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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 D1.3

EILD Risk:

Resilience Assessment and Improvement Framework

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GLOSSARY

Acronym	Description
EILD	Earthquake Induced Liquefaction Disaster
RAIF	Resilience Assessment Improvement Framework
DRR	Disaster Risk Reduction
FCM	Fuzzy Cognitive Map
SH	Stakeholder

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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 aim of this report is to outline a resilience assessment and improvement framework (RAIF) that will form the basis of the creation of risk-based assessment and improvement decision support tools that will help end-users to develop mitigation plans to reduce the effects of EILD. The RAIF not only considers mitigation measures to improve the resistance of building / infrastructure assets but also considers the consequences that those measures have on the resilience of the wider urban community. To this end this report will:

1. Review the background theory to community resilience presented in Deliverable 1.1;
2. Present a more detailed discussion on risk and disaster risk framing;
3. Provide definitions of vulnerability, resilience and adaptive capacity;
4. Consider the SENDAI framework for Disaster Risk Reduction in the context of the LIQUEFACT project;
5. Describe the theoretical background to the RAIF that will be developed later in the LIQUEFACT project; and
6. Consider the relationship between the RAIF and the SELENA-LRG software toolkit.

Goal: **This document aims to provide the project partners and researchers with an introduction to the resilience assessment and improvement framework that will be developed in Work Package (WPs) 5 and 6.**

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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 is primarily an internal document intended for the LIQUEFACT partners and researchers.

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EILD Risk: Resilience Assessment and Improvement Framework

1. Introduction

1.1 This report provides a description of a desk based study to outline a resilience assessment and improvement framework (RAIF) 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 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. The resilience assessment and improvement framework is based on the risk/resilience framework developed by Prof Jones to extreme weather events (CREW, 2012) that was presented as part of the original LIQUEFACT project proposal. The risk/resilience framework has been enhanced and refined to reflect the latest disaster risk reduction guidance provided through the SENDAI Framework; best practice extracted from other earthquake risk reduction frameworks; and the specific EILD risk framing approaches used by various existing protocols and software tools. This report will:

- Review the background theory to community resilience presented in Deliverable 1.1;
- Present a more detailed discussion on risk and disaster risk framing;
- Provide definitions of vulnerability, resilience and adaptive capacity;
- Consider the SENDAI framework for Disaster Risk Reduction in the context of the LIQUEFACT project;
- Describe the theoretical background to the resilience assessment improvement framework that will be developed in the LIQUEFACT project; and
- Consider the relationship between the resilience assessment improvement framework and the SELENA-LRG software toolkit.

1.2 The work reported in this Deliverable represents a collaboration between the LIQUEFACT project partners, stakeholders and end-users during the first 6 months of the LIQUEFACT project.

1.3 The desk based study presented in the report should be considered a work in progress which will be reviewed and modified throughout the duration of the LIQUEFACT project to reflect emerging issues identified by the research team, project partners, and external stakeholders and advisors.

1.4 Whilst this is a public document it is primarily intended for LIQUEFACT researchers and Stakeholders.

2. Background

2.1 The review of the theory of community resilience to EILD events presented in Deliverable D1.1 (Jones, 2016) drew attention to the need to understand the complex interaction between the inter-related component sub-systems that constitute "a community" if an effective mitigation framework is to be developed to improve a community's resilience to an EILD event. In particular, D1.1 identified the need for the RAIF to consider how individual factors within each sub-system respond to an EILD event and how each sub-system's responses affect, and are affected by, the responses of other sub-systems to the EILD event. In essence, the RAIF needs to adopt a multi-dimensional systems analysis approach that allows for inter-action and feedback within and between sub-systems to be identified, measured, modelled and evaluated. To this end each component sub-system's vulnerability, resilience and adaptive capacity needs to be understood in the context of an EILD event and of the antecedent conditions that are present in each sub-system prior to the event. These antecedent conditions include the ability of the physical, social, economic and environmental sub-systems present within (or supporting) the community to withstand the impacts of an EILD event and to recover from the event as soon as possible after the event. The physical, social and environmental sub-systems affect, and are affected by, the robustness, redundancy, resourcefulness, and rapidity of the system as a whole and these are in turn influenced by personal (individual), community, institutional and governance factors. Finally, the RAIF has to also reflect the impact that multiple stressors following a disaster event have on community resilience; in many cases it is the secondary stressors that have the longest (and most devastating) impact on a community.

2.2 Deliverable 1.1 (*ibid*) also reviewed a number of toolkits that have been developed to translate the theory of community resilience into measurement instruments to assess a specific community's resilience to disaster events. D1.1 identified two types of toolkit; those that attempt to measure the characteristics of a system to a disaster event (resilience scoring), and those that attempt to capture / describe the system's resilience to a disaster event (disaster resilience frameworks).

2.3 Resilience scoring systems seek to identify which resilience components exist within a community and then score each in turn against quantitative criteria. The quantitative criteria seek to divide the component into a number of operational factors. The individual scores for each operational factor are then combined to produce an overall score for the component's resilience. The aggregated scores for the components are then combined to produce an overall score for the community's resilience. However, when aggregating the individual component scores together the toolkits do not generally consider inter-dependencies between components but mealy sum or average individual component 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 Disaster Resilience Frameworks seek to improve community resilience by providing a check list of actions or contingencies that should be in place to enhance community resilience to a disaster event. Whilst frameworks tend to be generic they can be customised to reflect different disaster scenarios and many use probability based risk assessments to identify and reduce disaster risk. Whilst these toolkits are good at identifying centrally organised responses to disaster events they are less able to stimulate local responses, especially where responsibility for preparing for a possible event lies with the private sector or at the individual citizen level. In essence, whilst frameworks can complement resilience scoring systems in providing an assessment of the level of engagement/awareness of a community to a potential disaster event they do not generally provide details metrics against which the effectiveness of mitigation strategies to improve community resilience to a potential disaster event can be measured.

2.5 What is needed is an integrated decision support framework that combines a resilience scoring system with a disaster resilience improvement framework that is capable of:

- Assessing the antecedent vulnerability, resilience and adaptive capacity of a community to an EILD event; and
- Providing a decision support framework to assess the improvements in resilience that could be achieved through mitigation actions that seek to reduce vulnerability or enhance adaptive capacity.

2.6 The remainder of this report will outline the theoretical basis of the RAIF. The RAIF will comprise a:

- Resilience Assessment that integrates the hazard mapping that will be developed in WP2 with the infrastructure vulnerability and resilience assessments tools developed in WP3 and the mitigation options developed in WP4;
- Resilience Improvement Framework that will integrate the outputs from the Resilience Assessments into a wider assessment of the impact that building/infrastructure level mitigation actions will have on community level resilience developed in WP5.

2.7 The RAIF will then be integrated into the Liquefaction mitigation planning software toolbox being developed in WP6.

3. Vulnerability, Resilience, Adaptive Capacity and Risk

3.1 Vulnerability, resilience, and adaptive capacity are concepts from the biophysical and social realms that are increasingly being applied to the understanding of the complex relationships between communities, the built environment, and the drivers that may affect change. Whilst there is considerable debate over the precise definitions of the terminology (Gallopín, 2006), the UNISDR defines:

- **Vulnerability** as *"the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard"*. Vulnerability is considered as the principal component of risk (Hewitt, 1983) which encompasses physical, social, economic, and environmental factors and the effect that these have across geographical, social and temporal scale.
- **Resilience** as *"the ability of a system, community or society exposed to hazards to resist, absorb, accommodate 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".* Resilience is both the capacity of a system to react appropriately to moments of crises that have not been entirely anticipated, and its ability to anticipate these crises and to enact, through planning and recovery, changes in the systems that will mitigate their effects (Aguirre, 2006). Therefore, the resilience of a community is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need.
- **Adaptive Capacity** as *"the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*[1] Adaptation can occur in an autonomous fashion, for example through market changes, or as a result of intentional adaptation policies and plans. Thus adaptive capacity can be considered as the capacity of a system to adopt mitigation measures (physical, social, economic, environmental etc.) to potential disaster events.

3.2 Risk is an often used (and misused) word that has two distinct connotations. In popular usage the word risk is usually associated with the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings risk is usually associated with the consequences, in terms of "potential losses", for some particular cause, place and period. Also, it can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks. Therefore developing a single definition

[1] This definition addresses the concerns of climate change and is sourced from the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). The broader concept of adaptation also applies to non-climatic factors such as soil erosion or surface subsidence.

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of risk that is applicable across a range of circumstances and can be measured consistently and in a robust manner is difficult and probably impossible to achieve. As such it is important to the LIQUEFACT project that clear definitions of risk are developed and whilst this will be explored in detail in Deliverable 1.4 initial definitions are presented here to inform the development of the RAIF.

3.3 The UN International Strategy for Disaster Risk Reduction (UNISDR, 2009) defines risk as:

"The combination of the probability of an event and its negative consequences".

