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LIQUEFACT

Assessment and mitigation of Liquefaction potential across Europe: a holistic approach to protect structures/infrastructure for improved resilience to earthquake-induced Liquefaction disasters.

H2020-DRA-2015

GA no. 700748

DELIVERABLE D1.4

Detailed user requirements and research output protocols for the LIQUEFACT Reference Guide

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GLOSSARY

Acronym	Description
EILD	Earthquake Induced Liquefaction Disaster
RAIF	Resilience Assessment Improvement Framework
FCM	Fuzzy Cognitive Map
SH	Stakeholder
BAMP	Built Assessment Management Plan
WP	Work Package

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EXECUTIVE SUMMARY

Recent events have demonstrated that Earthquake Induced Liquefaction Disasters (EILDs) are responsible for significant structural damage and casualties with, in some cases, EILDs accounting for half of the economic loss caused by earthquakes. With the causes of Liquefaction being substantially acknowledged, it is important to recognize the factors that contribute to its occurrence; to estimate the impacts of the EILD hazards; and to identify and implement the most appropriate mitigation strategies that improve both building/infrastructure and community resilience to an EILD event.

The LIQUEFACT project adopts a holistic approach to address the mitigation of risks to EILD events in European communities. The LIQUEFACT project sets out to achieve a more comprehensive understanding of EILDs, the applications of the mitigation techniques, and the development of more appropriate techniques tailored to each specific scenario, for both European and worldwide situations.

INTRODUCTION, GOAL AND PURPOSE OF THIS DOCUMENT

The Resilience Assessment and Improvement Framework (RAIF) is a decision support tool that can be used by built assets owners and/or managers to assess the antecedent vulnerability, resilience and adaptive capacity of their built assets (buildings and infrastructure) to EILD events. The framework can also be used by EU, national, regional and local decision makers to assess vulnerability, resilience and adaptive capacity of urban communities to EILD events.

The framework integrates the outputs from WP2 to 6 and allows different stakeholders groups to make decisions about liquefaction mitigation options.

This report establishes the user requirements for the framework in order to ensure consistency in the format of outputs from the different WPs to guarantee the effectiveness of the framework.

This report will:

- Recall the description of the Resilience Analysis and Improvement Framework (RAIF) from Deliverable 1.3 and explain the 6 stages that allow users to make improvement decisions at all levels (chapter 1);
- List the data/information requirements to integrate outputs from the other WPs into the RAIF (chapter 2);
- Develop protocols for data collection, analysis and reporting for sharing data and outputs between work packages in line with the project Data Management Plan, including standard protocols for the integration of the outputs into the RAIF and liquefaction mitigation planning and decision support software toolbox (chapter 3);
- Explain the relationship between WP5 and WP6 and show how the RAIF will be implemented in the SELENA-LRG software to complement the structural damage and socio-economic resilience analyses (chapter 4);
- Establish a lexicon of common terms that will be used throughout all the LIQUEFACT project by all project partners (chapter 5);
- Summarise all the tasks and outline the next steps including establishing virtual workshops amongst project researchers (chapter 6).

In addition to the above the report will also introduce the Fuzzy Cognitive Map (FCM) method which will be developed in the LIQUEFACT project (WP5) as the basis to assess antecedent community resilience to a liquefaction event and to evaluate the potential improvement to community resilience that could be achieved by adopting a range of mitigation measures. The FCM method will be used to develop a model of the complex interactions between community attributes in a way that acknowledges causal relations and accommodates inherent uncertainties between relevant community attributes. The FCM tool will also provide the opportunity to study the behaviour of the system in detail and to explore the effect that the various mind models of different stakeholders have on community resilience to EILD events.

Goal: **This document aims at establishing a common working practice to ensure that activities undertaken in other work packages produce outputs that are directly usable in the decision making framework.**

SCOPE OF THIS DOCUMENT

The review presented in this report should be considered a work in progress which will be amended and modified throughout the duration of the LIQUEFACT project to reflect emerging issues identified by project partners and any location specific characteristics of the 4 case study sites identified by the external stakeholder and expert advisory groups.

TARGET AUDIENCE

This report provides an overview reference guide for both internal LIQUEFACT project partners and researchers as well as external stakeholders and interested parties wishing to further develop EILD understanding.

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DETAILED USER REQUIREMENTS AND RESEARCH OUTPUT PROTOCOLS FOR THE LIQUEFACT REFERENCE GUIDE

1 Introduction

1.1 The Resilience Assessment and Improvement Framework (RAIF) is a decision support tool that can be used by built assets owners and/or managers to assess the antecedent vulnerability, resilience and adaptive capacity of their built assets (buildings and infrastructure) to EILD events. The framework can also be used by EU, national, regional and local decision makers to assess vulnerability, resilience and adaptive capacity of urban communities to EILD events.

1.2 The framework integrates the outputs from WP2 to 6 and allows different stakeholders groups to make decisions about liquefaction mitigation options.

1.3 In order for the framework to function effectively, user requirements and research output protocols are established to ensure consistency in the format of outputs from the different WPs and transferability of all the data generated in each work package.

1.4 Over the last seven months four formal meetings have been organised to gather all the project partners together to discuss the user requirements and to define the interrelationships between the various WPs.

1.5 The kick off meeting held in May explored the strategic direction of the project and sought to identify the inter-relationships within and between WPs and to establish procedures to manage inputs into WPs from all those involved with the LIQUEFACT project.

1.6 The stakeholder meeting held in Bologna (03/10/2016) presented the LIQUEFACT project to 205 professionals involved in earthquake resilience in the Emilia Romagna Region of Italy and sought their views on the strategic aims and objectives of the project. Although the data gathered from this meeting is still being analysed initial findings confirmed the appropriateness of the approach outlined in the LIQUEFACT project for improving community resilience to EILD events and these findings have been used to inform this report.

1.7 Following the stakeholder meeting a two-day workshop examined interim outputs from WP1 (theory of community resilience to disaster events and the RAIF) and WP2 (site selection). As part of the discussion around these outputs, and in particular how the RAIF could be used in practice, the team explored the data needs of the RAIF and how these needs would be satisfied by other LIQUEFACT WPs. From these discussions a definition of the specification for the data, tools and models needed by the LIQUEFACT project was developed along with a lexicon of common terminology that would be used throughout the LIQUEFACT project.

1.8 Finally, a one day training course was provide by project partner NORSAR on the theoretical background to, and application of, the current SELINA-LRG software tool. This training ensured that the LIQUEFACT project consortium understood how their own work would feed into the

SELINA-LRG software and raise awareness of the data that would be needed from their WP to support the software, design guidance and the RAIF.

2 The Resilience Assessment and Improvement Framework (RAIF)

2.1 Background

2.1.1 The RAIF is the result of the desk based study conducted through Deliverable 1.1 and 1.3 and provides a decision support framework to assess the improvements in resilience that could be achieved through mitigation actions, which seek to reduce vulnerability or enhance adaptive capacity to EILD events. The RAIF provides an over-arching structure in which built asset management mitigation decisions are made in response to an EILD event. The RAIF, through the use of a FCM of local community resilience, will allow alternative mitigation scenarios to be evaluated and their wider socio-economic impact on the resilience of the urban community to be assessed.

2.1.2 The RAIF will be used by built asset owners and/or managers to assess the impact of an EILD event on individual buildings/infrastructure assets, multiple buildings/infrastructure assets on a single site, or portfolios of buildings/infrastructure assets across multiple sites. The RAIF can also be used by international, EU, regional and local decision makers to assess the impact of an EILD event on community support systems (e.g. healthcare, public transportation, etc.). The RAIF also provides a mechanism to assess the potential improvements to the resilience of built assets and community systems that can be achieved from a range of mitigation actions.

2.1.3 The RAIF provides the theoretical basis for the development of a range of decision support tools (to be developed in WPs 5 and 6) that will be integrated into the SELENA-LRG Software and associated LIQUEFACT decision making toolbox.

2.1.4 The framework consists of 6 stages (Fig. 1) that help stakeholders to:

- Assess the hazard liquefaction susceptibility and define physical vulnerabilities of assets;
- Assess the impact of the EILD event and the relative loss of function of the asset;
- Identify possible mitigation measures to reduce failure probabilities and the consequences of loss of function on community resilience;
- Evaluate the adoption of mitigation measures in terms of improvements to community resilience;
- Cost and prioritize the mitigation measures to optimize adaptive capacity;

- Develop built asset management plans.

