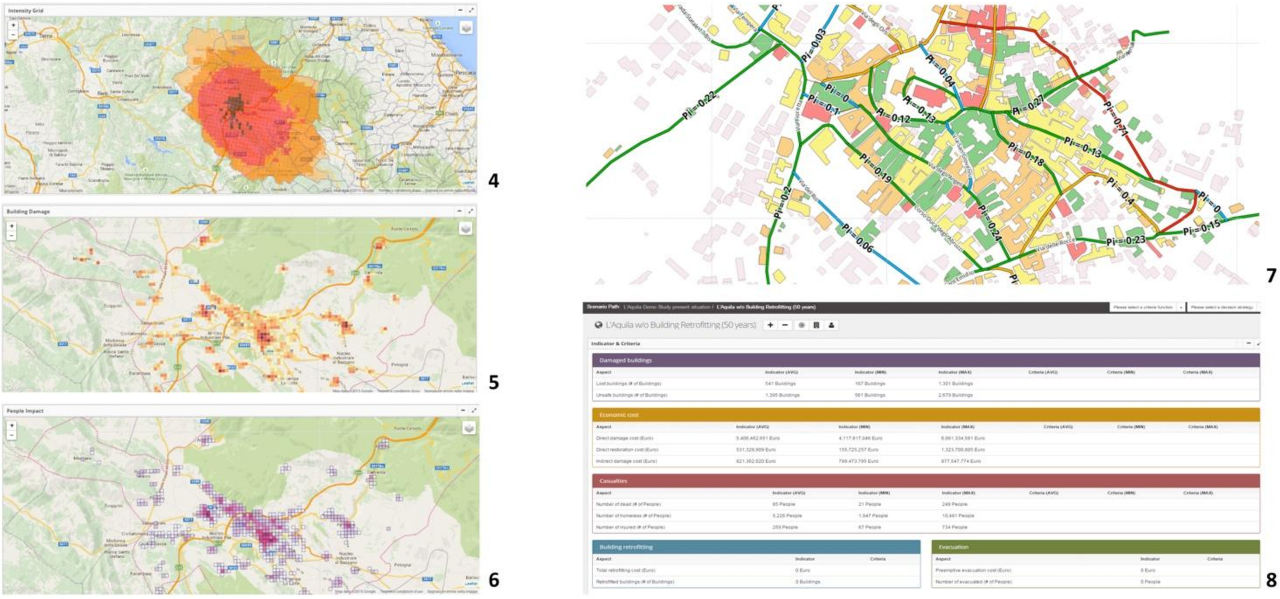
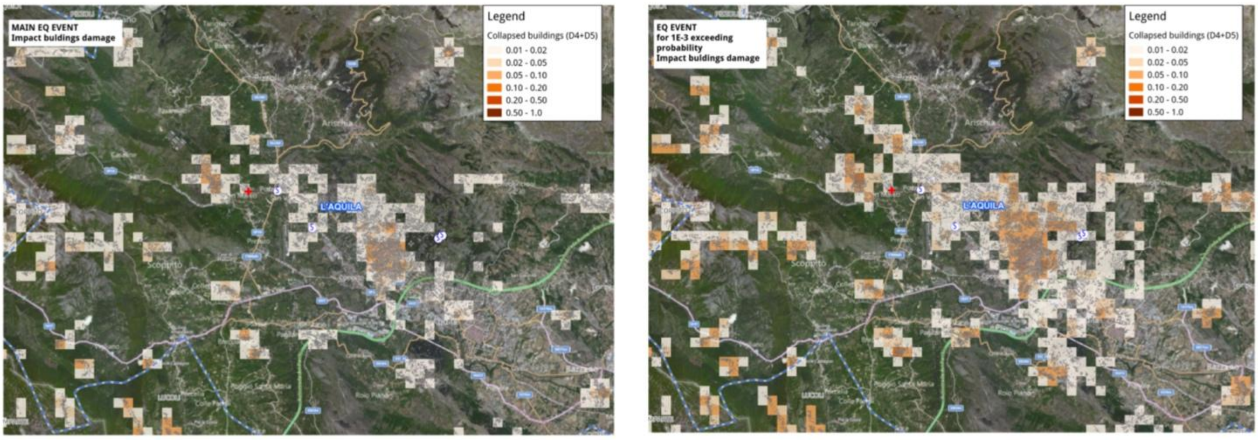


Figure 4: Step 2 - Calculate and visualize impact (OPTION A – No action). Average values for: 4. Hazard intensity, 5. Impact on people, 6. Damage on buildings; 7. Probability of interruption of the transport network links, color-coded; 8. Value of impact indicators after the simulation (see Figure 8 for readability).