In this context (*ibid*) the term risk extends beyond a single measure of the impact of an event to encompass a range of "… 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". Thus disaster risk reflects the concept of disaster as the outcome of continuously present conditions of risk and comprises different types of potential losses which are often difficult to identify and quantify. Thus, whilst in its simplest form risk may be expressed as:

$$R = H\,V\,E$$

Where:
Risk (R): the combination of the probability of an event and its negative consequences
Hazard (H): the probability of an event occurring
Vulnerability (V): the characteristics of a system that make it susceptible to the damaging effects of a hazard
Exposure (E): all the elements of the system that are subject to potential loss

3.4 The metrics required to measure vulnerability and exposure are complex and need to reflect the inter-relationships between the characteristics of the system (or indeed systems) and multiple potential losses and as such a single measurement of risk is not meaningful in a disaster risk context. Despite this, the formula is sometimes used with specific meaning and purposes. For example, in the insurance world risk often refers to the maximum liability for payment of compensation to policy holders (Van Der Voet & Slob, 2007). Establishing a measure of risk is further complicated when one considers the relationship between vulnerability and resilience[2]. Resilience is related to vulnerability; the more resilient a system the less vulnerable it is to the impacts of a hazard. Given the relationship between resilience and vulnerability the risk formula may therefore also be expressed as:

[2] See Deliverable 1.1 a more detailed discussion.

$$R = H \frac{V}{Re} E$$

Where:

Risk (R): the combination of the probability of an event and its negative consequences
Hazard (H): the probability of an event occurring
Vulnerability (V): the characteristics of a system that make it susceptible to the damaging effects of a hazard
Resilience (Re): 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
Exposure (E): all the elements of the system that are subject to potential loss

3.5 Given the above, in the LIQUEFACT project risk is perceived as a multi-dimensional (e.g. vulnerability, coping capacity, exposure of persons and assets etc.) construct that needs to be assessed across of range of scales rather than as a single measure at a single scale. Further, the RAIF also needs to reflect the multi-stressor nature of earthquake events. Thus, whist the specific focus of the LIQUEFACT project is on Liquefaction the RAIF cannot ignore the other effects that result from an earthquake hazard (e.g. ground shaking/movement, landslides, ground cracks, displaced boulders, tsunami and hydrological anomalies etc. (Michetti et al., 2007)). In essence the RAIF must accommodate all the impacts that earthquakes have on buildings and critical infrastructure (e.g. public buildings, including schools and hospitals; together with elevated highway and port installations, water treatment facilities, crude oil storage tanks etc.) as it is the combination of these that effect the wider resilience of the system (economic, political, social and business effects) and the community.

3.6 Thus the RAIF needs to be rooted in an evidence-based knowledge and understanding of disaster risk and all its dimensions of vulnerability, adaptive capacity, exposure of persons and assets and hazard characterization. Exposure, for example, needs to reflect both a single building and the system as the set of all such buildings; whilst vulnerability, for example, must relate to the ability of a single building to continue to perform its functions and the impact that any loss of function is likely to have on the whole system. Finally, the RAIF must also reflect the different governance models within which mitigation decisions are made as these play a pivotal role in creating and improving better disaster risk reduction strategies across all sectors.

4. Disaster Risk Reduction Frameworks

4.1 The SENDAI Framework for Disaster Risk Reduction 2015-2030 (UN General Assembly, 2015) is a 15-year non-binding agreement that was adopted at the Third United Nations World Conference on Disaster Risk Reduction, held from 14 to 18 March 2015 in SENDAI, Miyagi, Japan. The following sections are extracts from, or summaries of, the principles embedded in the SENDAI Framework (*ibid*) that will be used to inform the development of the LIQUEFACT

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RAIF. A summary of the SENDAI Framework can be found in Appendix A of this report. The full text of the SENDAI Framework can be found at http://www.unisdr.org/we/coordinate/SENDAI-framework.

4.2 The stated intention of the SENDAI Framework is to support a ''… substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.'' To this end the SENDAI Framework represents a unique opportunity for countries to:

- Adopt a concise, focused, forward-looking and action-oriented post 2015 framework for disaster risk reduction;
- Complete the assessment and review of the implementation of the Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters;
- Consider the experience gained through the regional and national strategies/institutions and plans for disaster risk reduction and their recommendations, as well as relevant regional agreements for the implementation of the Hyogo Framework for Action;
- Identify modalities of cooperation based on commitments to implement a post 2015 framework for disaster risk reduction;
- Determine modalities for the periodic review of the implementation of a post 2015 framework for disaster risk reduction.

4.3 The SENDAI Framework replaces the Hyogo Framework for Action: Building the Resilience of Nations and Communities to Disasters. The SENDAI Framework has been specifically developed to apply to a wide spectrum of small-large scale, frequent and infrequent, sudden and slow onset disasters caused by natural and man-made hazards. As such the SENDAI Framework should provide a suitable vehicle for assessing the community level risk to EILD.

4.4 The SENDAI Framework is based on (but not limited to) the following guiding principles:

- Disaster risk reduction is a shared responsibility between government, authorities, sectors and stakeholders. It requires all-of-society engagement;
- When managing disaster risk consideration should be given to protecting people, their health, property and livelihoods, as well as productive, cultural and environmental assets;
- Disaster risk reduction depends on coordination mechanisms within and across sectors and with relevant stakeholders; and requires empowerment of local communities;
- Disaster risk reduction requires a multi-hazard and risk–informed decision making based on scientific information complemented with local knowledge that contextualises the information to local circumstances;

- Disaster risk reduction is more cost-effective than post disaster response and recovery and a "build-back-better" philosophy reinforces future risk reduction.

This approach is again consistent with the objectives of the LIQUEFACT project and with the requirements of the RAIF.

4.5 When developing implementation plans the SENDAI Framework suggest that national states should focus on 4 priority areas for action.

- **PRIORITY 1: Understand the disaster risk**
  A holistic understanding of disaster risk in all its dimensions is essential to support effective risk management. Using relevant and reliable data (nationally and locally) will provide base-line information on vulnerability, adaptive capacity, exposure and hazard characterisation which will allow primary and secondary impact scenarios to be modelled and the effectiveness of coping strategies to be evaluated. The scenarios can also provide a mechanism to communicate the disaster risks to central planners and the wider community. In the LIQUEFACT project this priority will be addressed in WPs 2, 3 and 4 and embedded in the RAIF developed in WP 5.
- **PRIORITY 2: Strengthen disaster governance to manage risk**
  Develop clear vision, plans, guidance, command, control, and coordination activities within and across sectors that engage all the stakeholders in disaster risk management. In developing the systems consideration should be given to publicly and privately owned critical infrastructure as well as to households, communities and businesses. Whilst systems can be designed centrally they should be enabled locally with local authorities empowered to act at the local level. In the LIQUEFACT project this priority will be addressed in WPs 5 and embedded in the SELENA-LRG Software developed in WP 6.
- **PRIORITY 3: Invest in disaster risk reduction to improve resilience**
  Public and private investment in disaster risk reduction is essential to enhance economic, social, health and cultural resilience of people, communities, countries and their assets. Effective mechanisms should exist to promote disaster risk transfer (e.g. insurance, risk sharing and retention, financial protection etc.) for both public and private assets and in particular critical infrastructure assets including appropriate design standards; building materials; and maintenance and refurbishment strategies. With regards to business resilience, effective understanding of the integration of disaster risk management into business models, including the supply chain, is critical if livelihoods are to be protected. In the LIQUEFACT project this priority will be addressed in WPs 5, 6 and 8.
- **PRIORITY 4: Enhance disaster preparedness and build-back-better**
  Pre-planning is essential for an effective recovery, rehabilitation and reconstruction following a disaster event. This phase also offers an ideal

opportunity to build-back-better by integrating disaster risk reduction into development and reconstruction projects. To prepare for disaster events requires contingency plans and programmes to be developed and tested routinely across the community. These plans need to consider forecasting and early warning systems as well as communication systems and channels. Policies to improve the resilience of existing critical infrastructure should be developed and implemented as part of routine refurbishment. Logistics required immediately after a disaster event should be stockpiled and a distribution system established for their release immediately following a disaster event. In the LIQUEFACT project this priority will be addressed in WPs 5, 6, 7, and 8.

4.6 One of the pivotal strengths of the SENDAI Framework is that it recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government and the private sector[3]. The SENDAI Framework also emphasises the role of stakeholders in disaster risk reduction; identifying in particular civil society; volunteers, organised voluntary work organisations, and community based organisations; businesses; professional associations; financial institutions; and media organisations as critical components to community resilience.

4.7 However, whilst the SENDAI Framework is well founded in disaster resilience theory it doesn't provide detailed tools or metrics to allow community resilience to be measured in response to any given hazard threat. Indeed, the SENDAI Framework poses many challenges to those seeking to implement it. The challenges to science posed by adoption of the SENDAI Framework were explored in a meeting of international disaster risk experts held at the Royal Society in London on the 24-35 June 2015 (UNISDR, 2015). Whilst the meeting acknowledged the readiness of the scientific and technology communities to address disaster risk reduction it also highlighted a number of areas where further work was needed if the Framework was to be fully effective. Amongst the issues that the meeting highlighted were the need to mainstream disaster risk reduction amongst the scientific community; and a clear understanding of disaster risk reduction potential offered by scientific and technological advances. In addition a number of specific gaps in scientific knowledge were identified including:

- The need to study disaster risk reduction as multiple hazards from interdisciplinary, inter-sectoral, trans-boundary and trans-national perspectives;
- A better understanding of how risks escalate over time and in particular the social, economic and institutional factors that contribute to risk and the transfer of risk between stakeholders;
- Development of early warning systems; and

[3] http://www.unisdr.org/we/coordinate/SENDAI-framework

- Improved data on risk-related phenomena and in particular people's changing vulnerabilities and expose to hazards over time.

4.8 At a subsequent meeting of the United Nations Office for Disaster Risk Reduction held in January 2016 in Geneva (UNISDR, 2016) a scientific and technology road map was developed to support the implementation of the SENDAI Framework[4]. A summary of the SENDAI Framework can be found in Appendix B of this report. This road map identified the expected science and technology outcomes needed to support the four SENDAI Priority Action areas and provided detailed actions required to achieve each expected outcome. The summary of expected outcomes extracted from the Geneva meeting (*ibid*) and mapped to LIQUEFACT outputs and WPs are shown in Table 1.

