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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.

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Deliverable D5.4

WHOLE LIFE BUILT ASSET MANAGEMENT MODELLING FRAMEWORK:

Integrating mitigation to earthquake induced liquefaction disaster events into strategic built asset management planning

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List of Partners

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ARU (Coordinator)	Anglia Ruskin University Higher Education Corporation	United Kingdom
UNIPV	Universita degli Studi di Pavia	Italy
UPORTO	Universidade do Porto	Portugal
UNINA	Universita degli Studi di Napoli Federico II.	Italy
TREVI	Trevi Societa per Azioni	Italy
NORSAR	Stiftelsen Norsar	Norway
ULJ	Univerza v Ljubljani	Slovenia
UNICAS	Universita degli Studi di Cassino e del Lazio Meridionale	Italy
SLP	SLP Specializirano Podjetje za Temeljenje Objektov, D.O.O, Ljubljana	Slovenia
ISMGEO	Istituto Sperimentale Modelli Geotecnici Societa a Responsabilita Limitata	Italy

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Istan-Uni	Istanbul Universitesi	Turkey

Glossary

Acronym	Description
AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
BAM	Built Asset Management
BCMS	Business Continuity Management Systems
BCP	Business Continuity Plan
BCRP	Business Continuity Resilience
BOD	Benefit of Doubt
CBA	Cost Benefit/Analysis
CI	Critical Infrastructure
CREW	Community Resilience to Extreme Weather
CRM	Community Resilience Model
CSF	Critical Success Factor
DMP	Disaster Management Planning
DRR	Disaster Risk Reduction
DTA	Dependence Tree Analysis
EILDs	Earthquake Induced Liquefaction Disasters
ENSURE	Enhancing Resilience of Communities and Territories Facing Natural and na-tech Hazards
ERMG	The European Resilience Management Guidelines
FA	Factor Analysis
FCM	Fuzzy Cognitive Mapping
FEMA	Federal Emergency Management Agency
KPI	Key Performance Indicator
LRG	Liquefact Reference Guide
MCDM	Multi Criteria Decision Making
MS	Member States
RAIF	Resilience Assessment and Improvement Framework
RICS	Royal Institution of Chartered Surveyors
RIVANs	Relationally Integrated Value Networks
SLA	Service Level Agreement
UCM	Unobserved Component Model
UNISDR	United Nations International Strategy for Disaster Reduction
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 with, in some cases, EILDs accounting for up to half of the economic loss caused by earthquakes. With the causes of liquefaction being largely acknowledged, it is important to recognise the factors that contribute to its occurrence; to estimate the impacts of EILD hazards; and to identify and implement the most appropriate mitigation strategies that improve both building/critical infrastructure and community resilience to an EILD event. The LIQUEFACT project adopts a holistic approach to address the mitigation of risks to EILD events. The LIQUEFACT project sets out to:

- Achieve a more comprehensive understanding of the impacts that EILD events have on the resilience of communities and buildings/critical infrastructure on which they rely;
- Achieve a more comprehensive understanding of the range of mitigation techniques (technical, operational, managerial and organizational) that can be implemented to improve the resilience of communities and building/critical infrastructure to EILD events;
- Develop more appropriate mitigation techniques (technical, operational, organizational and managerial), for both European and worldwide situations; and
- Develop a Resilience Assessment and Improvement Framework (RAIF) to allow community and building/critical infrastructure stakeholders to make the business case for mitigation interventions.

This report summarises the work of WP5.

- Section 1 provides an introduction to the deliverable
- Section 2 presents the background theory to built asset management and reviews its application to mitigation and adaptation studies
- Section 3 presents the final beta test version of the community resilience to EILD events toolkit
- Section 4 presents the final beta test version of the critical infrastructure toolkit
- Section 5 presents the final beta test version of the cost benefit analysis toolkit
- Section 6 presents the final beta test version of the Resilience Assessment and Improvement Framework
- Section 7 presents the final beta test version of the built asset management planning Toolkit
- Section 8 outlines the next steps in the validation of the toolkits

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Scope of this document

This is a working document that will be amended and modified to reflect changing needs of the LIQUEFACT project and the views of the external stakeholder group and external advisory panel.