The impact assessment can also include the simulation of a series of earthquakes and the consequent calculation of the expected cumulative damage on buildings, through the use of the Time Dependent Vulnerability model, based on stochastic/seismological models for the assessment of aftershock event occurrences that can straightforwardly be used to forecast future event occurrences (including the location). Time-dependent vulnerability functions enable the assessment of the cumulative effect of the sequence of events, which progressively load and deteriorate the inherent resistance capacity of building structures (Figure 5).



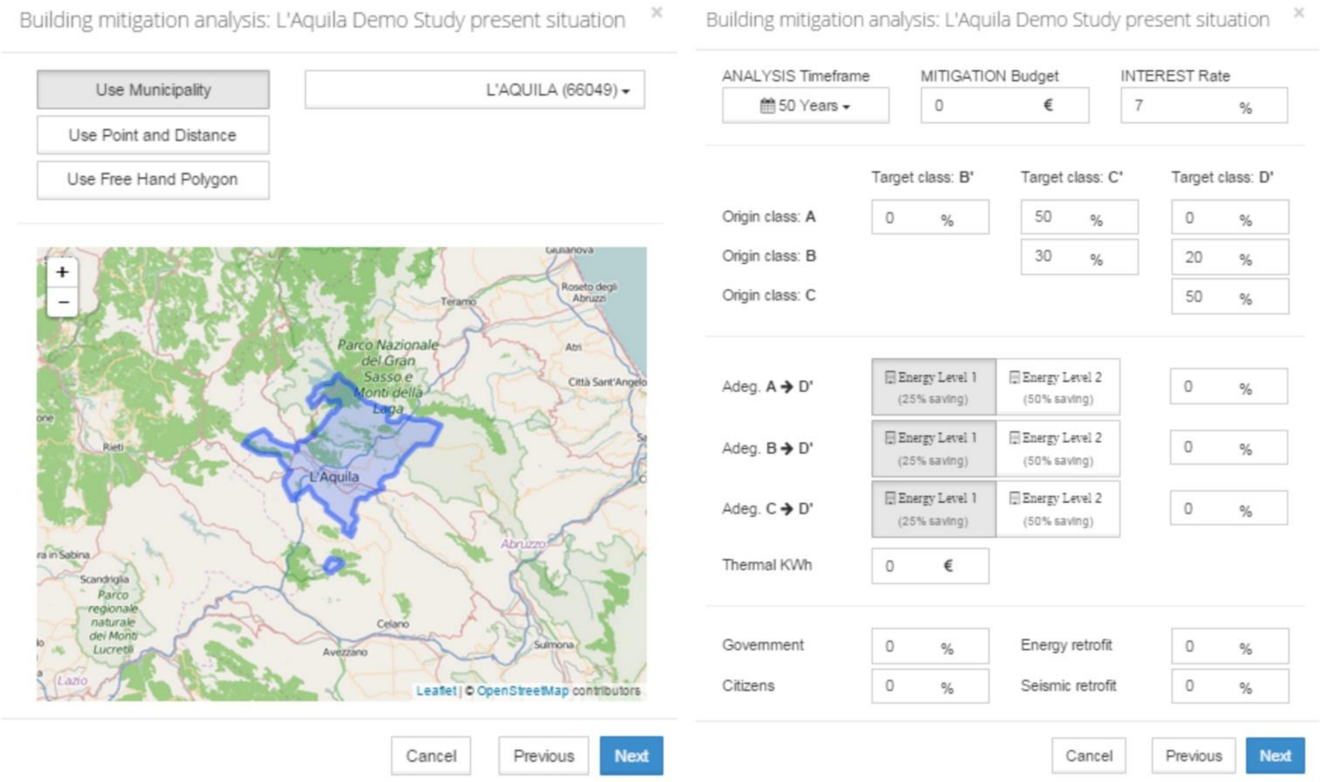
(a) (b)

Figure 5: Example of the impact assessment from a series of earthquakes: (a) collapsed buildings in the target area after the main seismic event; (b) collapsed buildings after a second triggered earthquake.

3. IMPACT ASSESSMENT AND EFFECTS OF ALTERNATIVE MITIGATION SCENARIOS

The key functionalities of CRISMA-NH are linked to the possibility of applying alternative “short-term” (population evacuation) and “long-term” (buildings retrofitting) mitigation options and assessing their effects on a given hazard scenario, both in terms of physical and economic impact reduction, with the support of multi-criteria and cost-benefit analyses.