SENDAI PRIORITIES FOR ACTION	EXPECTED OUTCOME & LIQUEFACT IMPLEMENTATION
PRIORITY 1: Understanding disaster risk in all its dimension	Assess and update current state of knowledge (hazard mapping, vulnerability assessment, mitigation options, community resilience). **WP's 1, 2, 3, 4, 5 and 6.** Disseminate to policy-makers/stakeholders (tools and guidelines). **WP's 5, 6 and 8.** Use scientific data for disaster risk assessment and to build resilience (models and tools). **WP's 1, 5 and 6.** Build capacity to use the data (training, codes and guidelines). **WP's 6, 7 and 8.**
PRIORITY 2: Strengthening disaster risk governance to manage disaster risk	Inform policy/decision makers across all levels (models, tools, training and guidelines). **WP's 5, 6, 7 and 8.**
PRIORITY 3: Investing in disaster risk reduction for resilience	Policy options for development appraisal (tools and models). **WP's 5 and 6.**
PRIORITY 4: Enhancing disaster preparedness for effective response, and to 'Build Back Better' in recovery, rehabilitation and reconstruction	Provide data to strengthen preparedness and response and support 'build back better' (models, tools, guidelines and codes). **WP's 3, 4, 5, 6, 7 and 8.**

Table. 1: The 4 SENDAI priorities for actions and the implementation actions of the LIQUEFACT project

[4] Full details can be found at:

http://www.preventionweb.net/files/45270_unisdrscienceandtechnologyroadmap.pdf

4.9 It can be seen from Table 1 that the LIQUEFACT project is clearly aligned to the principles underpinning the SENDAI Framework and fully integrated in the research and dissemination agenda developed by UNSIDR to support its implementation in the context of EILD events. The risk-based models and tools developed will be applicable across geographical and temporal scale; from improving the resistance of structures to EILD events to improving the resilience of the collective urban community in relation to their quick recovery from an occurrence; from short term building adaptation planning to long term mitigation planning. Further, combining the individual models and tools through the use of the SELENA-LRG Software (see next section) and associated guidelines will allow a range of stakeholders (from building owners/managers to emergency planners/government agencies) to evaluate the impact of a range of EILD scenarios and evaluate the potential benefits of alternative mitigation techniques to improve overall community resilience to an EILD event. Finally, the development of design guidance suitable for inclusion in Eurocodes will enable engineers to build back better and thus improve the overall community resilience in the future. The models and tools developed in the LIQUEFACT project will be tested and validated through peer review of the project's international stakeholder/expert advisor group and through a detailed case study of the Emilia Romagna region of Italy.

4.10 Whilst the SENDAI framework provides the high level strategic guidance needed to drive improvements in disaster risk reduction it doesn't provide operational guidelines on how to deliver improvements at a local policy or building level. In particular it doesn't provide an action-oriented framework that relevant stakeholders at all levels can use to identify disaster risks and guide mitigation investment decisions to improve community resilience. However, one such a framework was produced by the New Zealand Ministry of Business, Innovation and Development (Taig & GNS Science, 2012) following a series of earthquake disaster events. The "Risk Framework for Earthquake Prone Building Policy was developed to support an earthquake prone building policy review (BPR) and represents an attempt to express building standards in risk-based terms to allow central government to identify the factors that need to be considered when developing risk and evidence based policy. The framework is shown in Figure 1.

4.11 The BPR Framework suggests a two-phase approach to assessing building resilience and developing mitigation plans. In phase 1 (a and b) the policy context in which the disaster event resides is defined and metrics are developed to quantify the risks and set performance thresholds (e.g. "*how safe is safe enough?*"). In phase 2 (c, d, e and f) the solution space is addressed with policy instruments and design guidance being developed along with rules for ensuring compliance and procedures for checking outcomes. This approach, is similar in concept to that developed by Prof Jones in the CREW project (CREW, 2012) that forms the basis of the RAIF that will be developed in WP 5 (see section 6 for further details) and integrated into the SELENA-LRG Software in WP 6.

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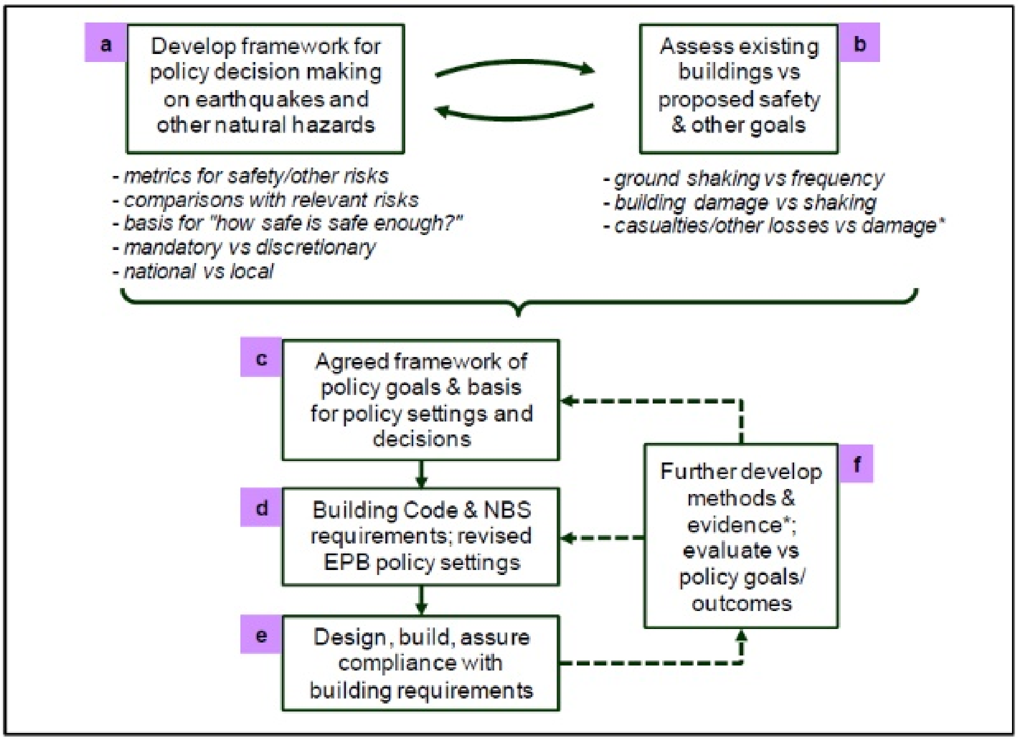

Figure 1: Risk Framework for Earthquake Prone Building Policy developed by the New Zealand Ministry of Business, Innovation and development

5. The SELENA-LRG Toolbox

5.1 Earthquake risk and resilience assessment computation basically requires software that is able to process available information on ground motion characteristics, inventory and building vulnerability. The earthquake risk assessment software of one of our project partners (NORSAR), SELENA (SEismic Loss EstimatioN using a logic tree Approach) will be a focus of the LIQUEFACT project with the LRG (LIQUEFACT Reference Guide) software toolbox developed as an extendable module that can be integrated with it. The software adopts a classic approach to seismic risk and loss assessment, using physical data such as building inventory data, demographic data, seismic scenarios etc. to estimate physical and financial losses at the buildings, regional and or national scales. The new GUI-based LRG toolbox will have the following specifications/characteristics for liquefaction risk assessment:

- **Stage 1:** The evaluation of Liquefaction Susceptibility: this requires quantification from a geological map of the probability of an area to liquefaction (see Appendix C);
- **Stage 2:** The evaluation of Liquefaction Probability for a given susceptible category at specified level of PGA;

- **Stage 3:** The evaluation of liquefaction-induced ground deformation, where various mechanisms can be observed, e.g. lateral spreading, ground settlement, differential movements, etc. Presents a number of methodologies for estimating the PGD based on field observation using different approaches;
- **Stage 4:** Identify deformation modes (damage) that building may experience when subject to liquefaction-induced ground deformations;
- **Stage 5:** The evaluation of the overall damage from the combined damage probabilities due to occurrence of ground failure liquefaction and ground shaking.

5.4 The five (05) stages are addressed through the various WPs associated with the LIQUEFACT project (Figure 2). The Liquefaction Risk Assessment will be integrated with the knowledge and the methodologies analysed in WPs 2, 3, 4, 5 in order to create the Liquefaction Mitigation Planning Software (Figure 2). Specifically it will integrate procedures and regression models for liquefaction hazard map (WP2), the methodologies of liquefaction vulnerability analysis of critical infrastructures (WP3), the mitigation measures (WP4) and the socio-economic loss computation (WP5). The applicability of the software toolbox will be tested in the widest possible range of situations and addressed to selected sample cases representative of the European different characteristics (WP7). Finally, both the software toolbox and the validation will be used to support and guide the technical and non-technical decision maker during the planning process and in the development of the Built Assess Management Plan.

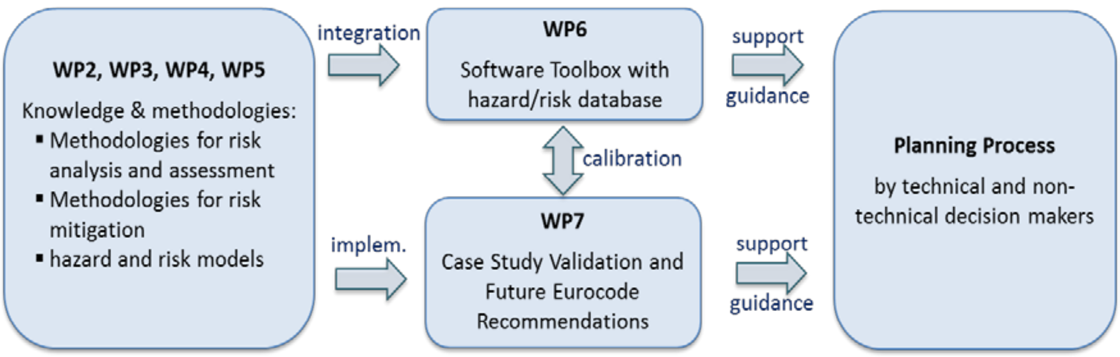

Figure 2: The integration of knowledge and methodologies from WPs into the SELENA-LRG software toolbox

5.5 All the methodologies coming from the different WPs will be reviewed, developed and integrated in the SELENA-LRG software in WP6 (Figure 3). The WP will develop an easy-to use software application toolbox, wherein the civil engineers and other relevant stakeholders involved in the design and implementation of a structure / infrastructure is guided to make informed assessments on the feasibility and cost-benefit of applying certain liquefaction mitigation techniques within specific European regions. The toolbox will be implementable for

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an individual level (single structure / infrastructure) and for region/city level (i.e. in an urban area, GIS-based outputs) with procedures for calculating socio-economic impacts and proposing risk reduction and resilience improvement strategies.