Target Audience

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

1.0 Introduction

Built asset management (BAM) is the process by which facilities/building managers ensure that their built assets continue to perform at a level appropriate to their organisation's needs. Throughout a built asset's life cycle, its ability to meet users' needs diminishes, either because of physical decay or because of increased demands placed on the built asset through changes in use or external circumstances (e.g. technological developments, social expectations, impacts of natural or manmade disasters etc.). The resulting gap between desired and actual performance is known as the obsolescence gap. Strategic built asset management seeks to minimise the obsolescence gap through routine maintenance, which seeks to repair physical decay, and periodic refurbishment, which seeks to address changes in user demand or external circumstances. However, because most organisations (both public and private sector) have limited resources for maintenance and refurbishment activities, the obsolescence gap can never be completely eliminated and invariably continues to widen over time. Once the obsolescence gap becomes too wide to close through cost-effective refurbishment the built asset is either sold, repurposed or demolished. The process from built asset inception to demolition is known as the built asset life cycle.

The LIQUEFACT project is investigating alternative approaches to reducing the impact that an earthquake induced liquefaction disaster event (EILD) will have on European communities through mitigation interventions (technical and operational) that reduce the vulnerability or improve the resilience of built assets to an EILD event. The technical mitigation interventions being developed by LIQUEFACT can either be applied to the design stage of new built assets or retrofitted to existing built assets as part of the BAM process. The operational mitigation interventions can be integrated into business continuity/resilience (BCRP) and disaster management planning (DMP).

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Recent earthquake disaster events (Marmara-1999[1], Emilia Romagna-2012[2], Christchurch and Canterbury-2010/2011[3], Indonesia-2018[4]) have resulted in significant damage to buildings and critical infrastructures (collectively referred to in this report as built assets) which significantly inhibits their ability to perform their primary function immediately following a disaster event. The Sendai Framework for Disaster Risk Reduction (UNISDR, 2015) has reinforced the importance of preparing for a disaster event (the Sendai principles) through: a greater understanding of risk; improved governance systems; investing in risk reduction to improve resilience and building back better following a disaster event. The LIQUEFACT project has developed a Resilience Assessment and Improvement Framework (RAIF) that integrates the Sendai principles into the BAM process. To support the RAIF LIQUEFACT has developed a series of tools that will allow facilities/built asset managers and community stakeholders assess their antecedent resilience to an EILD event and evaluate the potential of a range of technical and operational mitigation interventions to improve built asset and community resilience (Figure 1.1). This deliverable presents the final Beta Test versions of these tools.