The buildings retrofitting option represent the main mitigation measure aimed at reducing physical damages and casualties from a seismic event, to be applied in a long-term preparedness phase. In this context, the application of the mitigation option results in an improvement of the building vulnerability class (e.g. from A to C; B to D, etc.). Figure 6 shows the GUI to select the area of interest, using a free hand polygon on the GIS interface (other options for area selection are point and distance or name of Municipality) and set up of retrofitting parameters. In order to prepare the assessment of alternative retrofitting scenarios, the share of A, B, C class building that have to be improved (in this case 30% of A class buildings are brought to C class; 30% of B to C; 20% of B to D and 50% of C to B) can be selected. An additional option considers that seismic retrofitting is coupled with an “energy retrofitting” measure (2 options are included, targeting respectively 25% and 50% reduction of energy consumptions, to be applied on a selected share of retrofitted buildings, see Table 4), thus resulting in an extra cost for the mitigation option implementation. At the same time, however, that would provide a yearly cash flow from energy saving that would increase the cost-effectiveness of retrofitting action in case an earthquake occurs after many years once retrofitting action is completed. Moreover, the combined application of seismic and energy retrofitting measures allows a significant optimization of construction works, compared to the cost of the two interventions carried out separately, e.g. for what concerns demolition works, scaffolding, surface preparation, etc.


Building mitigation analysis: L'Aquila Demo Study present situation

Use Municipality
Use Point and Distance
Use Free Hand Polygon
L'AQUILA (66049)

Building mitigation analysis: L'Aquila Demo Study present situation

ANALYSIS Timeframe: 50 Years
MITIGATION Budget: 0 €
INTEREST Rate: 7 %

	Target class: B'	Target class: C'	Target class: D'
Origin class: A	0 %	50 %	0 %
Origin class: B		30 %	20 %
Origin class: C			50 %

Adeg. A → D'	Energy Level 1 (25% saving)	Energy Level 2 (50% saving)	0 %
Adeg. B → D'	Energy Level 1 (25% saving)	Energy Level 2 (50% saving)	0 %
Adeg. C → D'	Energy Level 1 (25% saving)	Energy Level 2 (50% saving)	0 %

Thermal KWh: 0 €

Government: 0 %
Citizens: 0 %
Energy retrofit: 0 %
Seismic retrofit: 0 %

Figure 6: Step 2' - Select mitigation options (OPTION B – Apply mitigation measure). Area selection and GUI for long-term mitigation - buildings retrofitting.

The evaluation of energy consumption reduction achievable by applying retrofitting interventions has been carried out through simulations with dedicated energy analysis software on two sub-sets of building samples related to masonry and reinforced concrete structures, taking into account the recurring building typologies, construction technologies and dimensional ratios available from the building inventory database. Parametric cost data have been modelled for each of the different vulnerability classes identified by the simulation model, as an average of the diverse construction and typo-morphological features identified for each class, including structure and walls, roof system and windows.

Table 4: Summary of energy retrofitting actions the two targeted levels of consumption reduction

Key "level 1" energy retrofitting actions (-25% consumption)	**Key "level 2" energy retrofitting actions (-50% consumption)**
• Thermal plaster application • Glazing system substitution • Roof insulation	• External insulation application • Glazing system substitution • Roof insulation • HVAC system substitution

Source: PLINIVS-LUPT Study Centre

A key variable of the tool is represented by the possibility of customizing the level of public funding for the retrofitting actions, both in terms of share of cost directly borne by the government, both in terms of tax incentives, thus resulting in different cost-benefit outputs related to "government" and "citizens" perspective (Figure 10). The tool also allows analysing the cost-benefit ratio of a given retrofitting scenario simply by modifying the time of the earthquake after the completion of mitigation actions setting different inputs in the "analysis timeframe" tab.

Once a set of "mitigated" scenarios is realized (either through the "evacuation" or "retrofitting" option), the impact of a seismic event can be re-calculated, resulting in a variation of expected physical damage thanks to the reduction of exposure and vulnerability (Figure 7), and in a variation of the economic impact, which in this case takes into account also the cost of mitigation actions implementation.