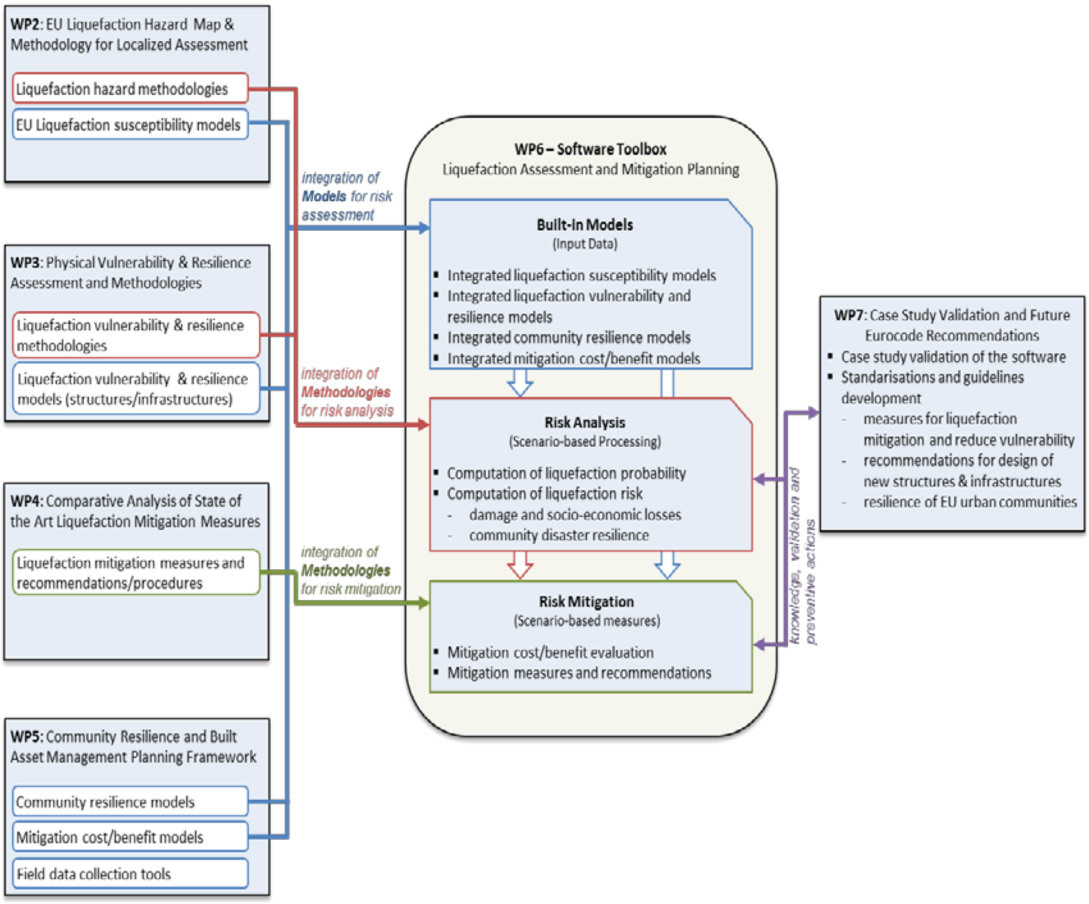

Figure 3: Detailed knowledge and methodologies related inputs for the development of liquefaction mitigation planning software toolbox

6. Resilience Assessment and Improvement Framework

6.1 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 (CREW, 2012). 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 (Figure 4) in which antecedent conditions, including coping response and absorptive capacity, directly affect speed of recovery and system resilience. 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. This section of the report provides an overview of the adaptation framework.

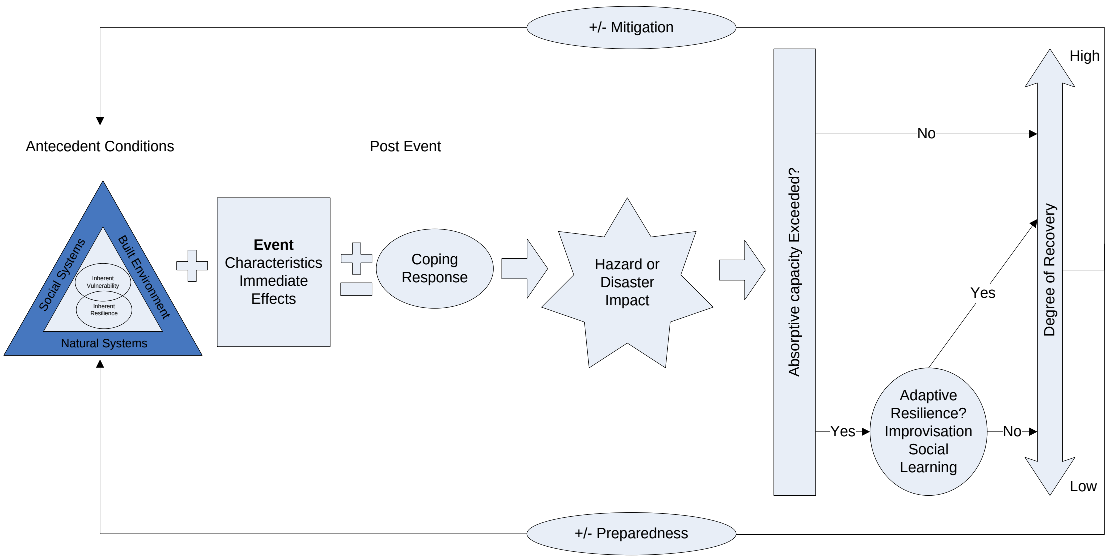

Figure 4: Schematic representation of the disaster resilience of place (DROP) model (Source: Cutter et al, 2008)

6.2 The RAIF draws together two main activities; a risk-based assessment of the antecedent conditions that affect building and community resilience pre event and a resilience improvement framework that will allow alternative mitigation options to improve building and community resilience to be evaluated against a range of post event scenarios. The RAIF is show in Figure 5.

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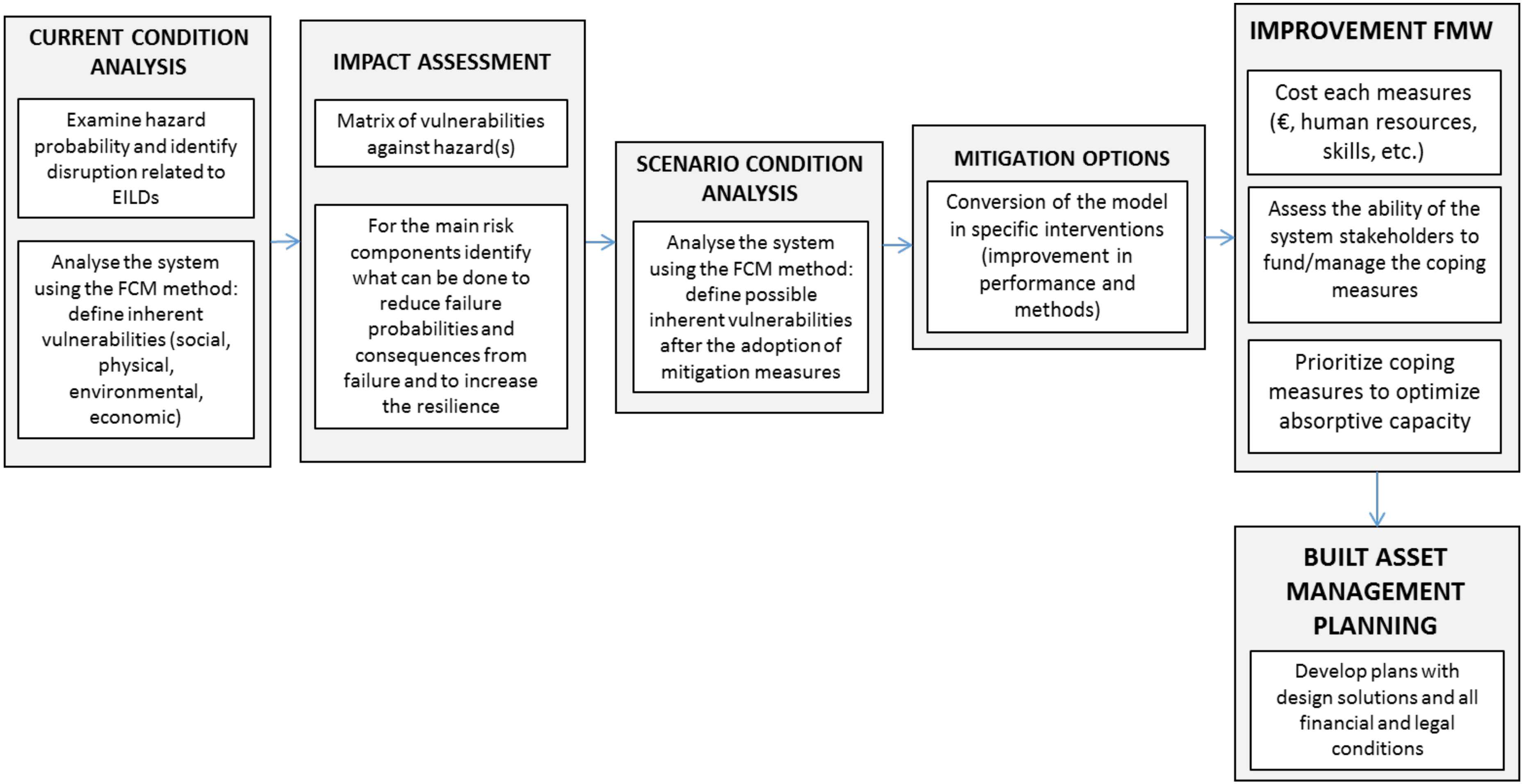

Figure 5: Resilience Assessment and Improvement Framework (adapted from the CREW Adaptation Framework, 2012)

6.3 **Stage 1 - Current Condition Analysis:** requires an examination of the hazard risk to the buildings and critical infrastructure within the geographical area under investigation (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.). The hazard risk assessment needs to consider both direct and indirect impacts of the hazard on the community. The hazard risk assessment will use Fuzzy Cognitive Mapping (FCM) to define inherent vulnerabilities at the physical, social, environmental and economic level.