2.1.5 Further details of the RAIF can be found in LIQUEFACT Deliverable 1.3.

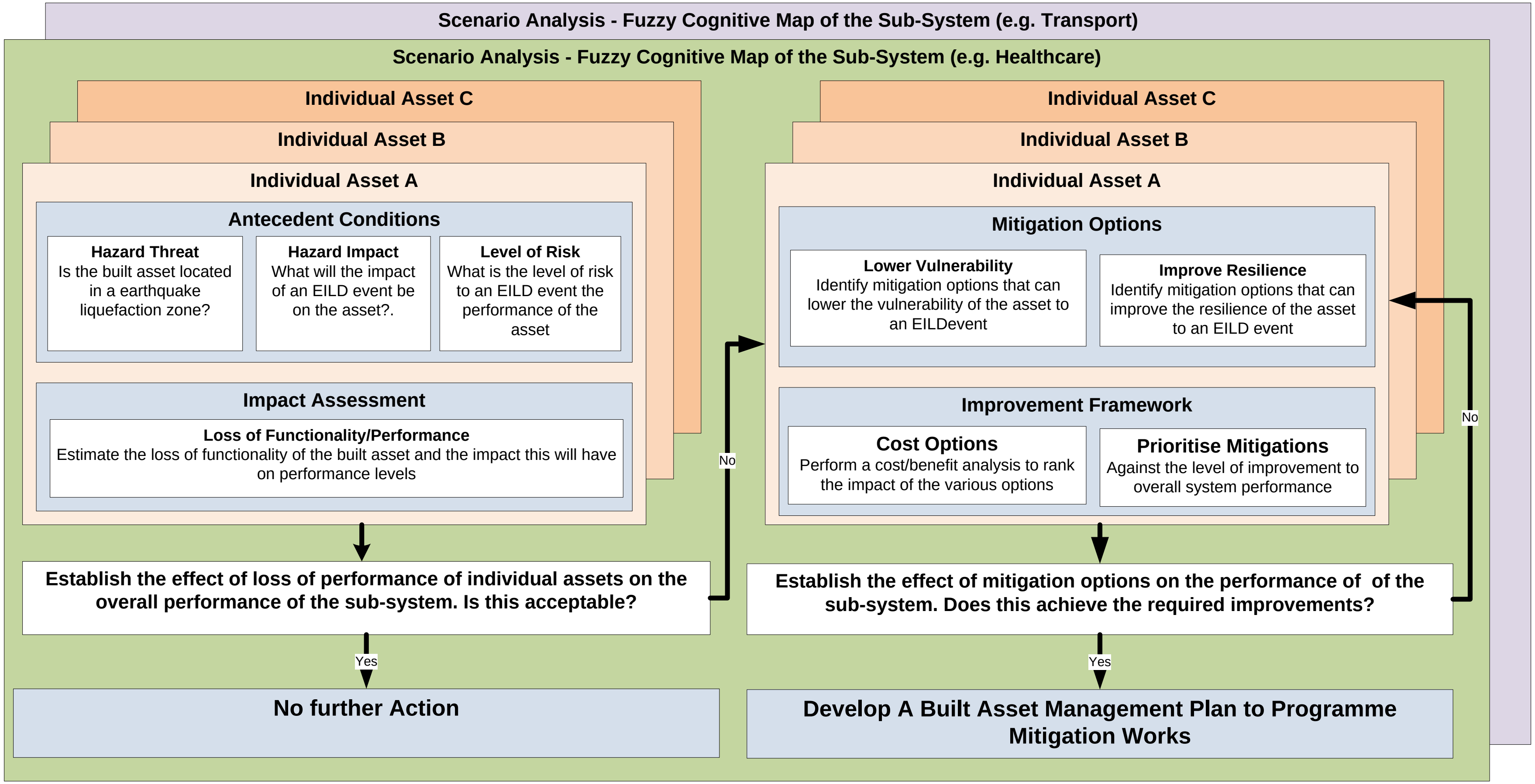

Figure 1: Resilience Assessment and Improvement Framework (adapted from the CREW Adaptation Framework, 2012)

2.1.5 The RAIF developed for the LIQUEFACT project is based on the risk/resilience framework developed by Prof Jones in the CREW project, which examined the factors that affected community resilience to extreme weather events. The CREW project developed and tested a 6 stage adaptation framework that was integrated into a built asset management model that would allow building owners/managers to identify and programme interventions (physical and social) to improve the resilience of their built assets to extreme weather events. Whilst the stressor behind the disaster risk associated with the LIQUEFACT project is different to that used in the CREW project the general theory supporting the adaptation framework is similar. The underlying theory is based on Cutter's (2008) Disaster Resilience of Place model (Fig. 2) in which antecedent conditions, including coping response and absorptive capacity, directly affect speed of recovery and system resilience.

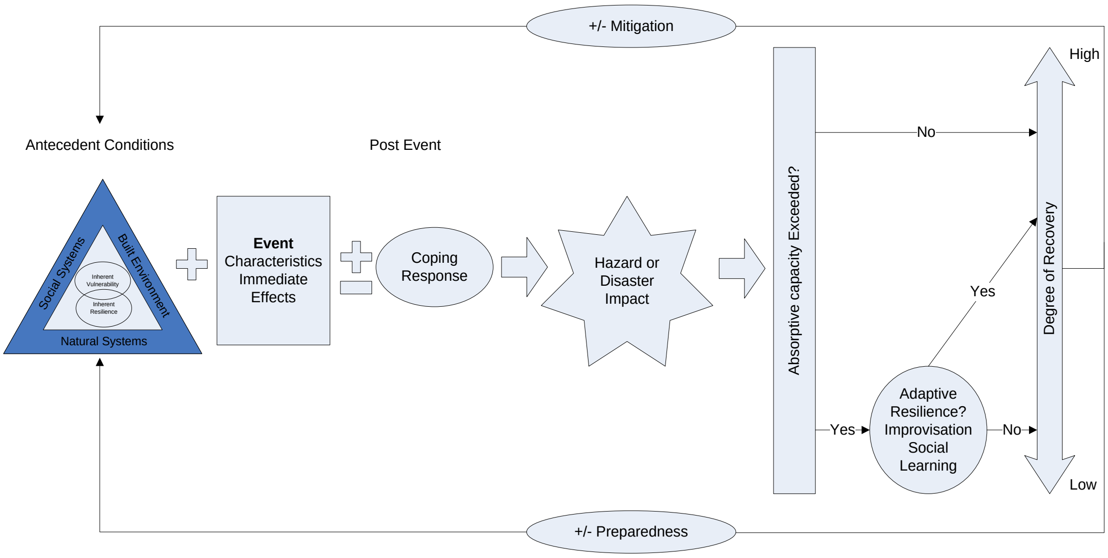

Figure 2: Schematic representation of the disaster resilience of place (DROP) model (Source: Cutter et al, 2008)

2.1.6 The LIQUEFACT project has re-interpreted the adaptation framework developed in the CREW project to reflect the specific characteristics associated with EILD events to provide guidance on the metrics, tools and models that need to be developed (WP's 2, 3, 4 and 5) to operationalise the RAIF and provide the input into the SELENA-LRG software toolkit and wider guidance documentation[1].

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[1] More details of the CREW project, funded by the EPSRC, can be found here: http://www.arcc-network.org.uk/wp-content/pdfs/CREW_Final_Report.pdf

2.1.7 In order for the RAIF to function effectively the format of the outputs from the different WPs must be consistent with each other and the data generated in each work package must be directly transferable to other WPs. The remainder of this section identifies the data interactions between WPs and the RAIF. Each stage of the RAIF is described in detail and its potential application to a region is described using a simplified primary health care scenario.

Case study box 1: Primary Health Care Scenario

The facilities manager for a regional hospital has been asked to assess the potential impact of an EILD event on the functioning of the hospital. The hospital is located on 4 sites across a small city. Each site contains a number of buildings that provide primary care, administrative and support services to the city community. Whilst each hospital unit concentrates on a primary specialism (e.g. maternity, oncology etc.) they all have a small emergency unit and orthopaedic capabilities. The hospital's buildings range from 100 year old masonry structures; through 50 year old steel and concrete frame structures to modern pre-cast modular units. All buildings are in a good state of repair.

2.2 Stage 1: Antecedent Condition Analysis

2.2.1 The first stage of the RAIF requires an assessment of the vulnerability of an asset (e.g. individual building/infrastructure asset, portfolio of buildings/distributed infrastructure assets, town/city wide buildings/infrastructure, regional wide buildings/infrastructure, state wide buildings/infrastructure assets etc.) to an EILD event. The first stage of this assessment is to identify whether the asset is located in a geographical area likely to be affected by an EILD event.

2.2.2 WP2 will develop a GIS platform to be used for localised regional assessments of EILD hazards across Europe and to develop a European Liquefaction Hazard Mapping Framework. Through a review of past liquefaction occurrences in Europe areas prone to liquefaction will be identified. This information will be integrated into a GIS platform which will allow end-users to geo-locate their built/infrastructure asset(s) onto the platform and assess their Hazard Level to a localised liquefaction event. If there is no exposure then the assessment is complete. If there is an exposure then the level of the exposure is investigated further.

2.2.3 For each built/infrastructure asset identified as at potential exposure to an EILD event the level of hazard is evaluated by considering the probability of an earthquake hazard and the susceptibility of the ground to liquefaction. The data on liquefaction hazard mapping generated in WP2 will be used to develop a Susceptibility Matrix (Table 1) that relates Earthquake Characteristic to Ground Characterization to identify the level of Hazard of the asset. The level of hazard will be classified using qualitative labels ranging from "Very Low" to "Very High" that express the level of likelihood of the ground below the asset to liquefaction for any given earthquake characteristic. This analysis will provide asset managers and other stakeholders with an assessment of the range of exposures that their asset(s) are likely to be susceptible to.