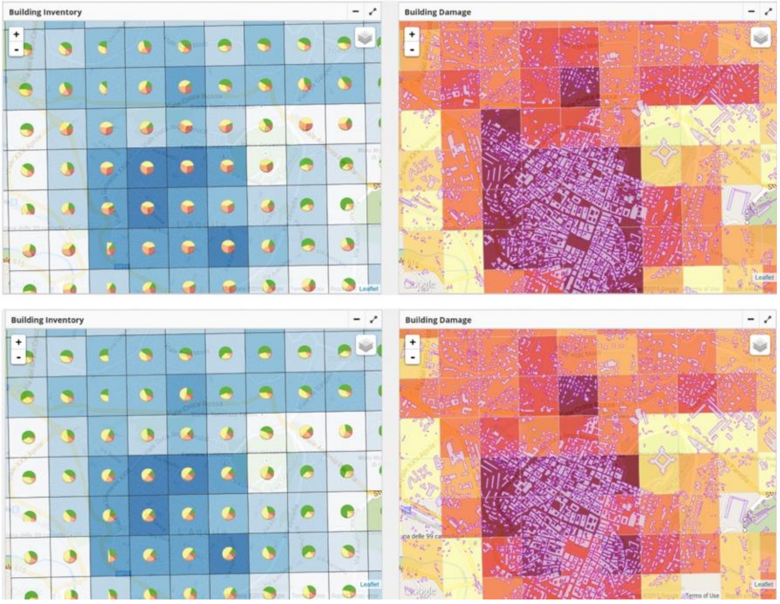
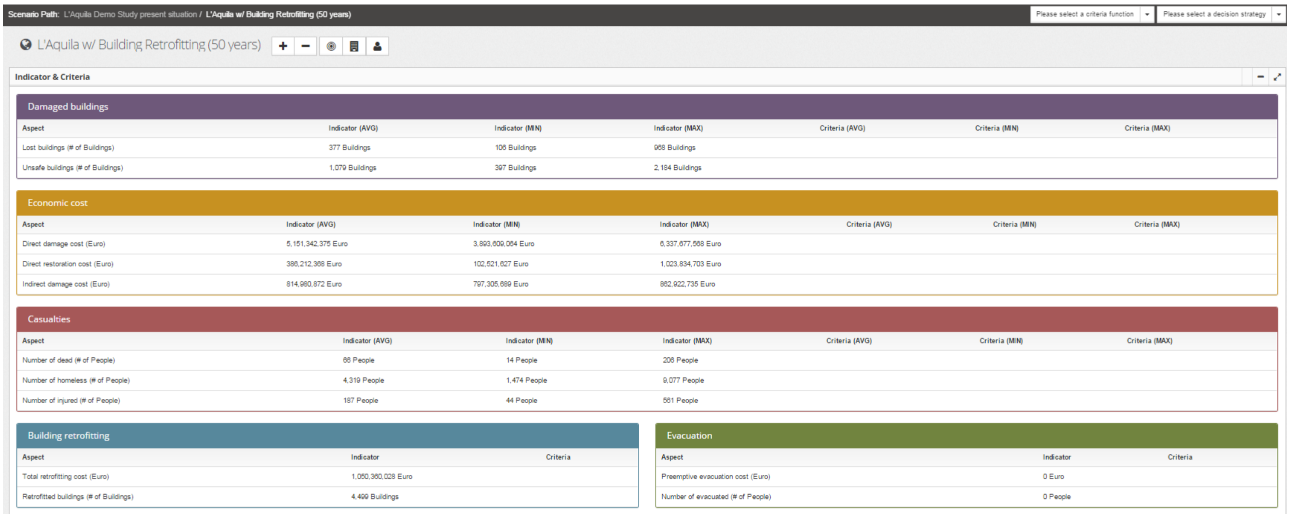


Figure 7: Displaying of impact variation following building retrofitting mitigation action. Vulnerability distribution and expected impact is shown on a map in case of no mitigation (top) and mitigation implementation (bottom).

After the simulation the results can be displayed. In Figure 8 the same indicators as in Figure 4 are shown, with values in the bottom sections corresponding to the building retrofitting indicators (namely: "n. of retrofitted buildings" and "total retrofitting cost").

In order to assess the effect of alternative mitigation measures compared to the "no action" scenario, the same hazard parameters should be set for the simulation, so to make the obtained results comparable both in terms of cost-benefit and according to the selected indicators for the multi-criteria analysis. The functionality "world state analysis and comparison" can be activated from the "Decision support" tab (Figure 9, left), with the possibility of selecting multiple world states to visualize and compare different aggregated indicators such as number of collapsed buildings, number of injured, deaths, homeless, total direct costs, etc. Different kinds of representations can be selected (e.g. bar chart, cake chart, radar chart, etc.) to facilitate comparison of the world states. In addition to the simple visualization and comparison of indicators, multi-criteria analysis can be performed. The Ordered Weight Analysis (OWA) approach enables to define custom decision strategies by choosing the relevance and weight of the different criteria. The ranking result is then visualized for every selected world state.