6.4 **Stage 2 - Impact Assessment:** requires a matrix of vulnerabilities against hazard impacts to be developed. 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. For each sub-system component that has a high vulnerability and a low coping capacity, possibly mitigation interventions to either reduce vulnerability; improve coping capacity; or achieve both need to be identified.

6.5 **Stage 3 - Scenario Condition Analysis:** requires the effect of the interventions identified in stage 2 at the sub-system component level to be re-modelled using FCM at the system level to establish the overall effect of the mitigation interventions on inherent system vulnerability. The scenario condition analysis will also require inter-actions between systems (e.g. physical, social etc.) to be modelled to identify the collective impact of each of the sub-system component interventions on the overall resilience of the community.

6.6 **Stage 4 - Mitigation Options:** requires the conversion of the FCM model into a series of specific (sub-system component level) interventions that can be specified at the level of detail required to allow initial options appraisal to be carried out. The specification should describe explicitly the improvement in performance required at the sub-system component level and the methods that will be used to measure whether this performance is achieved in practice.

6.7 **Stage 5 - Improvement Framework:** requires a cost/benefit analysis to 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 these 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). Once the cost/benefit analysis has been completed for all sub-system components interventions 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).

6.8 **Stage 6 - Built Asset Management Planning:** 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.

6.9 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.

7. Fuzzy Cognitive Mapping

7.1 Whilst the detailed development of the FCM models to be used in the RAIF will be developed in WP5; for completeness of this report a brief introduction to the process is given here. As stated previously, risk is "the combination of the probability of an event and its negative consequences" with risk assessment being "a methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend"(UNISDR, 2009). Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities against potential (likely) risk scenarios. This series of activities is sometimes known as a risk analysis process.

7.2 The examination of recent events/current conditions allow users to identify possible disruption caused by a hazard and to assess the risks to themselves and their community. The hazard of concern to the LIQUEFACT project are earthquake induced Liquefaction events. Such hazards result of a variety of geological, pedological, hydrological and technological sources: sometimes acting in isolation; other times in combination. In a technical setting, hazards are described quantitatively by the likely frequency of occurrence of different intensities, frequencies and probabilities for different locations, and are determined primarily from historical data or scientific analysis (modified from SENDAI).

7.3 Vulnerability assessment aims at defining and investigating all the factors that influence the vulnerability of an urban community to a hazard. Unfortunately, because of inert-relationships and interdependences between vulnerability indicators (vulnerability is in essence a concept and as such cannot be measured directly) and the uncertainties that these place on quantitative measurements, vulnerability in absolute terms is difficult to measures. However, vulnerability is an essential concept in hazard research to estimate current and future risks and to support the decision making process that drives the development of hazard mitigation strategies at the local, national and international level. One way in which the uncertainties associated with vulnerability assessments can be accommodated is to develop a vulnerability assessment tool based on the FCM method.

7.4 Fuzzy Cognitive Maps are fuzzy signed graphs with feedbacks (Stylios, Georgopoulos, & Groumpos, 1997) that consist of nodes, also called "concepts"(C_i), and "inter-connections" (e_{ij}) between concepts (see Figure 6).

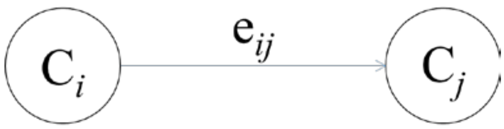

Figure 6: Concepts and inter-connections scheme

7.5 A FCM model is a dynamic complex system structured as a collection of concepts with cause and effect relations between concepts. Inter-connections e_{ij} among concepts are characterized by a weight w_{ij} that describes the grade of causality between two concepts. 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.

7.6 Fuzzy Cognitive Maps have been used to model and study many different scientific problems ranging from health care (Giabbanelli, Torsney-Weir, & Mago, 2012; Mei et al., 2014), Collaborative Planning Forecasting and Replenishment, (Büyüközkan & Vardaloğlu, 2012), reliability analysis of electric power systems (Salmeron & Gutierrez, 2012), the investigation of social ecological systems (Vanwindekens, Stilmant, & Baret, 2013), and the scenario analysis of complex environmental systems (Kok, 2009). In each of these applications the FCM method helped analysts visualise and model the complex system they were researching; highlighting the causal relations between relevant attributes and managing inherent uncertainties. The

FCM tool also provided analysts the opportunity to understand in detail the behaviour of the system to different scenarios and to the mind models of different stakeholders.

7.7 The application of FCM to EILD events will comprise of two main phases:

1. The establishment of a group of experts (stakeholders);
2. The development of the vulnerability FCM.

7.8 The identification of the problem space is fundamental to defining the scope and focus of the analysis and in establishing all the important characteristics of the complex system model. The whole process is realized in collaboration with a group of experts, selected for their knowledge of the problem space. To test whether such a panel could be identified from amongst the LIQUEFACT stakeholders an *ad hoc* panel of experts 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.

7.9 During the Bologna workshop each panel member was asked to complete a self-administered questionnaire in which they scored a range of concepts (Table 2) 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.

7.10 Data collected from the questionnaire is still being analysed to inform the development of a more compressive panel assessment that will be replicated to provide a more detailed FCM in WP5 but it would appear from the work to date that the FCM process can provide a suitable vehicle for modelling the vulnerability of a community to an EILD event.

7.11 The outputs from the FCM model will be used in the RAIF. Once the FCM has been developed (from the input from the expert panel) it is used to create a generic model of the vulnerability of a 'typical' system to an EILD event. This in essence represents a general antecedent vulnerability of a typical system subjected to an EILD event. Analysts can then enter the details of their own system and by comparison with FCM model obtain an assessment of their system's vulnerability to an EILD event. Figure 7 shows an example of the vulnerability of a technical sub-system of community where the Indirect and Total Effect (respectively IE and TE) along with the importance of each concept to the system's resilience can be seen. The total effect is the aggregate sum of all the paths' indirect effects from each causal variable associated with each effect variable. Each factor is represented by an output number; the proximity of the output value to the edge of the Kiviat diagram factor is proportional to the magnitude of the variable for the data point relative to the maximum magnitude of the variable across all data points.

Technical factors	Organizational 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 2: 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

7.12 Once the vulnerability of the system has been assessed a series of potential mitigation interventions can be identified to reduce failure probabilities (and the consequences of failure) and to improve the resilience of the system. Further, the mitigation interventions can be used to create a series of scenarios that can be input into the FCM model to re-evaluate the vulnerability of the system after the mitigation intervention. The analysis will produce another Kiviat diagram (Figure 8) in which it is possible to assess how the mitigation measures affect the overall system vulnerability, both positively and/or negatively. The new diagram shows how the adoption of the selected mitigation measures change the values of the system.

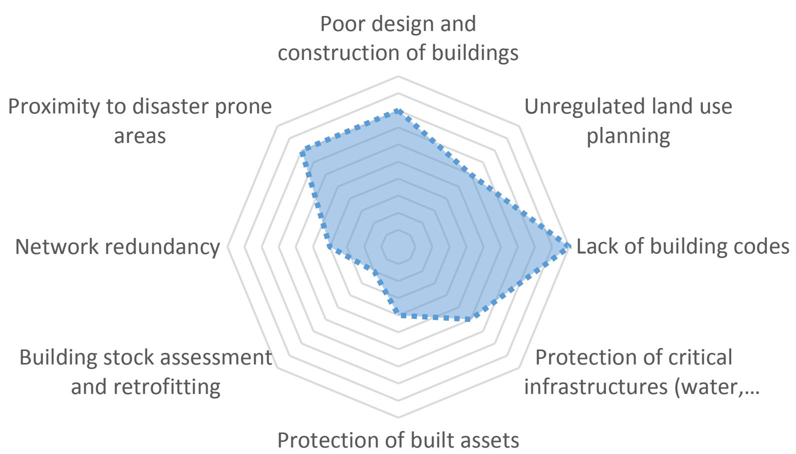

Figure 7: The Kiviat diagram represents the vulnerability assessment of the technical factors

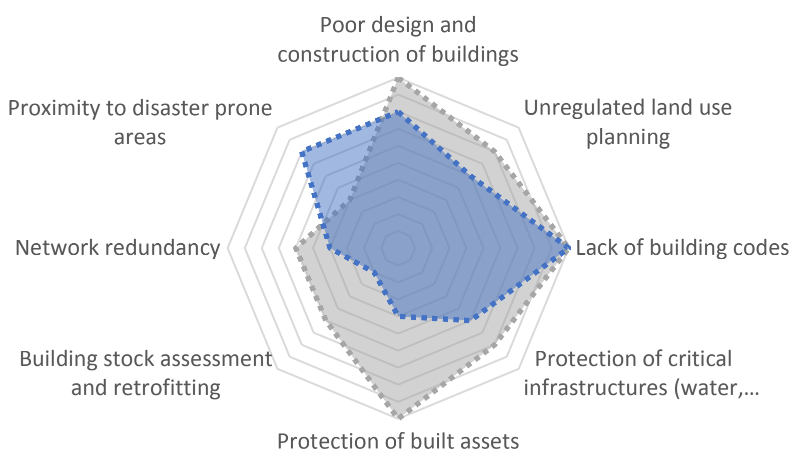

Figure 8: The Kiviat diagram represents the vulnerability assessment of scenario condition, after mitigation interventions

7.13 The FCM approach along with the other risk framing tools needed to operationalise the RAIF will be developed and tested in WP5.