		Earthquake Hazard Characteristic					
		TBD	TBD	TBD	TBD	TBD	TBD
Ground Characterization	TBD	Medium	Medium	High	High	Very High	Very High
	TBD	Low	Medium	Medium	High	High	Very High
	TBD	Low	Low	Medium	Medium	High	High
	TBD	Very Low	Very low	Low	Low	Medium	Medium
	TBD	Very Low	Very Low	Very Low	Low	Low	Medium

Table 1: Hazard level matrix for selected site

Case study box 2: Hazard level of a hypothetical health care structure

The GIS map allows the hospitals facilities manager to geo-locate each of the hospital's built assets onto the European Liquefaction Hazard Mapping Framework and to identify those assets that are potential exposed to EILD event. For each asset that is potentially exposed to such an event the facilities manager can assess the level of exposure of the assets using Table 1. The exposure for each asset will comprise a range of levels depending on the assumptions made about the earthquake characteristics (e.g. intensity range) and ground conditions. Because of the granularity of the data available at this stage of the assessment the levels of exposure are indicative and will require refinement before any detailed mitigation actions are programmed.

On applying the above methodology the facilities managers has identified that two of the hospital's sites are located in an earthquake zone where the generic ground conditions are prone to liquefaction. The hazard level for each of these sites ranges from medium to high depending upon the earthquake characteristic scenario considered. Each of these sites therefore warrants further investigation.

2.2.4 In order to assess how an individual building/infrastructure asset is likely to be affected by an EILD hazard an assessment needs to be made of the potential impact of liquefaction on the integrity of the building/infrastructure assets on the site. This in essence will be an assessment of the inherent level of vulnerability/resilience of a building/infrastructure asset topology to a potential EILD event. For buildings, for example, the vulnerability/resilience is likely to be a combination of construction and foundation type. The typical vulnerability matrix shown in Table 2 below provides a rapid screening tool with which to identify the relative levels of vulnerability/resilience of each building on a site. The level of vulnerability/resilience will be classified using qualitative labels ranging from "Very Low" to "Very High". Although the vulnerability/resilience matrix in Table 2 is shown as 2 dimensional it is more likely to be 3 dimensional to take account the different hazard levels identified in Table 1 above.

2.2.5 WP3 will identify different building/infrastructure topologies and assess their inherent resilience to EILD events. The data from these assessments will be used to develop the classification systems needed to assess the potential level of damage of a range of building/infrastructure assets to the ground condition scenarios identified in WP2.

		Building/infrastructure typology					
		TBD	TBD	TBD	TBD	TBD	TBD
Foundation typology	TBD	Medium	Medium	High	High	Very High	Very High
	TBD	Low	Medium	Medium	High	High	Very High
	TBD	Low	Low	Medium	Medium	High	High
	TBD	Very Low	Very low	Low	Low	Medium	Medium
	TBD	Very Low	Very Low	Very Low	Low	Low	Medium

Table 2: Typical Building Vulnerability/Resilience Matrix

Case study box 3: Vulnerability of a hypothetical health structure

The facilities manager undertakes further investigation of the two hospital sites located in an earthquake zone where the generic ground conditions are prone to liquefaction.

Hospital A contains a single multi-story hospital building with a footprint of about 1000m^2. The building is of steel frame construction with infill panel walling designed and built to national design and construction codes applicable in the 1990's. The buildings foundations are typical for this type of building. The vulnerability/resilience of this building topology for a medium level of hazard-exposure from Table 2 is likely to be low whilst for a high level hazard-exposure it is likely to be medium.

Hospital B contains 4 low rise hospital buildings located separately on a large site. Each building has a separate primary function (acute medical services, out-patient services, administration, and support services). The buildings are of different construction types and date from the 1920's to the 1970's. All the buildings have been regularly maintained and refurbished so that they are currently in good condition. The buildings foundations are typical for the different types of building. The vulnerability/resilience level of these building topologies under the medium level hazard-exposure scenario has been assessed as:

- Building A – Low
- Building B – Low
- Building C – Medium
- Building D – High

The vulnerability/resilience of these building topologies under the high level hazard-exposure scenario has been assessed as:

- Building A – Medium
- Building B – Medium
- Building C – High
- Building D – Very High

2.3 Stage 2: Impact Assessment

2.3.1 The two scores from the hazard-exposure and vulnerability/resilience matrices (Table 1 and Table 2) will be used to assess the level of risk to building/infrastructure asset(s) which in turn will be used as the basis to assess the loss of functionality of the building/infrastructure asset(s) immediately following an EILD event (Table 3). The loss of functionality will be made on a case by case basis using the expert knowledge of the facilities manager and building users to interpret the impact that any given level of risk will have on functionality and performance. It is currently assumed that the loss of functionality will be categorised using qualitative labels ranging from "minor cosmetic damage" to "major structural damage" with the loss of performance being a further qualitative statement contextualising the impact of the loss of functionality.

		Hazard Level					
		TBD	TBD	TBD	TBD	TBD	TBD
Building Level	TBD	Medium	Medium	High	High	Very High	Very High
	TBD	Low	Medium	Medium	High	High	Very High
	TBD	Low	Low	Medium	Medium	High	High
	TBD	Very Low	Very low	Low	Low	Medium	Medium
	TBD	Very Low	Very Low	Very Low	Low	Low	Medium

Table 3: Level of risk of the single asset

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Case study box 4: Risk/Impact Assessment of a hypothetical health structure

Hospital A has a low vulnerability/resilience when exposed to a medium level hazard event; and a medium vulnerability/resilience when exposed to a high level hazard event. Thus the potential impact on functionality for the medium level hazard exposure scenario is likely to be Low whilst the for the high level hazard exposure scenario it is likely to be High.

For the Low Risk scenario discussions between the facilities manager, building users and the health authorities technical consultants identified the likelihood of "minor cosmetic damage" to the building resulting in minimal impact on the performance of the hospital immediately following an EILD event. The hospital could be back to full performance levels once emergency clean-up operations were complete.

For the High Risk scenario discussions between the facilities manager, building users and the health authorities technical consultants identified the likelihood of "major structural damage" to the building resulting in complete loss of performance of the hospital immediately following an EILD event. The hospital would be back to full performance levels once rebuilding work had been completed.

A similar exercise for Hospital B identified 4 risk scenarios for each hazard-exposure level. For the medium level hazard-exposure scenario the level of risk, impact on functionality and loss of performance were:

- Building A – Low Risk; minor cosmetic damage; minimal impact on performance
- Building B – Low Risk; minor cosmetic damage; minimal impact on performance
- Building C – Medium Risk; cosmetic damage and minor building services disruption; major impact on performance until post event safety checks on building services are complete then depending on the outcome of the checks full performance levels will be achieved once repairs are complete.
- Building D – High Risk; major structural damage; complete loss of performance until repairs are complete.

The vulnerability/resilience of these building topologies under the high level hazard- exposure scenario has been assessed as:

- Building A – Medium Risk; cosmetic damage and minor building services disruption; major impact on performance until post event safety checks on building services are complete then depending on the outcome of the checks full performance levels will be achieved once repairs are complete.
- Building B – Medium Risk; cosmetic damage and minor structural damage; major impact on performance until post event safety checks on building integrity are complete then depending on the outcome of the checks parts of the hospital may be out of action until structural repairs are complete. Full performance levels will be only achieved once repairs are complete.
- Building C – High Risk; major structural damage; complete loss of performance until repairs are complete.
- Building D – Very High Risk: partial or full failure of the building; complete loss of performance until rebuilding is complete.

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2.4 Stage 3: Community Impact Scenarios

2.4.1 The impact of the loss of performance of individual building/infrastructure assets on the resilience of a community following an EILD event will be assessed by integrating the performance outcomes identified in stage 1/2 of the RAIF (above) into a FCM (stage 3 of the RAIF) that describes the complex relationships (physical, social, organizational, economic etc.) that constitute a communities resilience to disaster events.

2.4.2 The resilience modelling component of the RAIF seek to identify and investigate all the factors that influence the vulnerability, resilience and adaptive capacity of an urban community to an EILD event. Unfortunately, because of inter-relationships and interdependences between resilience indicators (resilience, vulnerability and adaptive capacity are in essence concepts and as such cannot be measured directly) and the uncertainties that these place on quantitative measurements, resilience in absolute terms is difficult to measure.

2.4.3 However, resilience is an essential concept in hazard research as it provides a mechanism to estimate the ability of a system, community or society exposed to a hazard to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner. This estimation plays a fundamental role in supporting the decision making process that drives the development of hazard mitigation strategies at the local, national and international level.

2.4.4 The uncertainties associated with the resilience assessments can be accommodated by applying the FCM to the development of resilience models. The RAIF will use FCM to define inherent vulnerabilities (physical, social, environmental, economic etc.) at the sub-system level (e.g. health care, transport etc.) to provide a resilience assessment of each sub-system to an EILD event. The RAIF will then combine the sub-system FCMs to provide a resilience assessment at the overall community level. The FCMs will be developed in WP5.

2.4.5 A Fuzzy Cognitive Map is a fuzzy-graph structure for representing causal reasoning and it is especially applicable in soft knowledge domains (Kosko, 1986). Fuzzy Cognitive Maps (FCMs) are fuzzy signed graphs with feedbacks (Chrysostomos D. Stylios, Georgopoulos, & Groumpos, 1997) that consist of nodes, also called "concepts"(C_i), and "inter-connections" (e_{ij}) between concepts (see Figure 3). Further details of the background theory and application on FCM see the appendix 1.

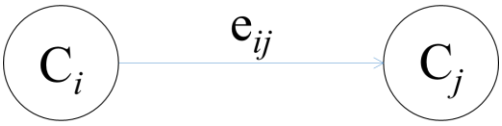


Fig. 3: Concepts and inter-connections scheme

The method is used to develop semi-quantitative models of complex system by:

- Defining the main components of the system;
- Defining the relationships between these components; and
- Running "what if" scenarios to determine how the system might react under a range of possible changes.