Scenario Path: L'Aquila Demo Study present situation / L'Aquila w/ Building Retrofitting (50 years)

L'Aquila w/ Building Retrofitting (50 years)

Indicator & Criteria

Damaged buildings

Aspect	Indicator (AVG)	Indicator (MIN)	Indicator (MAX)	Criteria (AVG)	Criteria (MIN)	Criteria (MAX)
Lost buildings (# of Buildings)	377 Buildings	106 Buildings	968 Buildings			
Unsafe buildings (# of Buildings)	1,079 Buildings	397 Buildings	2,184 Buildings			

Economic cost

Aspect	Indicator (AVG)	Indicator (MIN)	Indicator (MAX)	Criteria (AVG)	Criteria (MIN)	Criteria (MAX)
Direct damage cost (Euro)	5,151,342,375 Euro	3,893,609,064 Euro	6,337,677,568 Euro			
Direct restoration cost (Euro)	386,212,368 Euro	102,521,627 Euro	1,023,834,703 Euro			
Indirect damage cost (Euro)	814,980,872 Euro	797,305,689 Euro	862,922,735 Euro			

Casualties

Aspect	Indicator (AVG)	Indicator (MIN)	Indicator (MAX)	Criteria (AVG)	Criteria (MIN)	Criteria (MAX)
Number of dead (# of People)	66 People	14 People	206 People			
Number of homeless (# of People)	4,319 People	1,474 People	9,077 People			
Number of injured (# of People)	187 People	44 People	561 People			

Building retrofitting

Aspect	Indicator	Criteria
Total retrofitting cost (Euro)	1,050,360,028 Euro	
Retrofitted buildings (# of Buildings)	4,499 Buildings	

Evacuation

Aspect	Indicator	Criteria
Preemptive evacuation cost (Euro)	0 Euro	
Number of evacuated (# of People)	0 People	

Figure 8: Step 2'' - Calculate and visualize impact after mitigation. Value of indicators after mitigated scenario simulation, considering and building retrofitting.

The decision maker has the possibility to give a neutral, positive or negative emphasis to the overall mitigation strategy and to assign the single weight to each criterion. The level of satisfaction associated with each indicator according to the established criteria functions are shown e.g. through the radar chart. As final outcome of the overall multi-criteria analysis a world state ranking is produced, accounting for the preferred mitigation policy.

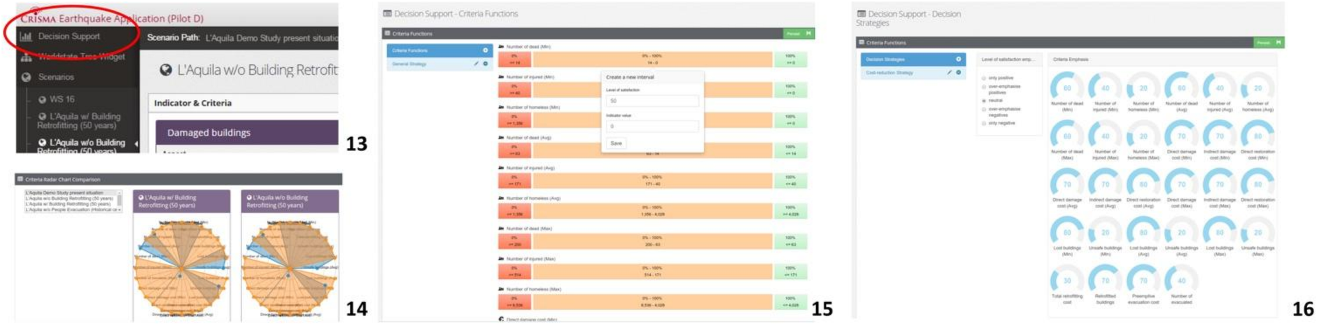
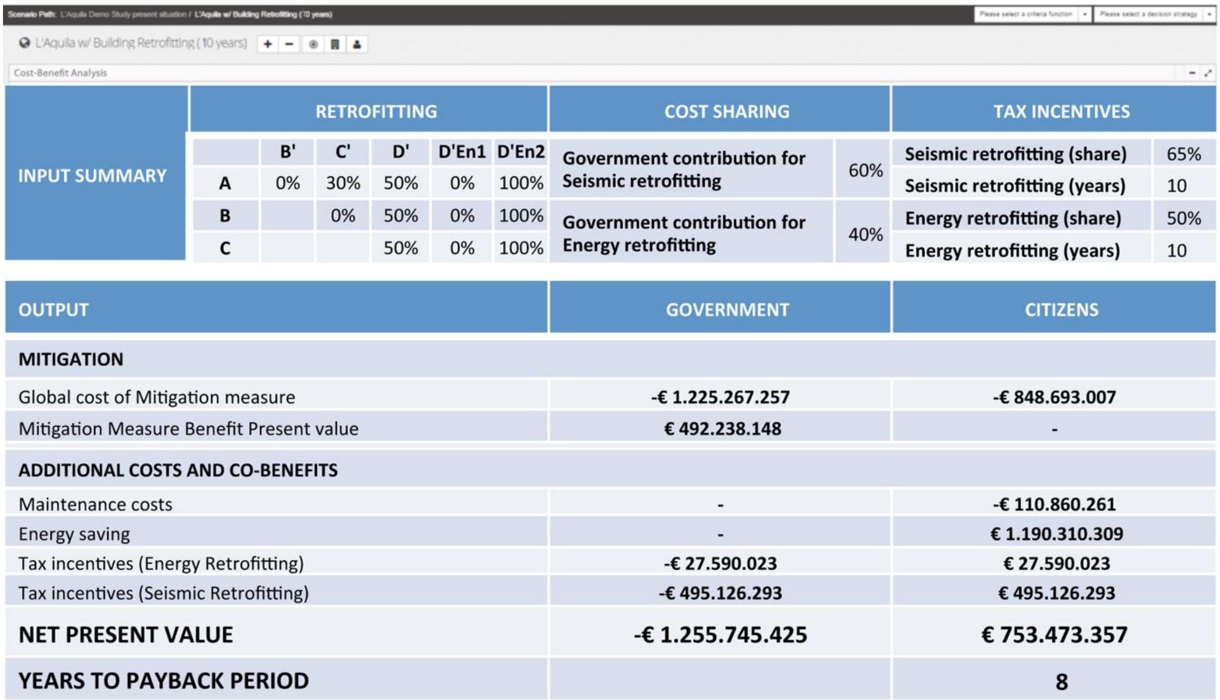