8. Summary Discussion and Next Steps

8.1 This report outlines a RAIF that will be developed in the LIQUEFACT project to assist end-users in assessing the vulnerability and resilience of critical buildings / infrastructure to the impacts of EILD events. The report outlines the theoretical background to the RAIF and provides an initial description of how the RAIF can be applied at different scales to aid mitigation planning to improve community resilience to EILD events. This report should be read in conjunction with the Review of Theory presented in Deliverable 1.1 and with the SENDAI Framework for Disaster Risk Reduction.

8.2 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. To this end the LIQUEFACT project will develop and evaluate a RAIF that is based on the risk/resilience framework developed by Prof Jones in the CREW project and is consistent with the guidance for disaster risk reduction contained in the SENDAI Framework. The RAIF, which is based on a combined resilience framework and resilience scoring methodology, will comprise a community resilience model that can be used to assess the antecedent vulnerability and resilience of the community to EILD events. The RAIF 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.

8.3 The next steps in the development of the RAIF are to establish a more detailed understanding of how it could be used in practice and to define specifications for the data, tools and models that need to be developed WP2, 3, 4 and 5 to support the integration of the RAIF into the SELENA-LRG software (WP6). Further details of data needs, including a lexicon of terminology and initial data specifications, will be presented in Deliverable 1.4.

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APPENDIX A: THE SENDAI FRAMEWORK FOR DRR

Chart of the Sendai Framework for Disaster Risk Reduction

2015-2030

Scope and purpose

The present framework will apply to the risk of small-scale and large-scale, frequent and infrequent, sudden and slow-onset disasters, caused by natural or manmade hazards as well as related environmental, technological and biological hazards and risks.
It aims to guide the multi-hazard management of disaster risk in development at all levels as well as within and across all sectors

Expected outcome

The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries

Goal

Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience

Targets

Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality between 2020-2030 compared to 2005-2015	Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 between 2020-2030 compared to 2005-2015	Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030	Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030	Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020	Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this framework by 2030	Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030

Priorities for Action

There is a need for focused action within and across sectors by States at local, national, regional and global levels in the following four priority areas.

Priority 1 Understanding disaster risk	Priority 2 Strengthening disaster risk governance to manage disaster risk	Priority 3 Investing in disaster risk reduction for resilience	Priority 4 Enhancing disaster preparedness for effective response, and to «Build Back Better» in recovery, rehabilitation and reconstruction
Disaster risk management needs to be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment	Disaster risk governance at the national, regional and global levels is vital to the management of disaster risk reduction in all sectors and ensuring the coherence of national and local frameworks of laws, regulations and public policies that, by defining roles and responsibilities, guide, encourage and incentivize the public and private sectors to take action and address disaster risk	Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment. These can be drivers of innovation, growth and job creation. Such measures are cost-effective and instrumental to save lives, prevent and reduce losses and ensure effective recovery and rehabilitation	Experience indicates that disaster preparedness needs to be strengthened for more effective response and ensure capacities are in place for effective recovery. Disasters have also demonstrated that the recovery, rehabilitation and reconstruction phase, which needs to be prepared ahead of the disaster, is an opportunity to «Build Back Better» through integrating disaster risk reduction measures. Women and persons with disabilities should publicly lead and promote gender-equitable and universally accessible approaches during the response and reconstruction phases

Guiding Principles

Primary responsibility of States to prevent and reduce disaster risk, including through cooperation	Shared responsibility between central Government and national authorities, sectors and stakeholders as appropriate to national circumstances	Protection of persons and their assets while promoting and protecting all human rights including the right to development	Engagement from all of society	Full engagement of all State institutions of an executive and legislative nature at national and local levels	Empowerment of local authorities and communities through resources, incentives and decision-making responsibilities as appropriate	Decision-making to be inclusive and risk-informed while using a multi-hazard approach

Coherence of disaster risk reduction and sustainable development policies, plans, practices and mechanisms, across different sectors	Accounting of local and specific characteristics of disaster risks when determining measures to reduce risk	Addressing underlying risk factors cost-effectively through investment versus relying primarily on post-disaster response and recovery	«Build Back Better» for preventing the creation of, and reducing existing, disaster risk	The quality of global partnership and international cooperation to be effective, meaningful and strong	Support from developed countries and partners to developing countries to be tailored according to needs and priorities as identified by them

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APPENDIX B: THE ROAD MAP FOR THE IMPLEMENTATION OF THE SENDAI FRAMEWORK

The Science and Technology Roadmap for the Implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030		
Sendai Framework Priority Action 1: Understanding Disaster Risk		
Expected Outcomes	**Actions**	**Deliverables**
1.1 Assess and update the current state of data, scientific and local and indigenous knowledge and technical expertise availability on disaster risks reduction and fill the gaps with new knowledge.	• Establish a global database of existing hazards, including information on exposure and vulnerability to build awareness and knowledge of changing disaster risk and to better disseminate risk information, including for public health emergencies. • Develop methods, models and tools including spatial for national risk assessments and monitor changes in disaster risk and risk profiling. • Archive disaster data, land use and information on social and economic activities and promote community engagement in risk data collection. • Conduct solution-driven surveys and research in disaster risk management and increase research for global, regional, national and local application. • Analyse the ethics of scientific input before, during and after disaster and address the ethical challenges in accessing science and technology for everyone.	• Network established for sharing disaster data and statistics. • Improved, open and accessible data and integrated metrics on exposure and vulnerability from local to global scale. • Periodic reports produced on the state of global risk. • Guidelines and standards developed for data archiving, recording and reporting disaster loss and disaggregated impact data. • Support implementation of national disaster loss and damage databases. • Guidelines developed for national and regional, multi-hazard, risk assessments, mapping and risk profiles. • Guidelines developed for national and regional disaster risk management capability assessment. • Periodic surveys on disaster risk management capability. • Analysis and practices on ethics disaster risk reduction disseminated.

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1.2 Synthesize, produce and disseminate scientific evidence in a timely and accessible manner that responds to the knowledge needs of policy-makers and practitioners.	• Promote real-time and near real-time access to reliable data and use of information and communications technology. • Integrate traditional, indigenous and local knowledge and practices in disaster risk reduction. • Promote intergenerational partnership between scientists, policy makers, private sectors and community leaders. • Develop partnerships between science and technology community and the disaster risk management institutes and agencies. • Promote scientific focus on disaster risk factors and scenarios, including emerging disaster risks and public health threats. • Develop expertise and personnel to use the statistics to develop policies for disaster risk reduction.	• National and regional knowledge centres and hubs for disaster risk management established/and mapped. Methodologies for knowledge hubs linked. • Good practises and case studies on use of indigenous, traditional and local knowledge practices documented and disseminated. • Evidence of partnerships between science and technology community and disaster risk management institutes and agencies. • Studies conducted on gaps in disaster risk reduction evidence and knowledge. • National Statistical Offices roles and responsibilities identified and supported.
1.3 Ensure that scientific data and information support are used in monitoring and reviewing progress towards disaster risk reduction and resilience building.	• Develop and monitor a set of indicators, including a gender marker, to measure progress of use science and technology in disaster risk reduction. • Promote the development and use of standards and protocols, such as certifications, for national and regional levels. • Adopt a multi-hazard approach that integrate lessons learned, including from transboundary and biological and technological hazards. • Incorporate gender equality and integration in science and technology for disaster risk reduction partnerships.	• Indicators and terminology for use by the science and technology community in disaster risk reduction developed. • Data is gender-differentiated in disaster and climate risks. • Best practices for a multi-hazards approach developed and disseminated. • Challenges for women role in the science and technology and in disaster risk reduction identified and addressed in partnerships. • Tools (indicators and date collection) developed for

	• Promote coherence with disaster risk reduction and post-2015 agenda (in particular SDGs and climate change) in data collection and indicators to assist in monitoring and evaluation - so that they do not create additional reporting burden for countries.	monitoring and evaluation of disaster risk reduction that are mutually reinforced with post-2015 agenda (in particular SDGs and climate change).
1.4 Build capacity to ensure that all sectors and countries have access to, understand and can use scientific information for better informed decision-making	• Promote research on insurance and social protection and safety nets for developing countries. • Promote integrated and multi-disciplinary research that bridges social and natural sciences and uses both quantitative and qualitative data. • Involve the users of science in the earliest stages of research and technology. • Mobilize the research community to ensure design, implementation and improvement of risk reduction plans with the identification of metrics and methodologies. Standardize the monitoring of implementation. • Integrate risk assessments into disaster risk management across sectors. • Promote inclusiveness, interdisciplinary, and inter-generational participatory approaches. Engage young scientists in in applying science for disaster risk reduction.	• A mechanism to provide technical advice (e.g. help desks, knowledge centres and hubs) on disaster risk management. • Dialogues with communities and citizen groups and the use of scenarios that make science sensible to decision-makers and the general public. • Measure to build capacity development in knowledge management, innovation and learning, research and technology initiated. • Training and capacity building of science and technology in disaster risk reduction undertaken. • Guidance developed on integrated and multi-disciplinary research that bridges social and natural sciences, and supportive publishing practices enhanced. • User-friendly web-based interactive platforms used for science and technology capacity building and training. • Design and implement a young scientists forum at the Global Platform (including possible establishment of an Young Scientist award or scholarship).