2.4.6 The proposed approach in the RAIF is based on FCM modelling framework and consists of two main phases (as shown in Figure 4):

- The development of a **Cognitive Modelling Group**;
- The development of **FCM Resilience Indicator**

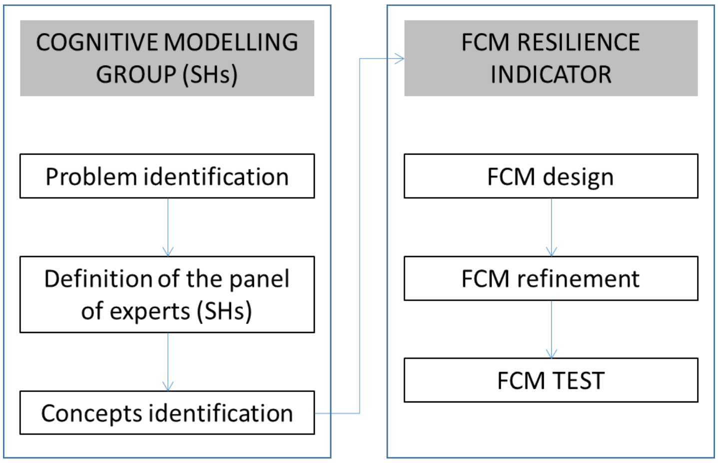


Figure 4: The research approach. The figure shows all of the phases for the realisation of the Fuzzy Cognitive Map.

2.4.7 The development of a COGNITIVE MODELLING GROUP phase consists of three steps:

Problem identification

The project will investigate the main factor (physical, economic, organizational and social) that affect (enhance/reduce) the resilience the community and increase the impact susceptibility of building/system to the damaging effects of the liquefaction hazard. This step plays a pivotal role in selecting and organizing the panel of experts and to identifying all the sources of information to the definition of the concepts.

Definition of the panel of experts.

The whole process is realized in collaboration with a group of experts, selected according to criteria of competence and area. The "Definition of a panel of expert" requires the development of a "Group Cognitive Mapping". The panel consists of a group of individual stakeholders, which mostly included householders, business, emergency responders, health care providers, municipalities, etc. The exact composition of the group will be defined in the WP5 as part of the T5.1 and T5.2.

Concepts identification

The factors that affect the resilience of a community (Table 4) are based on the detailed literature on existing resilience frameworks and resilience measures literature described on Deliverable 1.1 and 1.3 and are divided in 4 main categories: a) organizational factors; b) physical factors; c) social factors and d) economic factors.

Technical factors	Organisational factors	Social factors	Economic factors
Poor design and construction of buildings	Early warning system	Education	Empowerment
Unregulated land use planning	Risk assessment	Disaster preparedness	Disaster insurance
Lack of building codes	Trained staff	Social cohesion	Funding mechanism
Protection of critical infrastructures	Emergency response plan	Social support	Business continuity plan
Protection of built assets	Public information	Social networks	Ability to mobilising resources
Building stock assessment and retrofitting	Hazard mitigation plan	Poverty	
Network redundancy	Effective leadership	Collaboration with research institution	
Proximity to disaster prone areas	Pre-Disaster planning	Public participation in decisions	
Building typology			

Table 4: List of the 30 factors that affect the vulnerability, adaptive capacity and resilience of an urban community. All the concepts are used as input for the creation of the FCM to use in the risk based assessment

The final step in the Group Cognitive Mapping focused on defining the character of causal links between different clusters. Through the identification of the bonds, this approach allows the user to distinguish main concepts and secondary ones, which plays a key role in the analysis.

To test the identified concepts a test panel of experts, mainly technical, was created during the initial stakeholder engagement workshop held in Bologna (03/10/2016) as part of Task 1.2. From this meeting 111 stakeholders were selected to make the first validation of the approach and review the factors.

During the test each panel member was asked to complete a self-administered questionnaire in which they scored a range of concepts (Table 4) derived from a review of literature (Deliverable 1.1) that proposed to affect vulnerability, resilience and adaptive capacity of a community to a disaster event. Panel members were asked to describe the relationships among concepts using a five-level Likert scale (ranging from 1 to 5) which was also expressed with linguistic terms such as "very little", "little", "enough", "much" and "very much". If the expert was confident that no relationships existed between two selected concepts they were told to leave the field blank. The final weight of each relationship is the average of the different weight provided by all the experts.

The following is an excerpt of the evaluation sheet provided to the experts (see Table 5).

FACTORS	Relationships		Very little	Little	Enough	Much	Very much
	+	-					
Technical factors							
Poor design and construction of buildings							
Unregulated land use planning							
Lack of building codes							

Table 5: Example of the questions administered to experts

2.4.8 The development of a FCM SURVIVORS' BEHAVIOR INDICATOR phase can be organised in three steps:

FCM design

The relationships among factors will be analysed and discussed to design a FCM. This step refers to the organization of the concepts, the identification of links and cause/effect relationships collection and mathematical translation of the relative importance of concepts into square matrix adjacency relationship. In order to develop a FCM of EILD events vulnerability, the Cognitive Modelling Group will create an adjacency matrix of the cognitive map defining the relations between concepts.

FCM refinement

Data collected from the questionnaire will be analysed and concepts modified as needed. The draft of the map will be sent to the panel of experts to be analysed and refined.

A set of interviews will be administered to the panel of experts and members of the advisory broad to test and compliment the results from the questionnaire. This step will be carried out in different time periods. The panel of experts will review any modifications and accept any changes, and highlight and reject any inconsistency to make the Fuzzy Cognitive Map ready to be analytically evaluated.

Simulation with designed FCM

The final FCM will be used to create a community level resilience model. The input data used in FCM and the results obtained from the model will be processed to be analysed by the expert panel. This will include a review of the fuzzy rules and fuzzy weight matrix used to simulate the decision system as this represents one of the most critical activities during the FES design. Bad rules imply bad results and consequently, the unreliability of the fuzzy expert system.

2.4.9 The resilience scoring system will identify which resilience sub-systems exist within a community and then score each in turn against quantitative criteria. The quantitative criteria seek to divide the sub-system into a number of operational factors. The individual scores for each operational factor are then combined to produce an overall score for the sub-system's resilience. The aggregated resilience scores for each sub-system are then combined to produce an overall score for the community's resilience. However, when aggregating the individual sub-system scores together the toolkits do not generally consider inter-dependencies between components but mealy sum or average individual sub-system scores to provide an indicative assessment of a community's resilience. This approach limits the usefulness of many of the resilience scoring systems to comparative assessments between communities rather than objective and quantifiable assessments of the resilience of a specific community.

2.4.10 In order to validate the model, some hypothetical scenarios will be used; the advisory board will be also be involved and real data coming from real events (i.e. The Christchurch earthquake) will be used to validate the analysis of socio-economic impact.

2.4.11 The matrix needs to consider each impact separately (e.g. physical system, social system etc.) and identify the ability of each sub-system component (e.g. building, infrastructure, employment etc.) to cope with and recover from the impact.

Case study box 6: Impact assessment of the hypothetical health system

Although not directly related to the assessment of the impact of an EILD event on the performance of individual hospitals the health care authority responsible for mitigation investment decisions wants to better understand the impact that the loss of performance of the hospital assets identified in its risk assessment will have on the overall resilience of the primary healthcare system. A FCM has been developed by the city authority that identifies the factors that affect the cities resilience to an EILD event; a part of which is a primary health care sub-system FCM. The facilities manager can enter the performance levels identified from the risk/impact assessments and the FCM models the impact that these scenarios will have on the resilience of the primary health care sector and on the community as a whole. This information can then be used as a baseline to estimate the improvement in resilience that could be expected from the different mitigation options that will be modelled in stage 4 of the RAIF. In essence the FCM resilience modelling can be used to set improvement performance standards that any mitigation options have to meet.

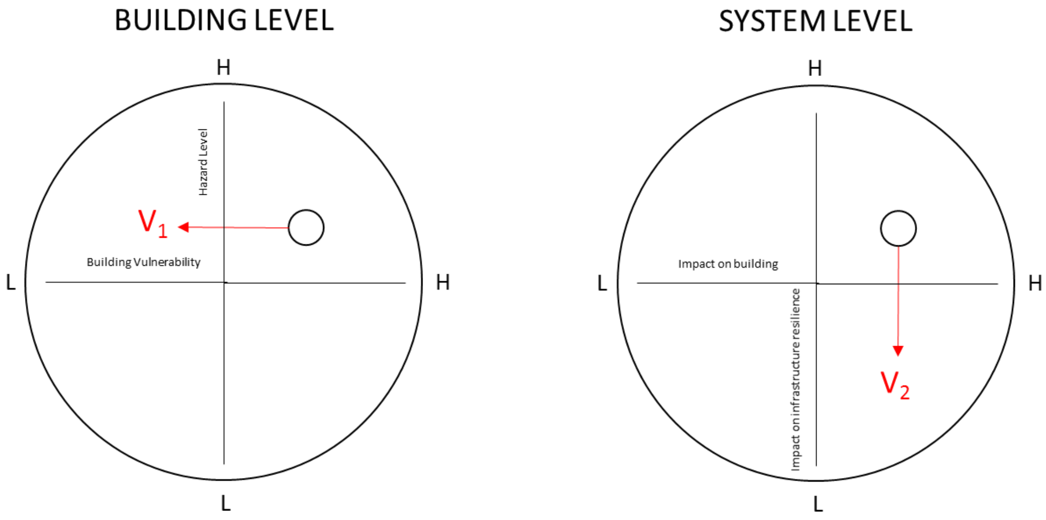
In the hypothetical scenario being considered here, of the 4 hospitals that constitute the primary care system only 2 are susceptible to liquefaction and of these one is classed at Low-High risk and the other as Medium-High risk. Under the Low-Medium risk scenarios it is unlikely that all performance would be lost with both hospitals able to continue to function after the EILD event. When this data is entered into the FCM it classifies the resilience of the primary health care system as Medium-High. Under the High risk scenarios then it is likely that all performance could be lost from both hospitals and when this data is entered into the FCM it classifies the resilience of the primary health care system as Low. These assessments now provide the basis by which improvements in resilience can be assessed for each mitigation option evaluated in stage 4.