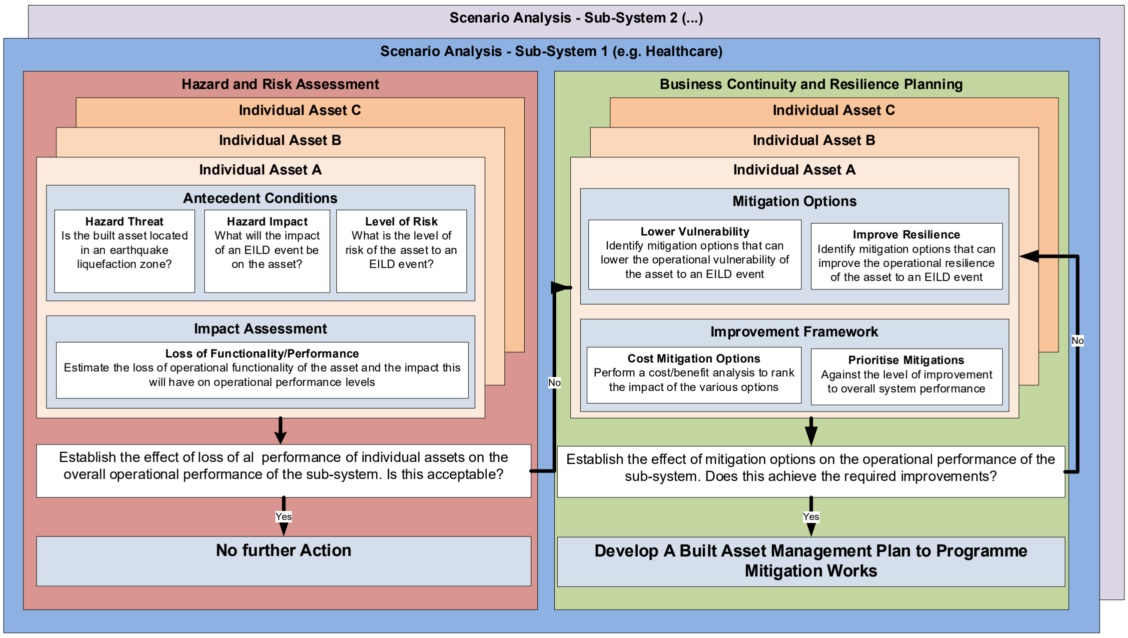

Figure 1.1: The LIQUEFACT Resilience Assessment and Improvement Framework

[1]https://www.recoveryplatform.org/assets/publication/PDNA/CountryPDNAs/Turkey_Earthquake_1999_Marmara%20Earthquake%20Assessment.pdf
[2] https://www.commercialriskonline.com/insured-losses-from-emilia-romagna-italy-earthquake-up-to-200m-eqecat/
[3] https://my.christchurchcitylibraries.com/christchurch-and-canterbury-earthquakes/
[4] https://www.worldvision.org/disaster-relief-news-stories/2018-indonesia-earthquake-facts

The loss of performance (functionality) of a built asset because of an EILD event is related to its antecedent vulnerability and resilience. A built assets antecedent vulnerability and resilience to an EILD event can be improved if specific mitigation measures have been incorporated into the built asset prior to the EILD event. The inclusion of specific mitigation measures for an EILD event can occur either as a part of the original design process (with design codes or performance-based design methods) or during routine maintenance and refurbishment (through effective integration of mitigation measures within BAM plans). Built assets designed and constructed to minimise the impacts of an EILD event should possess a level of resilience that will allow them to support the local community resist, absorb, accommodate and recover from the effects of the EILD event in a timely manner. Whilst most modern built assets (particularly critical infrastructure) located in known earthquake zones should have been designed to such standards, older built assets (and almost all domestic buildings) may not have been. For these type of built assets, mitigation measures to reduce their vulnerability or improve their resilience to an EILD event have to be fitted retrospectively; normally as part of the BAM process.

Retrofitting EILD mitigation measures as part of a built asset's normal maintenance/ refurbishment programme is an expensive activity that has to compete for funds alongside other strategic interventions that seek to reduce the built asset's obsolescence gap. Prioritising maintenance/refurbishment interventions forms part of the BAM options appraisal process. However, there are no generally accepted tools to support an options appraisal business model that allow EILD mitigation measures to be evaluated against each other (or other strategic maintenance/refurbishment priorities) or to be effectively integrated into short-term (0-5 years), medium-term (6-20 years) or long-term (21-75 years) built asset management plans. This deliverable outlines a series of tools to support the RAIF, including a:

- framework for evaluating community resilience to an EILD event and a methodology for assessing the improvement in resilience that could be achieved for a range of mitigation interventions;
- framework for evaluating CI resilience to an EILD event and a methodology for assessing the improvement in resilience that could be achieved for a range of mitigation interventions;
- Cost-benefit analysis modelling methodology; and
- BAM planning tool that integrates the above into the RAIF that will allow facilities/built asset managers and community stakeholders assess the impact that an EILD event will have on the performance of their built assets and on overall community resilience.

The RAIF BAM planning tool integrates the theories, models, metrics and tools developed in Work Package 5 (Tasks 5.1, 5.2 and 5.3) with other theories, models and tools developed across the LIQUEFACT project (Work Package 2, Work Package 3, and Work Package 4) and with the LRG software tool being developed in Work Package 6.

The work presented in this deliverable is a beta prototype version of the BAM planning tool. The final version of the BAM planning tool will be developed in Work Package 7 following validation using data gathered following the Emilia Romagna and Marmara earthquakes. The final version of the BAM planning tool will be presented in the form of use-cases as part of the LIQUEFACT final project report.

2.0 Built Asset Management

Built asset management is the combination of maintenance and refurbishment actions required to ensure that a built asset continues to perform in a way that satisfies the asset owners needs and expectations and adds value to an organisation over its life cycle (El-Akruti and Dwight, 2013; Ebinger and Madritsch, 2012; Wong et al, 2014; Kumaraswamy, 2011; Alwan and Gledson, 2015).

2.1 Built Asset Maintenance, Refurbishment and the Building Life-cycle

Puķītea and Geipeleb (2017) reviewed the academic literature on building maintenance and BAM and, whilst they identified a number of different definitions of building maintenance, they concluded that they all described a generic process in which a range of management activities are combined to identify, plan, implement, support, and control any building work required to support the core strategic goal of the organisation that owns and/or occupies the built asset for the pursuance of their business activities.

To this end Pukitea and Geipeleb (*ibid*) defined maintenance as:

> *"primarily focusing on actions required to keep, restore or improve every part of a building in order to maintain the performance of the building and to sustain its function and value.".*

The inclusion of performance as a key objective of building maintenance is consistent with the work of Jones and Sharp (2007) and most of the world's leading engineering and construction professional bodies (e.g. ICE[5], RICS[6], ASCE[7], etc.) who argue that any definition of built asset maintenance must include an assessment of 'performance' if it is to address the obsolescence gap.