Figure 9: Step 3 - Analyze and compare scenarios (OPTION A vs B1, B2, Bn). Multi-Criteria Analysis: 13. activating the "Decision support" tab; 14. Radar chart comparison; 15. Customize criteria functions; 16. Customize criteria weighting.

The mitigation option assessment and world state comparison can be also performed through a cost-benefit analysis. The application of PLINIVS Economic impact model (Zuccaro et al., 2013) allows getting an estimation of direct and indirect costs following the impact of the earthquake, taking into account several parameters (direct costs: Evacuation post-event, emergency management, sanitary costs, rumble clean-up, building rehabilitation and reconstruction; indirect costs: value of lost lives, losses in local value added from evacuation and psychological effects), including the cost of implementation of eventual seismic retrofitting actions. Figure 10 shows the cost-benefit analysis of a building retrofitting scenario, where 30% of "A" vulnerability class buildings are improved to a "C" class, and 50% of “A”, “B” and “C” classes are improved to a “D” class, applying to all the 50% reduction energy retrofitting option.

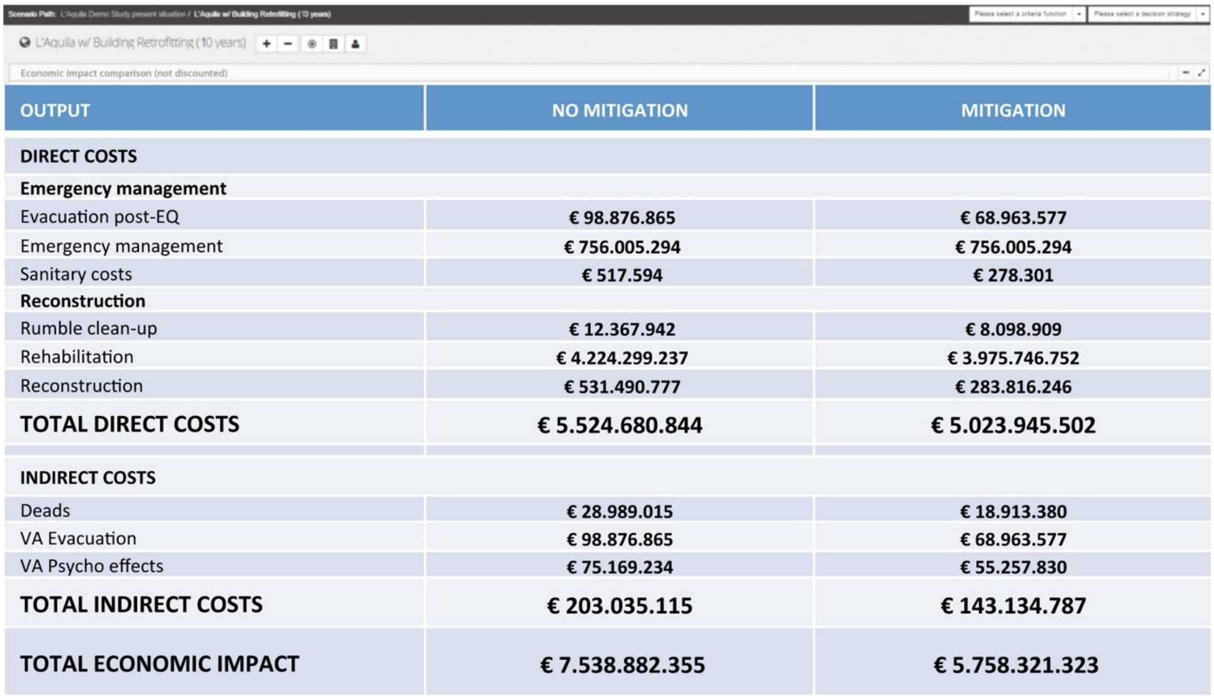
Figure 11 shows a comparison of expected economic impact with the “no mitigation” scenario.