Similar analyses can be done at the community level when all the sub-system FCMs are developed.

2.5 Stage 4: Mitigation Options

2.5.1 Once the baseline assessment of the resilience of the sub-systems and community to an EILD event has been established and the required improvements in resilience have been defined the ability of a range of mitigation actions to achieve the required improvements can be evaluated. This analysis requires a range of mitigation actions to be identified (both physical and operational) and the effect of each on the level of performance of individual buildings/infrastructure assets to be evaluated using the impact assessment matrix outlined in Stage 2.

2.5.2 Two types of mitigation actions need to be considered; those that seek to reduce a building/infrastructure assets vulnerability/increase its resilience; and those that seek to reduce the hazard level. The former are likely to be building level interventions; the latter are likely to be ground level interventions. The range and impact of technical building level interventions will be developed in WP3. The range and impact of ground interventions will be developed in WP4. Operational interventions will be developed in WP5. The vulnerability and resilience of the modified building/infrastructure assets will be remodelled (stages 1-2) and the impact on resilience (stage 3) re-assessed. Mitigation options will be ranked according to their impact on the sub-system level and on their contribution to improving overall community resilience.



V_1 = Vector 1
The reduction of the building vulnerability can be achieved with the improvement of the resistance of the structure and/or physical intervention on the soil
(intervention on physical resilience)

V_2= Vector 2
The reduction of the impact of the building on system resilience can be achieved with the adoption of social/organizational/economic measures to improve the resilience of the community

Figure 5: Impact matrixes at building and system level

Case study box 7: Mitigation Options for the hypothetical health system

The facilities manager has been tasked with evaluating the potential improvements that can be made to the resilience of both hospitals that are susceptible to EILD events. The facilities manager has commissioned technical consultants to prepare a feasibility report on a range of technical mitigation actions that can be applied to the hospital buildings to reduce their vulnerability or improve their resilience to an EILD event. A range of structural and foundation mitigation actions are identified and the impact that each of these would have on the building vulnerability and hazard impact are assessed.

For Hospital A the building level mitigation actions could lower the risk assessment from Low–High to Low-Medium. This would have the effect of reducing the impact on performance from potential long term closure of the hospital to possible short term loss of performance across part of the hospital. For Hospital B the risk assessment for all buildings could be lowed to Low-Medium meaning that no buildings would close as a result of an EILD event. When these scenarios were run through the FCM primary health care sub-system the level of resilience was predicted to rise from Low to Medium-High. In addition, for Hospital B it would be possible to improve the performance of the hospital by making changes to its operational characteristics by moving critical services from buildings that are highly vulnerable to those that are less vulnerable.

A similar set of technical feasibility reports were commissioned on ground improvement mitigation to reduce the hazard impact (reduce the likelihood of liquefaction). A range of ground improvement mitigation actions are identified and the impact that each of these would have on the buildings hazard level were assessed.

For Hospital A the ground improvement mitigation actions could lower the risk assessment from Low–High to Low. This would have the effect of reducing the impact on performance from potential long term closure of the hospital to possible short term loss of performance due to minor cosmetic damage. For Hospital B the risk assessment for all buildings could be lowed to Low meaning that no buildings would close as a result of an EILD event. When these scenarios were run through the FCM primary health care sub-system the level of resilience was predicted to rise from Low to High.

Each mitigation option was ranked on its potential improvement capability.

Similar analyses can be done at the community level when all the sub-system FCMs are developed.

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2.6 Stage 5: Improvement Framework

2.6.1 Once the mitigation options have been identified a cost/benefit analysis will be calculated for each specific sub-system component. The cost/benefit analysis will need to consider both direct and indirect costs (e.g. physical, loss of revenue during refurbishment period, etc.) and benefits (e.g. to the organisation, community, etc.) and extend the analysis across geographical and temporal scales (e.g. consider the inter-relationships between multiple similar assets, consider the implications of delaying refurbishment until later in a building/infrastructure life cycle).

2.6.2 Once the cost/benefit analysis has been completed for all sub-system components, consideration will need to be given setting intervention priorities and sequencing of work. The adaptive capacity of all stakeholder groups to fund and manage the retrofitting of mitigation interventions will need to be assessed (e.g. availability of capital, governance requirement, legislation etc.) and priorities set for both the mitigation interventions to be enacted (it is very unlikely that sufficient adaptive capacity will be available to adopt all the mitigation actions suggested by the FCM model) and the timescales over which they will be programmed (e.g. retrofitting of buildings/infrastructure mitigation interventions are likely to be programmed periodically over the assets normal refurbishment cycle – up to 30 years in some cases).

Case study box 8: Improvement Framework for the hypothetical health system

Following detailed cost/benefit analyses of the mitigation options for Hospitals A and B the health care authority have decided to instigate the ground work mitigation actions to Hospital A but not to instigate any mitigation actions to Hospital B.

Hospital A is a fairly new building, designed and built to a high standard and still retaining significant residual value. The investment in the ground mitigation actions is justified because of the residual value and other performance considerations.

Hospital B is a mixture of buildings from the 1920' to 1970's and although they are in a good state of repair they weren't designed to modern standards and they have low residual value and is due a major renovation in about 10 years' time when it will be demolished and replaced with a new hospital facility. In the meantime the resilience of Hospital B will be improved by re-organising its health care delivery model to ensure that high value activities (in terms of community resilience to a disaster event) are located in the least vulnerable/most resilient buildings.

2.7 Stage 6: Built Asset Management Planning (BAMP)

2.7.1 Once priorities have been set, detailed built asset management plans can be developed. These plans require detailed design solutions to be developed for each mitigation intervention and all financial and legal conditions to be addressed before contracts are let. Once implemented, the performance of mitigation intervention against the performance specification detailed in stage 4 is monitored through detailed simulation or in response to an EILD event.

Case study box 9: BAMP for the hypothetical health system

The facilities manager commissions the design and construction of the mitigation actions and monitors their performance through the use of simulations of an EILD event.

3 Data requirements

3.1 The theoretical model outlined above will be further developed in WP5 with inputs drawn from WP's 2, 3 and 4. The specific metrics, models and tools developed in WP5 will be tested through a detailed case study of the Emilia Romagna region of Italy in WP7 and disseminated widely through inclusion in the SELENA-LRG software (WP6) and through design and operational guidance disseminated through WP8.

3.2 WP2 will produce the European Liquefaction Hazard Map and a methodology for Localized Assessment of Liquefaction Potential. The research team will develop a tool for the ground characterization of the area selected as a testing site by using novel techniques and advanced methodologies to perform in situ and laboratory tests. The map will be produced narrowing down existing seismic hazard map to areas that have high risk of liquefaction and it will be used to assess the susceptibility of a building/infrastructure asset to the hazard (see section 2).

3.3 The RAIF will then use the assessment tools developed in WP3 to establish the antecedent vulnerability and resilience of each asset to the EILD event. The WP3 will develop methodologies and tools for the vulnerability assessment of structures to EILDs. The level of details is small to medium sized "critical infrastructures", both "lifelines" and low-rise structure; those structures can have cascading effects and impacts on the urban community

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during an EILD event. The data produced will be a framework procedure for use by decision makers to evaluate their structures. This is part of the impact assessment of the RAIF framework.

3.4 The WP4 is accountable for the analysis of the measures of liquefaction mitigation for protection/resilience of critical building/infrastructures, with a special focus on the infrastructures whose functioning during and after an earthquake is essential within urban community to ensure the continuity of their function. Starting from a small lab scale level, a comparative analysis of the existing techniques will be performed to create a list of possible intervention according to the different type of soils. This output will be integrated in the 4th stage of the RAIF.

3.5 The impact that the loss of function of a building/infrastructure has on community resilience will be assessed through a FCM model (WP5). The FCM model will be based on the opinion of a panel of experts and will represent a baseline model from which improvements in resilience as a consequence of alternative mitigation actions can be assessed. Once the antecedent resilience of a community has been established the potential improvements in resilience through the adoption of the Liquefaction mitigation techniques reviewed in WP4 will be evaluated. The FCM model will be re-run to assess the effect that each mitigation technique has on community resilience. Those interventions that are cost effective and where sufficient adaptive capacity exists within the system will be prioritised for inclusion in building/infrastructure built asset management plans and refurbishment programmes (WP5). Finally, the RAIF and all its supporting tools and guidance documentation, including design codes, will be integrated into the SELENA-LRG software (WP6).