[5] https://www.cices.org/content/uploads/2013/05/Guiding-Principles-of-Asset-Management-3.pdf
[6] https://www.google.co.uk/search?q=RICS+definition+of+building+maintenance&ie=&oe=
[7] https://ascelibrary.org/doi/10.1061/%28ASCE%29IS.1943-555X.0000436

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The emergence of Facilities Management as a growing profession responsible for the operational phase of a built asset has broadened the definition of built asset maintenance to include aspects of built asset refurbishment. The ISO41001 (ISO 41001, 2018) standard for Facilities Management defines building maintenance as:

"the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities."

Whilst the Royal Institution of Chartered Surveyors (RICS) consider both maintenance and refurbishment together under the overall banner of BAM[8].

However, whilst this widely accepted definition of BAM reflects the position of most engineering and construction professionals, it does not address some of the fundamental weaknesses that have been identified when trying to operationalise the concepts of 'building performance' and 'value'. Not least of these concerns is the use of the condition of a built asset (as measured through the stock condition survey) as a proxy for performance and value.

Many authors have questioned the effectiveness and efficiency of the stock condition survey process to support planned maintenance (O'Dell, 1996; Chapman, 1999) and despite numerous attempts to improve the process (Straub, 1998; Daman & Quah, 1998; Jones et al, 1999) fundamental problems still exist (Constructing Excellence 2019).

In a review of the use of the stock condition survey process in UK social housing, Chapman (1999) identified:

- poor specification of initial requirements;
- unclear aims and objectives and inappropriate frameworks;
- an inability to predict long term cost requirements;
- variations in levels of experience of those conducting surveys (similar findings were reported by Kempton et al, (2002) who also identified the existence of confirmation bias as an inherent weakness in the stock condition survey process);
- unrealistic claims by consultants selling survey services;
- inappropriate or unusable data;
- poor links to business objectives; and
- a lack of fit of survey data to maintenance programmes;

as the key factors that contributed to high levels of dissatisfaction of the approach amongst built asset owners.

[8] https://www.rics.org/uk/events/training-courses/asset-management-tools-techniques-and-practices/

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Chapman also identified the gap between client expectations of built asset management models and the limitations of the logic underpinning the stock condition survey process, acknowledging that the latter could at best provide short-term predictions of built asset management costs, but was unable to effectively inform long term built asset management planning. At best, a stock condition survey provides a snap shot of a built assets performance at a single point in time.

In an attempt to develop a more robust data model for long-term maintenance and refurbishment planning Kirkham (2004) developed deterministic and stochastic models of a built asset's remaining life (through the use of decay profiles). However, the volume of data needed for the models combined with the high levels of uncertainty and subjectivity associated with the remaining life predictions (Kirkham, 2004) meant that the models were rarely used in practice.

In addition to the practical problems associated with developing robust BAM models, Finch (1998) and Jones (2002) identified fundamental weakness in the underlying BAM theory.

Finch (1998) argued that a condition based approach to maintenance that focused on a narrow definition of 'function and value' would at best allow a building's capacity to be returned to its original level (or support an incremental improvement on the original level), whilst increased functional and technological demands would result in an obsolescence gap that, if not periodically addressed, would ultimately lead to the built assets demise.

Jones (2002) argued that the assumption that BAM is driven by organisational policies is in many cases flawed, with organisational policy objectives of being unclear and no direct (measurable) links existing between an organisation's strategic objectives and their built asset management programmes. Jones (*ibid*) argued that without a clear link between business objectives and BAM interventions it is impossible to decide on which BAM interventions to program first or to measure the effectiveness of BAM interventions over time. Both Finch (1998) and Jones (2002) concluded that such an approach would invariably fail to address business critical issues and result in increased building obsolescence and a growing maintenance backlog over time.

To address these weaknesses Jones (2002) re-interpreted Finch's model to reflect the changes in demand being placed on built assets by the sustainability agenda. In particular Jones (*ibid*) questioned whether a single measure of 'value' could really reflect the complex interaction of social, economic and environmental demands that will be placed on built assets when they are measured against the sustainability agenda. Jones (*ibid*) also questioned the degree to which whole-life thinking needs to underpin BAM plans if maintenance and refurbishment are to be used to effectively close the obsolescence gap. In addressing these questions Jones

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examined each stage of the BAM life-cycle and explored its relationship to the strategic objectives of the built asset's owners/occupiers.