INPUT SUMMARY	RETROFITTING						COST SHARING		TAX INCENTIVES	
		B'	C'	D'	D'En1	D'En2	Government contribution for Seismic retrofitting	60%	Seismic retrofitting (share)	65%
	A	0%	30%	50%	0%	100%			Seismic retrofitting (years)	10
	B		0%	50%	0%	100%	Government contribution for Energy retrofitting	40%	Energy retrofitting (share)	50%
	C			50%	0%	100%			Energy retrofitting (years)	10

OUTPUT	GOVERNMENT	CITIZENS
MITIGATION		
Global cost of Mitigation measure	-€ 1.225.267.257	-€ 848.693.007
Mitigation Measure Benefit Present value	€ 492.238.148	-
ADDITIONAL COSTS AND CO-BENEFITS		
Maintenance costs	-	-€ 110.860.261
Energy saving	-	€ 1.190.310.309
Tax incentives (Energy Retrofitting)	-€ 27.590.023	€ 27.590.023
Tax incentives (Seismic Retrofitting)	-€ 495.126.293	€ 495.126.293
NET PRESENT VALUE	-€ 1.255.745.425	€ 753.473.357
YEARS TO PAYBACK PERIOD		8

Figure 10: Step 4 - Cost-Benefit Analysis results according to the selected retrofitting scenario.



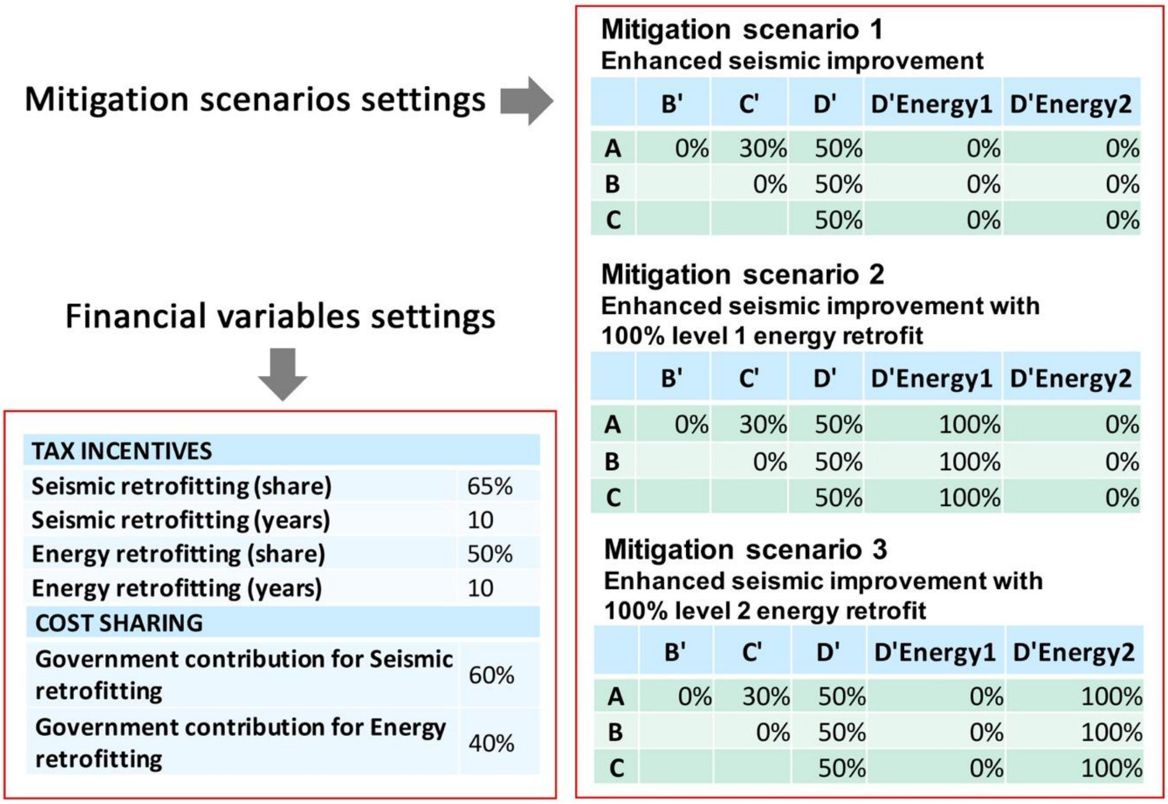
OUTPUT	NO MITIGATION	MITIGATION
DIRECT COSTS		
Emergency management		
Evacuation post-EQ	€ 98.876.865	€ 68.963.577
Emergency management	€ 756.005.294	€ 756.005.294
Sanitary costs	€ 517.594	€ 278.301
Reconstruction		
Rumble clean-up	€ 12.367.942	€ 8.098.909
Rehabilitation	€ 4.224.299.237	€ 3.975.746.752
Reconstruction	€ 531.490.777	€ 283.816.246
TOTAL DIRECT COSTS	€ 5.524.680.844	€ 5.023.945.502
INDIRECT COSTS		
Deads	€ 28.989.015	€ 18.913.380
VA Evacuation	€ 98.876.865	€ 68.963.577
VA Psycho effects	€ 75.169.234	€ 55.257.830
TOTAL INDIRECT COSTS	€ 203.035.115	€ 143.134.787
TOTAL ECONOMIC IMPACT	€ 7.538.882.355	€ 5.758.321.323