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Sendai Framework Priority Action 2: Strengthening Disaster Risk Governance to Manage Disaster Risk		
Expected outcomes	**Actions**	**Deliverables**
2.1 Support a stronger involvement and use of science to inform policy- and decision-making within and across all sectors at all levels	• Promote dialogue and networking on disaster risk reduction between scientists and policy-makers. • Raise scientific awareness and improve understanding of the impact of disaster risks on societies. • Promote disaster risk assessments in planning and development especially in land-use mapping (coastal areas, river basins, cities), rural development, and eco-system management. • Strengthen the engagement of science in national coordination mechanisms or platforms for disaster risk reduction.	• Establish national and regional multi-hazards knowledge centres for disaster risk management. • A created space for dialogue between scientists and policy makers. • Multi-sectoral platforms for post-disaster reviews • Use of scientific good practises and case studies on implementation of the Sendai Framework. • Science and technology expertise made available and used for regional and national platforms for disaster risk reduction.
Priority Action 3: Investing in Disaster Risk Reduction for Resilience		
Expected outcomes	**Actions**	**Deliverables**
3.1 Provide scientific evidence to enable decision-making of policy options for investment and development planning	• Provide funding and resources for science and technology to inform on understanding of risk, including through incentives and cooperation with the commercial sector and enhanced knowledge and technology transfer. • Present the impact of investment in disaster risk reduction based on the assessment on economic growth and the safety and wellbeing of the general public. • Support innovation in earth observation and geo spatial data for risk profiling and decision making.	• Design opportunities to promote cooperation and for funding and resourcing between academic, scientific and research entities and networks with the private sector to better use existing, and develop new products and services. • Develop and disseminate a periodic report on the state of science, including the role of social and anthropological science, in disaster risk reduction. • Established practices to include cost-benefit in risk reduction analysis.

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	• Identify the role of social and anthropological sciences can play in the analysis of investing in disaster risk reduction. • Research that reviews guidelines and detects new challenges and vulnerabilities to disasters.	• Increased shared information on early warning systems, hazard maps and earth observation, geo spatial data. • A report on investments in research programmes on disaster risk reduction. • A dialogue between science and policy makers arranged at global and regional platforms for disaster risk reduction.
Sendai Framework Priority Action 4: Enhancing Disaster Preparedness for Effective Response, and to "Build Back Better" in Recovery, Rehabilitation and Reconstruction		
Expected outcomes	**Actions**	**Deliverables**
4.1 Identify and respond to the needs of policy- and decision-makers at all levels for scientific data and information to strengthen preparedness, response and to "Build Back Better" in Recovery, Rehabilitation and Reconstruction to reduce losses and impact on the most vulnerable communities and locations.	• Promote multi-hazard early warning systems with improved climate information, aerial and spatial data, emergency response services and communication to end users. • Identify and address the needs for early warning for Least Developed Countries and Small Island Developing states • Develop and share best practices on new threats and risks (including infectious diseases) to inform preparedness planning. • Develop, disseminate information and practices on contingency planning and protection of critical infrastructure, including promotion of the build back better approach in recovery, rehabilitation and reconstruction. • Institutionalize effective recovery and reconstruction as strategies to reduce risks and promote resilient development.	• An international conference to develop new thinking and approaches to multi-hazard early warning systems. • Evidence of progress on the delivering of more effective early warning systems including mechanisms that ensure timely early warning to communities. • Implementation of and increased support for the Climate Risk Early Warning System (CREWS) Initiative for Least Developed Countries and Small Island Developing states. • A disaster risk reduction and health conference to share best practices and approaches preparing for health risks (including infectious diseases). • Forums and research that promote contingency planning, the protection of critical infrastructure, and the institutionalizing of a gender sensitive build back better approach in recovery, rehabilitation and reconstruction.

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	• Incorporate build back better in insurance policies. • Inform national diaster risk reduction plans and strategies that focus on community preparedness and awareness, including the needs of women, children, people living with a disability and the elderly in vulnerable situations. • Promote science based decision-making for resettlement processes.	• Deliver a special forum on insurance and build back better and other social protection mechanisms. • Simplified methodology developed for post disaster comprehensive needs assessment. • Dissemination of research and case studies on community preparedness and awareness, and resettlement processes to include the needs of women, children, people living with disability and the elderly in vulnerable situations.

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APPENDIX C: LIQUEFACTION RISK ASSESSMENT - LITERATURE REVIEW

Earthquake loss estimation is a technique used to quantify potential losses in a given region or to a particular portfolio of buildings and facilities, due to future earthquakes. Comprehensive earthquake loss estimations require interaction between earth scientists, engineers, public and private owners of facilities, lifeline operators, planners and financiers and as such are truly multi-disciplinary (Figure C.1).

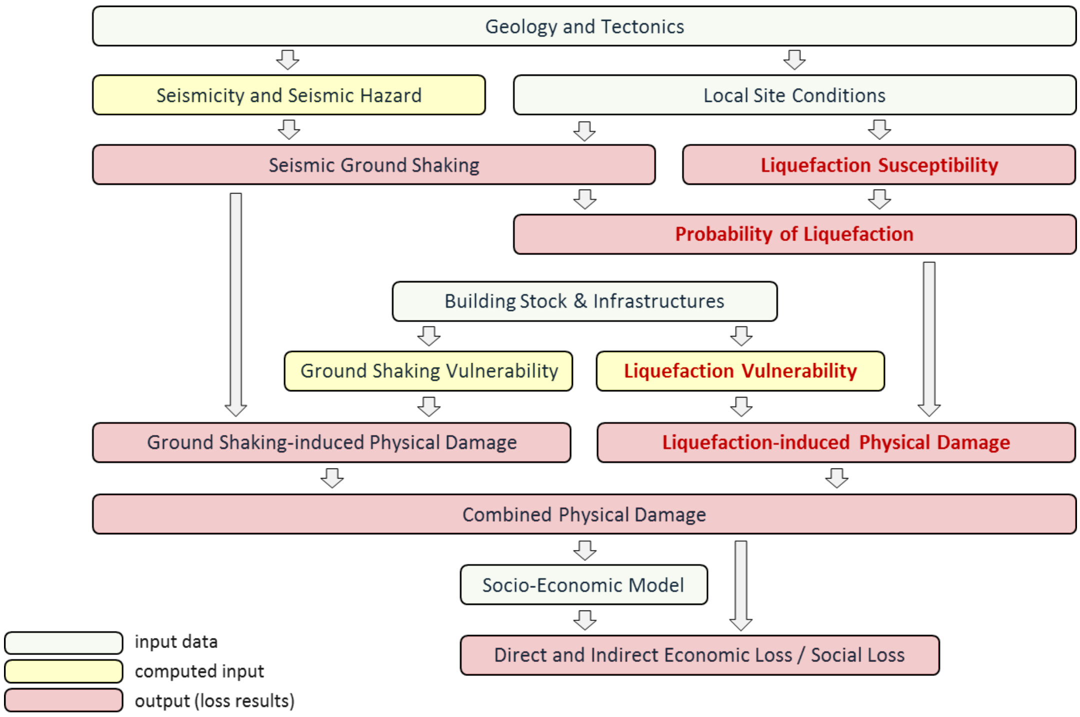

Figure C.1: Scheme for ground shaking and ground failure liquefaction risk assessment

In the current best practice, considering liquefaction in earthquake risk estimation would involve the following steps:

- The evaluation of Liquefaction Susceptibility: this requires quantification from a geological map of the probability of an area to liquefaction (see Figure C.2);
- The evaluation of Liquefaction Probability for a given susceptible category at specified level of PGA;

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- The evaluation of liquefaction-induced ground deformation, where various mechanisms can be observed, e.g. lateral spreading, ground settlement, differential movements…etc.;
- Identify deformation modes (damage) that building may experience when subject to liquefaction-induced ground deformations.
- The evaluation of the overall damage from the combined damage probabilities due to occurrence of ground failure liquefaction and ground shaking.