Figure 2.1 represents Jones' simplified model of the BAM life cycle. In this model a built assets value/performance specifications are developed at inception as part of the design and construction process.

Once the built asset is constructed it is handed over to the owner/user (a) who begins to use the built asset. However once handover occurs the value/performance of the built asset will begin to reduce (due to operational conditions) whilst the owner/user expectations will rise as a consequence of change demands. At some point in the future (b) the value/performance will have reduced to the extent that the owner/user instigates maintenance/repair activity to return the built asset to its original value/performance level (c). After maintenance/repair the performance of the building will again start to reduce and repeated maintenance cycles (a – d) will be undertaken over time to repeatedly return the built asset to its original value/performance level. This process represents a traditional view of maintenance where no improvement above the original value/performance specification is envisaged.

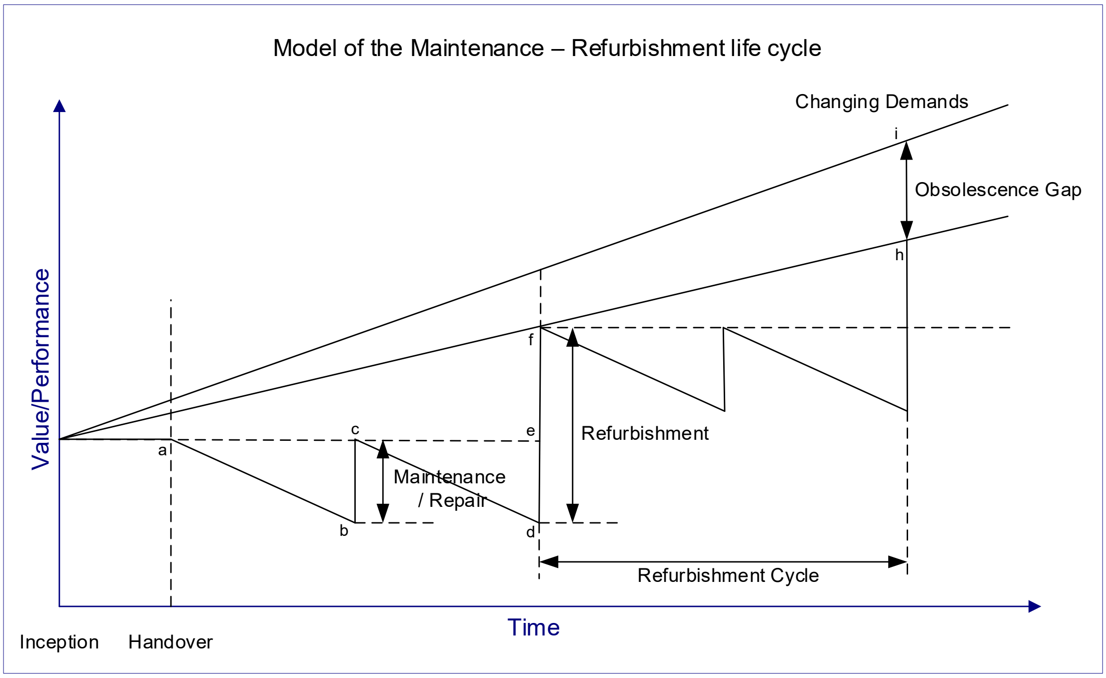

Figure 2.1: The maintenance – refurbishment life cycle

However, over the same time period the built asset will be subject to changing demands (as a consequence of technological developments, operational procedures, political requirements etc.) and expectations of its users and there will come a point at which returning the built asset to its original value/performance specification level (e) is no longer acceptable to the owner/user. At this point refurbishment is required to reduce the value/performance gap (f). However, because of legacy design decisions and past built asset intervention actions is unlikely that even the most ambitious refurbishment will be able to fully close the performance gap (g) and some residual obsolescence (the gap between the performance expectations on the performance levels that can be reached following refurbishment) will remain. This maintenance/refurbishment cycle continues over time until a point is reached where the residual obsolescence that exists following the refurbishment cycle (h to i) is unacceptable, or where the cost of closing the obsolescence gap is uneconomical. At this point the built asset owner/user either re-locates; the built asset is demolished and re-built; or the built asset is refurbished beyond its original purpose and a change of use occurs.