Figure 11: Step 4 - Comparison of economic impact (not discounted).

4. CONCLUSION

The application of an integrated retrofitting intervention which includes both seismic improvement and energy efficiency measures represents the most interesting outcome of the case study, and show the potential use of the tool both in the context of financial incentives allocation, both in case of planning of mass retrofitting at municipal or regional level.

Table 5 illustrates how the payback of investments, considering a 20 years' time window from the building retrofitting to the occurrence of a damaging earthquake, is present only when energy measures are implemented. The "retrofitting scenarios" hypothesized are represented in Figure 12.



Mitigation scenario 1
Enhanced seismic improvement

	B'	C'	D'	D'Energy1	D'Energy2
A	0%	30%	50%	0%	0%
B		0%	50%	0%	0%
C			50%	0%	0%

Mitigation scenario 2
Enhanced seismic improvement with 100% level 1 energy retrofit

	B'	C'	D'	D'Energy1	D'Energy2
A	0%	30%	50%	100%	0%
B		0%	50%	100%	0%
C			50%	100%	0%

Mitigation scenario 3
Enhanced seismic improvement with 100% level 2 energy retrofit

	B'	C'	D'	D'Energy1	D'Energy2
A	0%	30%	50%	0%	100%
B		0%	50%	0%	100%
C			50%	0%	100%

TAX INCENTIVES	
Seismic retrofitting (share)	65%
Seismic retrofitting (years)	10
Energy retrofitting (share)	50%
Energy retrofitting (years)	10
COST SHARING	
Government contribution for Seismic retrofitting	60%
Government contribution for Energy retrofitting	40%

Figure 12: Setting of alternative retrofitting scenarios (cost-benefit analysis results are shown in Table 5).

The proposed use of the tool is intended as a preliminary assessment of technical and financial actions to be taken into account while tackling the complex issue of mass seismic retrofitting of the residential building stock. The major advantages come from the potential of evaluating both the effects in terms of physical and economic impact reduction, following a given seismic scenario in the area object of the simulation (which can range from the municipality to regional level, according to data availability and models customization needs), both the effectiveness of different approaches in terms of costs' sharing and financial incentives, thus enabling decision makers and local authorities to implement policies and large scale programs aimed at safety improvements of the existing vulnerable building stock.

Table 5: Comparison of alternative retrofitting scenarios, highlighting the benefit in terms of return of investments when integrating energy efficiency measures (data limited to Municipality of L'Aquila)

Output	**Scenario 1** **seismic**		**Scenario 2** **seismic+energy25%**		**Scenario 3** **seismic+energy50%**	
	Government	**Citizens**	**Government**	**Citizens**	**Government**	**Citizens**
Mitigation (€)						
Global cost of Mitigation measure	-1.187.049.454	-791.366.303	-1.202.336.575	-814.296.984	-1.225.267.257	-848.693.007
Mitigation Measure Benefit Present value	492.238.148	0	492.238.148	0	492.238.148	0
Additional costs and co-benefits (€)						
Maintenance costs	0	-4.120.963	0	-102.490.612	0	-110.860.261
Energy saving	0	0	0	595.155.154	0	1.190.310.309
Tax incentives (Energy Retrofitting)	0	0	-11.036.009	11.036.009	-27.590.023	27.590.023
Tax incentives (Seismic Retrofitting)	-495.126.293	495.126.293	-495.126.293	495.126.293	-495.126.293	495.126.293
Net Present Value (€)	-1.189.937.599	-390.360.972	-1.216.260.730	184.529.861	-1.255.745.425	753.473.357
Years to Payback		**n.a.**		**13**		**8**

Source: PLINIVS-LUPT Study Centre

5. ACKNOWLEDGEMENT

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