3.6 Table 6 summarizes all the input produce by other WPs.

DATA DEFINITION	DATA SPECIFICATION	CURRENT STATUS
Liquefaction Hazard Map	Geo-referenced map showing the soil susceptibility to liquefaction event	Under development in WP2
Resilience & Vulnerability assessment of structures	Simulation of liquefaction-induced damage and fragility analysis of structures	Under development in WP3
Liquefaction mitigation measures	Analysis and test of the mitigation measures for protection/resilience of assets	Under development in WP4
Community Resilience Assessment	Analysis of the community resilience before and after mitigation	To be developed in WP5
Test and case study validation	Test of the framework and of all the models of analysis created	To be developed in WP7

Table 6: Data/information need for the framework and WPs' contribution

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4 Protocols for data collection

4.1 Protocols for data collection describe the steps to follow to ensure that every partner has an appropriate input into the design of the data collection tool and into the identification of the appropriate analysis techniques.

4.2 The protocol establishes virtual groups that involve all the representatives from other WPs in order discuss the correct use of data[2]. Each group will be led by the researcher directly responsible for collecting and/or analysing the data. The virtual groups will report every 6 months on what they have done to the project management committee.

4.3 This protocol have been tested and validated for the first time for the development of the first version of the common lexicon and terms that will be used throughout the project in the next months (see next section).

4.4 The same procedure will be used for all the data collection/analysis of the project. For each analysis (e.g. the analysis tools) the lead researcher responsible for the analysis will consult all other partners have an input to, or a need for the analysis, on data requirements for the analysis and the method of data collection. Researchers will also ask individual stakeholder from the case study site to provide input and information.

4.5 The data reporting will be consistent with the protocol developed separately as part of the initial open Data Management Plan which has already been submitted (Deliverable 9.16) and that will be updated regularly.

5 Interaction between WPs 2, 3, 4, 5 and WP6

5.1 One of the key outputs from the LIQUEFACT project will be SELINA-LRG software toolbox and guidance documents. The current SELENA-RISe tool has been developed over a number of years to provide seismic loss estimation using a logic tree approach in the form of ground shaking maps, direct and indirect economic loss and damage estimates, and casualty and shelter demand estimates. The SELINA-RISe tool is available in open source form from either NORSAR or the University of Alicante. The outputs from the LIQUEFACT project will be integrated into the SELINA-RISe software tool to produce a new version of the tool, SELINA-

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[2] The virtual groups will be meet in the virtual discussion space crated using through the Adobe Connect software.

LRG, which will consider the effect of liquefaction alongside ground shaking on the loss estimates. As such it is essential that the outputs from all the LIQUEFACT work packages are available to the SELINA-LRG development team in a format that is compatible with the needs of the SELNA software tool. To this end a one day training seminar was delivered by the NORSAR project team to the other LIQUEFACT team members to explain the concepts, logic and theory behind the SELINA-RISe software and to explain the data structures and protocols that are used by SELINA-RISe to produce it loss estimation outputs. The training workshop was dived into 4 sections:

- An introduction to earthquake damage and loss estimation;
- Seismic response estimation using non-linear methods;
- Technical background to the SELINA-RISe software;
- Discussion of the issues that would need to be considered when integrating liquefaction calculations into the SELINA-LRG software tool.

The training session was accompanied by over 400 pages of notes detailing all aspects of the SELINA software which, whilst not publically available through this deliverable, are available to all members of the LIQUEFACT team in both hard copy form and through the LIQUEFACT partner file store. From this point the SELINA-RISe and SELINA-LRG software tools will be referred to as the SELINA software tool.

5.2 The training workshop started with a detailed presentation of the theory of earthquake damage loss estimation that underpins the SELINA software tool. The session began by placing earthquake disasters in context of other natural disasters and presenting a range of loss statistics that are normally considered when discussing disaster events. This introduction then led to a more detailed examination of the calculations that underpin loss assessments and in particular the key relationships between risk, hazard, vulnerability and exposure. During this examination the characteristics of hazard assessment were reviewed along with their links to risk outputs and exposure and the factors that affect the vulnerability of fixed assets and populations. In the case of vulnerability attention was drawn to the difference observed in practice between predicted vulnerability based on expected performance of buildings from design specification, modelling and calculation and the observed vulnerability based on empirical methods. The concept of fragility and uncertainty in vulnerability assessments was also considered as were the need for capacity curves and fragility functions to be developed in response to liquefaction events. Detailed notes underpinning the development of these are available to the LIQUEFACT team.

5.3 Following a review of the technical considerations outlined above the workshop then considered risk awareness and risk framing. The differences between quantitative and qualitative definitions of risk were explored along with the ideas of attitudes towards risk and acceptable risk levels. In addition the concepts of loss were explored and in particular the relationships between economic and social loss were explored in the context of insurance cover, causality estimation, causality severity levels, and the lethality ratio. Finally alternative approaches to earthquake loss estimation were reviewed (empirical approach, analytical approach, hybrid approach, and expert opinion) and the concept of damage grades to buildings and infrastructure assets was explored along with alternative quantitative and qualitative measures of assessing damage to buildings and infrastructure assets. These approaches will be explored in more detail in WP3 and 5.

5.4 The workshop next considered the detailed application of non-linear analysis techniques to the various theoretical methods outlined above. Detailed analytical approaches were presented for the structural analysis of buildings and the development of fragility curves along with a review of the factors that affect the variability of these calculations. Detailed working examples of all the approaches are available to the LIQUEFACT team. The techniques will be used by WP3 and 5.

5.5 In addition alternative intensity measures, ground motion measures and engineering demand parameters were reviewed in terms of their usefulness in classifying earthquake potential to trigger liquefaction along with a generic approach to assessing the physical vulnerability of a building to liquefaction. Finally a selection of vulnerability models were presented for further consideration. Detailed working examples of all the approaches are available to the LIQUEFACT team. The measures reviewed will be used by WP2, 4 and 5.

5.6 The final technical part of the workshop explained how all the theory and methods outlined previously were used in the SELINA software tool. Following a general overview of how the tool worked the different types of analysis were considered along with the type of input data that was needed to drive the modelling. Through this presentation the LIQUEFACT team were made aware of the format and level of detail that would be required from their modelling as input to the SELINA software tool. This included ground mapping, ground motion predictions, design considerations, and building damage profiles. The presentation also explained how uncertainties were handled in SELINA and presented the logic tree underpinning vulnerability calculations. Finally, practical guidance was presented on how to prepare data files to run SELINA and how to interpret out results.

5.7 Following the formal presentations initial discussions were held amongst the LIQUEFACT team where there was general agreement that the SELINA approach could provide the basis for an output tool for the LIQUEFACT project but that much more work would need to be done to understand the detailed relationships between the outputs from the various work packages and the requirements of WP6. The facilitate this work a series of virtual workgroups would be established early in WP2, 3, and 4 to work closely with WPs 5 and 6 to further explore the specific relationships between their WPs and to develop specifications for data transfer

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between their WPs. A closer and more detailed working relationship would be developed between WPs 5 and 6 to ensure that the wider community resilience attributes of the RAIF could also be integrated into the SELINA software tool. Initial feedback from the virtual and face-to-face meetings will be reported to the next LIQUEFACT project management meeting.

6 Lexicon

6.1 As mentioned above, the protocol for data collection has been tested for the first time during the creation of a lexicon to use in the project. The creation of a common list of terms and definitions has been developed to ensure that the research consortium use the same definition in their works.

6.2 During the project meeting in Ferrara in October 2016, the lead partner of WP1 (ARU) hosted a research meeting to identify common needs in a face-to-face workshop. The definition of the main terms that will be used for the development of the framework come from a review of the literature which was performed over the period from June to August 2016. The draft list has been put on a shared online work area and over a period of 6 weeks projects researchers have refined and added terms to input into the final version of the lexicon.

6.3 The list of terms identified are presented in the annex section (Annex 2); this lexicon is intended to be updated and modified in the following months and throughout the duration of the project.

7 Summary Discussion and Next Steps

7.1 The LIQUEFACT project aims to develop a more comprehensive and holistic understanding of the earthquake soil liquefaction phenomenon and the effectiveness of mitigation techniques to protect structural and non-structural systems and components from its effects. In order for the framework to function effectively the format of outputs from the different work packages must be consistent with each other and the data generated in each work package must be directly transferable to other WPs.

7.2 This report defines a common working practice to ensure that all the activities undertaken in the other work packages produce outputs that are directly useable in the decision making framework. The report developed a common understanding of stakeholders and end-user requirements, criteria for the selection and analysis of the chosen case study example, a common reporting framework for sharing data and outputs, a common approach to dissemination of outputs and a common understanding of the potential routes to impact. This report should be read in conjunction with the description of the RAIF presented in Deliverable 1.3 and with the Review of Theory presented in Deliverable 1.1.