Table 4-1 Estimated Susceptibility to Liquefaction of Surficial Deposits During Strong Ground Shaking (after Youd and Perkins, 1978)

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments, When Saturated, Would be Susceptible to Liquefaction (by Age of Deposit)			
		Modern < 500 yr.	Holocene < 11,000 yr.	Pleistocene < 2 million yr.	Pre-Pleistocene > 2 million yr.
(a) Continental Deposits					
River channel	Locally variable	Very high	High	Low	Very low
Flood plain	Locally variable	High	Moderate	Low	Very low
Alluvial fan, plain	Widespread	Moderate	Low	Low	Very low
Marine terrace	Widespread	—	Low	Very low	Very low
Delta, fan delta	Widespread	High	Moderate	Low	Very low
Lacustrine, playa	Variable	High	Moderate	Low	Very low
Colluvium	Variable	High	Moderate	Low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Dune	Widespread	High	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very low	Very low
Tuff	Rare	Low	Low	Very low	Very low
Tephra	Widespread	High	Low	?	?
Residual soils	Rare	Low	High	Very low	Very low
Sebka	Locally variable	High	Moderate	Low	Very low
(b) Coastal Zone Deposits					
Delta	Widespread	Very high	High	Low	Very low
Esturine	Locally variable	High	Moderate	Low	Very low
Beach, high energy	Widespread	Moderate	Low	Very low	Very low
Beach, low energy	Widespread	High	Moderate	Low	Very low
Lagoon	Locally variable	High	Moderate	Low	Very low
Foreshore	Locally variable	High	Moderate	Low	Very low
(c) Fill Materials					
Uncompacted fill	Variable	Very high	—	—	—
Compacted fill	Variable	Low	—	—	—

Figure C.2: Relative liquefaction susceptibility rating for different soil/geology conditions, adopted in HAZUS-MH (Youd and Perkins 1978)

Modes of liquefaction-induced ground deformation

Over past earthquakes, various modes of liquefaction-induced failure/deformation have been observed, and which can be classified into 3 main modes (see Table C.1):

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- Lateral Spreading: a phenomenon in which the ground is deformed in horizontal direction. This deformation can result in considerable damage to overlying structures.
- Ground Settlement: in general caused by the change in volumetric strain as pore water pressures dissipate after liquefaction has taken place.
- Differential movements (differential settlements and differential lateral movements): occur beneath structures located on the boundary between liquefied and non-liquefied soils. This phenomenon is due to heterogeneity in soil stiffness and stratigraphy both laterally and with depth. Differential movements are the major cause of the damage to lifelines or other facilities.

Modes of liquefaction-induced ground deformation beneath buildings.	
Typical Field Observation	**Considered in Guidelines & Design Code**
• Uniform lateral spreading • Uniform ground settlement • Differential spreading/settlement • Flow failure of slopes • Loss of bearing capacity • Sand boil	• Lateral spreading (does not distinguish between uniform and differential movements) • Ground settlement (does not distinguish between uniform and differential movements)

Table C.1: Modes of ground failure liquefaction from filed observations

A number of methodologies for estimating ground failure liquefaction, in terms of permanent ground deformations, are available (analytical/numerical and empirical methods), all of which use different approaches and uncertain variables. In Analytical methods, significant simplifications is usually considered due to the complexities in accurate modelling and the difficulties in measuring the in-situ parameters of soil layers. Numerical methods have been found to be particularly sensitive to small variations in input parameters, an undesirable feature in such an uncertain field as loss estimation. Empirical methods are generally accepted to be accurate only to within a factor of 2 or 3 and their predictive capacity tends to be worst for small-to-moderate (0.3–0.75 m) deformations. Table C.2 summarises example of available methodologies for the assessment of expected liquefaction-induced ground deformation in terms of lateral spreads.

Method	Model Type	References
Simplified analytical methods	Sliding Block Model	Newmark (1965), Makdisi and Seed (1978), Wilson and Keefer (1985), Yegian, et al., (1991), Baziar, et al., (1992), Byrne, et al., (1992), Jibson, (1994), Olson and Johnson (2008)
	Minimum Potential Energy Model	Towhata, et al., (1991; 1992), Tokida, et al., (1993), Orense and Towahata (1992), Towahat and Toyota (1994)
	Shear Strength Loss and Strain Re-hardening Model	Byrne (1997)
	Viscous Models	Hamada, et al., (1994), Aydan, (1995), Kokusho and Fujita (2002)
	Centrifuge Models	Balakrishnan, et al., (1998), Manda, et al., (1999), Kutter, et al., (1999), Elgamal, et al., (2003)
Numerical methods	Finite element method & Finite difference techniques	Hameda, et al., (1987), Kuwano, et al., (1991), Yasuda, et al., (1991a;1991b;1992;a), Orense and Towhata (1992), Gu, et al., (1993; 1994), Finn, et al., (1994), Arulanandan, et al., (2000), Yang, et al., (2003)
Soft computing methods	Neural networks	Wang and Rahman (1999), Chiru-Danzer, et al., (2000)
	Genetic programing	Javadi, et al., (2006)
	Neurofuzzy	Garcia, et al., (2007)
Empirical methods	---	Hamada, et al., ,(1986), Youd and Perkins (1987), Bartlett and Youd (1995), Rauch (1997), Shamoto, et al., (1998), Bardet (1999), Youd, et al., (2002), Zhang, et al., (2004), Zhang and Zhao (2005)

Table C.2: Example of available methods for evaluation of liquefaction-induced Lateral Spreads

Building Response to Liquefaction-induced ground deformations

There are a number of deformation modes that buildings may experience when subject to liquefaction-induced ground deformations. These modes can be divided into two broad categories:

- rigid-body movements, whereby the structure moves without significant internal deformation, and
- Differential movements.

The type of response will depend primarily on the foundation type: for shallow foundations, the distinction will be whether these are rigid or flexible. In case of buildings on foundations that have sufficient relative stiffness, compared to soft underlying soils, this may lead to differential movements causing structures to behave as rigid bodies; there is no, or minor, damage to the structural elements of such buildings. In case of buildings on flexible (i.e. unrestrained) foundations, columns and walls can move independently and thus differentially and damage occurs in the structural elements. We can also observe rigid body damage.

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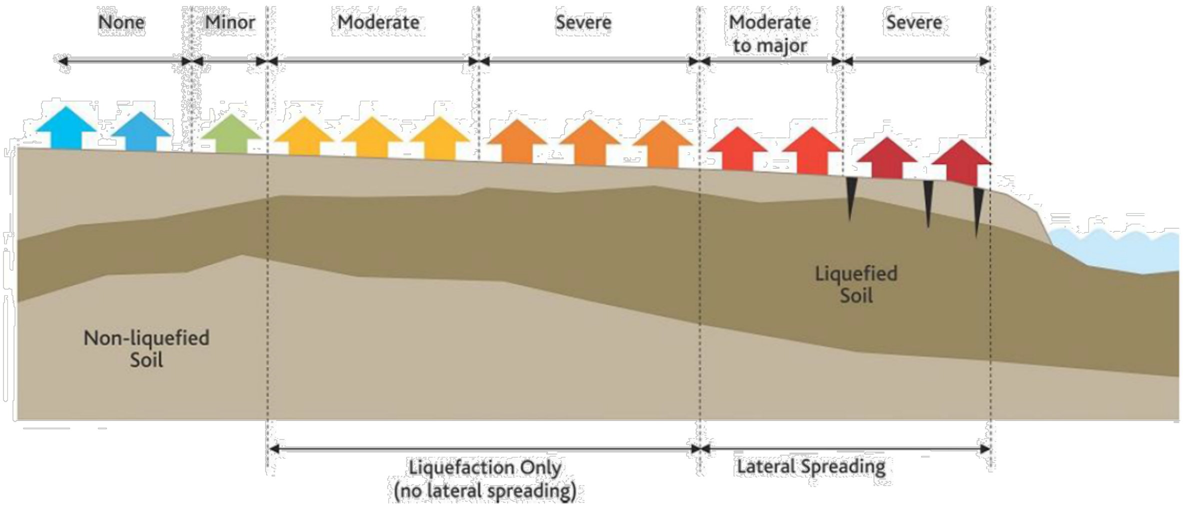

Blue	• No observed cracks, undulations / deformations at the ground surface, and, • No signs of ejected liquefied material at the ground surface, and, • No apparent lateral movement.	Dark Orange	• Large quantities of ejected liquefied material on ground surface (generally >25% of the site covered with ejected material), and/or, • Severe observed ground surface subsidence, and/or; • Small cracks from ground oscillations (<50 mm) may be present, but little to no vertical displacement across cracks, and, • Limited evidence of lateral movement.
Green	• Shaking-induced damage resulting from cyclic deformation and surface-waves causing ground surface damage. Ground surface damage likely limited to minor cracking (tension) and buckling (compression) and/or minor undulations at the ground surface, and, • No signs of ejected liquefied material at the ground surface, and, • No apparent lateral movement.	Red	• Moderate to major lateral spreading (<1 m cumulative), and/or, • Large cracks extending across the ground surface, with horizontal and/or vertical displacement (>50 mm, but generally <200 mm). • Ejection of liquefied material at the ground surface may also be observed
Light Orange	• Minor to moderate quantities of ejected liquefied material on ground surface (generally <25% of site covered with ejected material), and/or, • Small cracks from ground oscillations (<50 mm) may be present, but little to no vertical displacement across cracks, and, • No apparent lateral movement.	Dark Red	• Extensive lateral spreading (≥1 m cumulative), and/or, • Large open cracks extending through the ground surface, with very severe horizontal and/or vertical displacements (≥200 mm), and, • Ejection of liquefied material at the ground surface may also be observed.

Figure C.2: Pattern of liquefaction and lateral spreading observations during the Canterbury Earthquake Sequence, and categories used for mapping visible land damage after the main earthquake events (EQC 2014)

Understand and quantify the effects of the uncertainties

Understand and quantify the effects of the uncertainties in order to be considered when interpreting the results.

The likelihood of liquefaction triggering, based upon empirical data with associated scatter. There will be uncertainties (due to scatter) associated with the selected methodology and input parameters for the evaluation of liquefaction probability, liquefaction-induced permanent ground deformation.

The necessary simplification of soil properties, since event that comprehensive structural and geotechnical data were available, it would not be feasible on a large scale to incorporate this without some approximation.

Estimating differential ground movements on a regional scale has an even greater uncertainty than the estimation of uniform or average movements. This is principally because of the lack of sufficient geotechnical data (because of a very detailed geotechnical data requirement).

For a portfolio of buildings, knowledge of the foundations will be uncertain; from visual surveys, foundation types cannot be easily ascertained. This requires some significant assumptions which necessarily add an additional level of uncertainty to an inventory.

The epistemic uncertainties associated with the estimation of earthquake hazard and level of ground shaking (which have been shown to have a significant impact upon the estimated distributions of damage).