7.3 The RAIF framework is based on the WPs and will use the hazard maps developed in WP2 to identify critical building/infrastructure assets that are potentially at risk from an EILD event. The RAIF will then use the assessment tools developing in WP3 to establish the antecedent vulnerability and resilience of each asset to the EILD event. The impact that the antecedent vulnerability and resilience of each asset has on community resilience will be assessed through a FCM model (WP5). The FCM model will be built from an expert panel and will represent a baseline model from which improvements in resilience as a consequence of alternative mitigation actions can be assessed. Once the antecedent resilience of a community has been established the potential improvements in resilience through the adoption of the Liquefaction mitigation techniques reviewed in WP4 will be evaluated. The FCM model will be re-run to assess the effect that each mitigation technique has on community resilience. Those interventions that are cost effective and where sufficient adaptive capacity exists within the system will be prioritised for inclusion in building/infrastructure built asset management plans and refurbishment programmes (WP5). Finally, the RAIF and all its supporting tools and guidance documentation, including design codes, will be integrated into the SELENA-LRG software (WP6). A pilot version of the RAIF methodology was tested during the Stakeholders meeting in Bologna on October 3rd 2016. Although the results of this test are still being analysed the pilot did establish that the RAIF approach outlined in the report could be used as the basis for community resilience improvement planning.

7.4 The next step will be the start of the Work Package 5 that will create a tool to assess the vulnerability of a community. A range of performance metrics to assess vulnerability, resilience and adaptive capacity will be developed (T 5.1) also considering the effect of these factors on resilience of inter-relationships between the various stakeholders and policy makers.

7.5 To ensure the consistency of the data collected in WP5 with that in other WPs, a series of face and virtual team meeting will be arranged in January/February 2017; researchers from the WP5 will meet partners from WP2, 3, 4 and 6 to populate the matrices of the RAIF and define how to integrate all the information in the SELENA software. Furthermore, researchers will have meeting with Emilia Romagna Region authorities to investigate the key components of the FCM for the selected case study.

7.6 The results of the meetings and the case study will be reported to the Project Management Meeting in March 2017.

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ANNEX 1: FUZZY COGNITIVE MAP LITERATURE

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ANNEX 2: LEXICON

TERM	DEFINITION	REFERENCE
A		
Accelerogram	The recording of an instrument called accelerometer showing ground motion acceleration as a function of time. The peak acceleration is the largest value of acceleration on the accelerogram and very often used for design purposes.	World Meteorological Organization (2006)
Acceptable risk	The level of potential losses that a society or community considers acceptable given existing social, economic, political, cultural, technical and environmental conditions.	UNISDR (2009)
Active fault	A fault is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. Scientists have used a number of characteristics to identify active faults, such as historic seismicity or surface faulting, geological recent displacement inferred from topography or stratigraphy, or physical connection with an active fault. However, not enough is known of the behaviour of faults to assure identification of all active faults by such characteristics.	World Meteorological Organization (2006)
Assessment	A survey of a real or potential disaster to estimate the actual or expected damages and to make recommendations for prevention, preparedness and response	World Meteorological Organization (2006)
Attenuation	Decrease in seismic ground motion with distance. It depends generally on a geometrical spreading factor and the physical characteristics between source of energy and observation point or point of interest for hazard assessment.	World Meteorological Organization (2006)
B		
Bedrock	Any solid, naturally occurring, hard consolidated material located either at the surface or underlying	GEM-ASV Guidelines

	soil. Rocks have a shear-wave velocity of at least 500 m/s at small (0.0001 per cent) levels of strain.	(D'Ayala et al. 2015)
Building code	A set of ordinances or regulations and associated standards intended to control aspects of the design, construction, materials, alteration and occupancy of structures that are necessary to ensure human safety and welfare, including resistance to collapse and damage.	UNISDR (2009)
C		
Central Value of a Variable	The median value used to characterize the "central tendency" of the variable. This is not necessarily the most frequent value that it can take, which is called its mode. The three quantities, mean, median and mode, coincide for a normal distribution, but not necessarily for other types, e.g., a lognormal.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Coping Capacity	The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters	UNISDR (2009)
Cost Replacement (New)	The cost of replacing a component/group of components/an entire building. Since this is often compared to losses, demolition/removal costs may be added to it to fully represent the actual cost of constructing a new structure in place of the (damaged or collapsed) existing one.	GEM-ASV Guidelines (D'Ayala et al. 2015)
D		
Design earthquake	A specification of the ground motion at a site based on integrated studies of historic seismicity and structural geology and used for the earthquake resistant design of a structure.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Design spectra	Spectra used in earthquake-resistant design which correlate with design earthquake ground motion values. A design spectrum is typically a spectrum having a broad frequency content. The design spectrum can be either site-independent or site-dependent. The site-dependent spectrum tends to be less broad band as it depends also on (narrow band) local site conditions.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Direct damages	Property damage, injuries and loss of life that occur as a direct result of a natural disaster.	World Meteorological

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		Organization (2006)
Disaster	A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources. Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.	UNISDR (2009)
Disaster Risk	The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period. The definition of disaster risk reflects the concept of disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socio-economic development, disaster risks can be assessed and mapped, in broad terms at least.	UNISDR (2009)
Dispersion of a Variable	A measure of the scatter in the random variable, as measured around its central value. A typical quantity used is the standard deviation of the variable X, especially for a normal distribution. For a lognormal distribution, one often uses the standard deviation of the logarithm of the variable instead.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Distribution of a Variable	The probabilistic characterization of a random/uncertain variable. Comprehensively, this is represented by the probability density function (PDF), or its integral, the cumulative distribution function (CDF). For example, the PDF of a normally distributed variable is the well-known Gaussian bell function, while its CDF (and actually most CDFs regardless of distribution) resembles a sigmoid function, exactly like any fragility function.	GEM-ASV Guidelines (D'Ayala et al. 2015)

E		
Earthquakes	Sudden release of previously accumulated stresses in the earth's crust and thereby producing seismic waves.	World Meteorological Organization (2006)
Earthquake hazards	Probability of occurrence of natural phenomena accompanying an earthquake such as ground shaking, ground failure, surface faulting, tectonic deformation, and inundation which may cause damage and loss of life during a specified exposure time.	World Meteorological Organization (2006)
Earthquake-resistant design	Methods to design structures and infrastructure such that these can withstand earthquakes of selected intensities.	World Meteorological Organization (2006)
Earthquake risk	The social or economic consequences of earthquakes expressed in money or casualties. Risk is composed from hazard, vulnerability and exposure. In more general terms, it is understood as the probability of a loss due to earthquakes.	World Meteorological Organization (2006)
Exceedance probability	The probability (for example 10 per cent) over some exposure time that an earthquake will generate a value of ground shaking greater than a specified level.	World Meteorological Organization (2006)
Exposure	People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.	UNISDR (2009)
Engineering Demand Parameters (EDP)	A measure of structural response that can be recorded or estimated from the results of a structural analysis. Typical choices are the peak floor acceleration (PFA) and the interstorey drift ratio (IDR).	GEM-ASV Guidelines (D'Ayala et al. 2015)
Epicentre	The point on the earth's surface vertically above the point where the first fault rupture and the first earthquake motion occur.	World Meteorological Organization (2006)
F		
Fault	A fracture or fracture zone in the earth along which displacement of the two sides relative to one another has occurred parallel to the fracture. Often visible as	World Meteorological

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	fresh ground displacement at the earth's surface after strong, shallow events.	Organization (2006)
Fragility (Building/Infrastructure fragility curve/function)	A probability-valued function of the intensity measure that represents the probability of violating (exceeding) a given limit-state or damage state of the building or the storey given the value of the seismic intensity measure (IM) that it has been subjected to. Essentially, it is the cumulative distribution function (CDF) of the IM-capacity value for the limit-state and it is thus often characterized by either a normal or (more often) a lognormal distribution, together with the associated central value and dispersion of IM-capacity.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Fragility (Component fragility curve/function)	A probability-valued function of an engineering demand parameter (EDP), that represents the probability of violating (exceeding) a given limit-state or damage-state of the component, given the value of EDP that it has been subjected to. Essentially, it is the cumulative distribution function (CDF) of the EDP-capacity value for the limit-state and it is thus often characterized by either a normal or (more often) a lognormal distribution, together with the associated central value and dispersion of EDP-capacity.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Focal depth	The vertical distance between the earthquake hypocentre and the earth's surface.	World Meteorological Organization (2006)
G		
GIS	A geographic information system for managing spatial data in the form of maps, digital images and tables of geographically located data items such as the results of hazards survey	World Meteorological Organization (2006)
H		
Hazard	A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.	UNISDR (2009)
I		

Indirect damages	Economic losses resulting from the multiplier or ripple effect in the economy caused by damage to infrastructure resulting from a natural disaster. Damage done to lifelines such as the energy distribution network, transportation facilities, water-supply systems and waste-management systems, can result in indirect economic losses greater than the direct economic damage to these systems and a long-term drain on the regional or national economy.	…
Induced seismicity	Generated by human activities mainly in mining and reservoir areas. Can produce considerable or even dominating hazards. There are two likely causes for the triggering effect of a large reservoir. The strain in the rock is increased by the extra load of the reservoir fill, and reaches the condition for local faulting. However, this theory is physically not as acceptable as the second one, which involves increased pore pressure due to infiltrated water, thereby lowering the shear strength of the rocks along existing fractures and triggering seismicity. The focal depths of reservoir-induced earthquakes are usually shallower than 10 km.	World Meteorological Organization (2006)
Intensity	A numerical index describing the effects of an earthquake on the earth's surface, on people and on structures. The scale in common use in the USA today is the Modified Mercalli Intensity (MMI) Scale of 1931. The Medvedev-Sponheuer-Karnik (MSK) Scale of 1964 is widely used in Europe and was recently updated to the new European Macroseismic (EMS) Scale in 1998.These scales have intensity values indicated by Roman numerals from I to XII. The narrative descriptions of the intensity values of the different scales are comparable and therefore the three scales roughly correspond. In Japan the 7-degree scale of the Japan Meteorological Agency (JMA) is used. Its total range of effects is the same as in the 12-degree scales, but its lower resolution allows for an easier separation of the effects.	World Meteorological Organization (2006)
Intensity Measure (IM)	Particularly for use within this document, IM will refer to a scalar quantity that characterizes a ground motion accelerogram and linearly scales with any scale factor applied to the record. While non-linear IMs and vector IMs have been proposed in the literature and often come with important	GEM-ASV Guidelines (D'Ayala et al. 2015)

	advantages, they will be excluded from the present guidelines due to the difficulties in computing the associated hazard.	
J		
Joint Distribution of a Set of Variables	This refers to the probabilistic characterization of a group of random/uncertain variables that may or may not depend on each other. If they are independent, then their joint distribution is fully characterized by the product of their individual probability density functions (PDFs), or marginal PDFs as they are often called. If there are dependencies, though, at a minimum one needs to consider additionally the correlation among them, i.e., whether one increases/decreases as another decreases, and how strongly.	GEM-ASV Guidelines (D'Ayala et al. 2015)
L		
Liquefaction	The primary factors used to judge the potential for liquefaction, the transformation of unconsolidated materials into a fluid mass, are: grain size, soil density, soil structure, age of soil deposit and depth to ground water. Fine sands tend to be more susceptible to liquefaction than silts and gravel. Behaviour of soil deposits during historical earthquakes in many parts of the world show that, in general, liquefaction susceptibility of sandy soils decreases with increasing age of the soil deposit and increasing depth to ground water. Liquefaction has the potential of occurring when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil, distorting its granular structure and causing some of the void spaces to collapse. The pressure of the pore water between and around the grains increases until it equals or exceeds the confining pressure. At this point, the water moves upward and may emerge at the surface. The liquefied soil then behaves like a fluid for a short time rather than as a solid.	World Meteorological Organization (2006)
Loss	The quantifiable consequences of seismic damage. These can be (a) the actual monetary cost of repairing	GEM-ASV Guidelines

	a component, a group of components, or an entire building, or (b) the casualties, i.e., number of fatalities or injured occupants.	(D'Ayala et al. 2015)
Loss ratio	For monetary losses, this is the ratio of loss to the cost replacement new for a component/group of components/building. For casualties, it is the ratio of fatalities or injured over the total number of occupants	GEM-ASV Guidelines (D'Ayala et al. 2015)
M		
Magnitude	A quantity characteristic of the total energy released by an earthquake, as contrasted to intensity that describes its effects at a particular place. C.F. Richter devised the logarithmic scale for local magnitude (ML) in 1935.Magnitude is expressed in terms of the motion that would be measured by a standard type of seismograph located 100 km from the epicentre of an earthquake. Several other magnitude scales in addition to ML are in use; for example, body-wave magnitude (mb) and surface-wave magnitude (MS). The scale is theoretically open ended, but the largest known earthquakes have MS magnitudes slightly over 9.	World Meteorological Organization (2006)
Mean return period	The average time between occurrences of a particular hazardous event.	UNDHA (1992)
Mitigation	The lessening or limitation of the adverse impacts of hazards and related disasters.	UNISDR (2009)
Monitoring	System that permits the continuous observation, measurement and a valuation of the progress of a process or phenomenon with a view to taking corrective measures.	IDNDR- DHA (1992)
Monte Carlo simulation	In Monte Carlo simulation, probability distributions are proposed for the uncertain variables for the problem (system) being studied. Random values of each of the uncertain variables are generated according to their respective probability distributions and the model describing the system is executed. By repeating the random generation of the variable values and model execution steps many times the statistics and an empirical probability distribution of system output can be determined.	World Meteorological Organization (2006)

N		
Non-structural measures	Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.	UNISDR (2009)
P		
Peak acceleration	The value of the absolutely highest acceleration in a certain frequency range taken from strong-motion recordings. Effective maximum acceleration (EMA) is the value of maximum ground acceleration considered to be of engineering significance. EMA is usually 20–50 per cent lower than the peak value in the same record. It can be used to scale design spectra and is often determined by filtering the ground-motion record to remove the very high frequencies that may have little or no influence on structural response.	World Meteorological Organization (2006)
Population (of Buildings)	The ensemble of all buildings that actually constitute the class examined. For example, the set of all the existing US West Coast steel moment-resisting frames.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Preparedness	The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.	UNISDR (2009)
Prevention	The outright avoidance of adverse impacts of hazards and related disasters. Prevention (i.e. disaster prevention) expresses the concept and intention to completely avoid potential adverse impacts through action taken in advance.	UNISDR (2009)
Prediction	A statement of the expected time, place and magnitude of a future event (for volcanic eruptions).	IDNDR- DHA (1992)
R		
Reliability	Probability that failure or damage does not occur as the result of a natural phenomenon. The complement	World Meteorological

	of the probability of damage or failure, i.e. one minus the probability of damage or failure.	Organization (2006)
Relief	Assistance and/or intervention during or after disaster to meet life preservation and basic subsistence needs. It can be of emergency or protracted duration.	UNDHA (1992)
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions	UNISDR (2009)
Response spectrum	The peak response of a series of simple harmonic oscillators having different natural periods when subjected mathematically to a particular earthquake ground motion. The response spectrum shows in graphical form the variations of the peak spectral acceleration, velocity and displacement of the oscillators as a function of vibration period and damping.	World Meteorological Organization (2006)
Return period	For ground shaking, return period denotes the average period of time — or recurrence interval — between events causing ground shaking that exceeds a particular level at a site; the reciprocal of annual probability of exceedance. A return period of 475 years means that, on the average, a particular level of ground motion will be equalled or exceeded once in 475 years.	World Meteorological Organization (2006)
Risk	The combination of the probability of an event and its negative consequences.	UNISDR (2009)
Element at Risk	The population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc. exposed to hazard.	UNDHA (1992)
S		
Structural Capacity	The ability of a structure to withstand loads placed on the structure. These loads might be water levels for floods and storm surges, maximum acceleration for earthquakes, forces generated by winds for tropical storms, etc.	World Meteorological Organization (2006)
Susceptibility	See Vulnerability	

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Sample of Index Buildings	A sample of representative buildings, each called an index building, that may be either real or fictitious, yet they have been chosen to represent the overall population by capturing the joint probabilistic distribution of its most important characteristics.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Seismic Microzoning	The division of a region into geographic areas having a similar relative response to a particular earthquake hazard (for example, ground shaking, surface fault rupture, etc.). Microzoning requires an integrated study of: 1) the frequency of earthquake occurrence in the region; 2) the source parameters and mechanics of faulting for historical and recent earthquakes affecting the region; 3) the filtering characteristics of the crust and mantle along the regional paths along which the seismic waves are travelling; and 4) the filtering characteristics of the near-surface column of rock and soil.	World Meteorological Organization (2006)
Seismicity	The distribution of earthquake in space and time.	IDNDR- DHA (1992)
Seismic zoning	The subdivision of a large region (e.g., a city) into areas within which have uniform seismic parameters to be used as design input for structures.	World Meteorological Organization (2006)
Seismogenic source	Area with historical or/and potential earthquake activity with approximately the same characteristics.	World Meteorological Organization (2006)
Source	The source of energy release causing an earthquake. The source is characterized by one or more variables, for example, magnitude, stress drop, seismic moment. Regions can be divided into areas having spatially homogeneous source characteristics.	World Meteorological Organization (2006)
Standard normal variate	A variable that is normally distributed with a mean of zero and a standard deviation of one.	World Meteorological Organization (2006)
Strong motion	Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage resulting from earthquakes or in earthquake-resistant design of structures.	World Meteorological Organization (2006)
Structural Measures	Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard resistance and resilience in structures or systems	UNISDR (2009)

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U		
Uncertainty	A general term that is used within these guidelines to describe the variability in determining any EDP, cost, or loss value. The typical sources considered are the ground motion variability, the damage state capacity and associated cost variability, and the errors due to modelling assumptions or imperfect analysis methods.	GEM-ASV Guidelines (D'Ayala et al. 2015)
V		
Vulnerability	The characteristics and circumstances (physical, social, economic and environmental) of a community, system or asset that make it susceptible to the damaging effects of a hazard.	UNISDR (2009)
Vulnerability Curve/Function	A loss or loss ratio valued function of the intensity measure (IM), that represents the distribution of seismic loss or loss ratio given the value of IM that a certain building or class of buildings has been subjected to. Since at each value of IM we actually get an entire distribution of losses, there is never a single vulnerability curve. It is therefore most appropriate to directly specify which probabilistic quantity of the distribution each vulnerability curve represents, thus resulting, for example, to the 16/50/84% curves, the mean vulnerability curve or the dispersion curve.	GEM-ASV Guidelines (D'Ayala et al. 2015)
Z		
Zonation	In general it is the subdivision of a geographical entity (country, region, etc.) into homogenous sectors with respect to certain criteria (for example, intensity of the hazard, degree of risk, same overall protection against a given hazard, etc.).	IDNDR- DHA (1992)