However, whilst Jones' simplified model (2002) suggests a relationship between investment in BAM and improved value/performance to the built asset owner/user it doesn't explicitly link value/performance to the cost of BAM interventions and as such it doesn't provide the economic basis for an options appraisal process (i.e. evaluate the future return on investment).

2.2 Measuring BAM Value/Performance

A number of authors have attempted to develop process models that link maintenance and refurbishment decisions to built asset value/performance.

Vanier (1996) suggested that the requirements (performance) of a built asset could be defined in terms of the functional requirements of its users; expressed as a series of benchmarks and key performance indicators against which different BAM interventions could be evaluated.

Hassanain et al (2003) proposed a similar approach to Vanier which sought to evaluate built asset management interventions through a consideration of the extent to which the built asset was meeting pre-set performance criteria. Hassanain et al (*ibid*) assigned multiple performance criteria to built asset components and used upper and lower limit states to describe an acceptable performance range. Maintenance/refurbishment need was assessed with reference to the ability of a component to meet the performance criteria and maintenance/refurbishment action prioritised using a cost-risk model that sought to minimise the risk of failure whilst maximizing overall system performance.

El-Haram & Horner (2003) applied the theory of integrated logistic support to the identification and selection of built asset management actions. El-Haram & Horner argued that by integrating physical and functional models of a building together and applying failure

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mode effects analysis and reliability centred maintenance principles a more cost-effective approach to built asset management could be achieved.

Alwan and Gledson (2015) developed a conceptual framework for integrated built asset management in which a building performance attribute data model was developed to investigate the gap between design aspiration and operational performance of green buildings. In developing the framework Alwan and Gledson (*ibid*) identified the problem of defining attribute data against changing occupier's requirements and of linking specific data attributes to building performance over the lifetime of the built asset. This consistent and recurring problem was also identified by Munir et al (2019) who questioned both the quality of the data used by BAM systems and the apparent disconnect between the data held in BAM systems and the information needed by facilities/built asset managers for effective decision-making).

In an attempt to develop an integrated solution to BAM that focused on developing long term proactive solutions rather than short term reactive 'fixes' Smyth et al (2017) applied the principles of relationally integrated value networks (RIVANS) to help better understand the role of different stakeholder groups in delivering BAM programmes. Too and Too (2010) also stressed the need for facilities / built asset managers to take a pro-active, rather than reactive, approach to BAM decision making if they sought to add value to an organisation in the face of changing demands.

Ebinger and Madritsch (2012) used a functional analysis approach in an attempt to develop a generic BAM model that would link strategic and operational decision-making within the organisational value stream to identify gaps in performance and facilitate discussions between operational managers.

Finally, Alhazmi (2018) critically reviewed BAM international standards and guidelines, identifying a common 6-stage process model that was present (to some extent) in all of the standards and guidelines he examined. The first stage of the process model involved identifying strategic drivers that would inform the BAM decision-making process. Once these were established a rational reasoning process was used to operationalise the drivers to add value to an organisation (public and/or private sector). This reasoning process involved: identifying and diagnosing the problems to be addressed by the BAM; conceiving solutions to these problems and evaluating these against a set of performance indicators; evaluating priorities between conflicting solutions (in terms of an options appraisal approach); developing a portfolio intervention plan to programme individual projects over the building life cycle; and establishing a feedback mechanism to monitor actual added value.

However, whilst all the above seek to base performance issues at the centre of the BAM decision-making process, they all still primarily consider performance as the physical ability of the system (or its components) to meet a range of physical performance criteria. In essence

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the models are still primarily condition based and do not address the underlying issues linking BAM expenditure with income generation (for the private sector) or community service activities of an organisation (for the public sector). In essence they do not consider the wider meaning of 'value' to the built asset owner/user or provide the theoretical (or practical) tools needed if BAM is to be used to plan long-term improvements in the performance of built assets as envisaged by Finch and Jones.

2.3 Performance Based BAM Process Model

Jones and Sharp (2007) examined the changes that would be required to elevate the BAM process described in section 2.2 to one that could support the development of detailed business cases as part of an options appraisal process that would allow the implications of alternative maintenance and refurbishment interventions to be evaluated. As part of this process Jones and Sharp (2007) examined the wider meaning of value within the context of the simplified BAM life cycle model (Figure 2.1) as part of a series of projects that sought to develop a set of business models to justify long-term BAM expenditure for a large private sector commercial organisation. Through a series of meetings with the organisation's senior management Jones and Sharp (*ibid*) concluded that 'value' in the commercial context extends beyond a consideration of building technology issues, to one that acknowledged the impact of the performance of built asset has on the long-term viability of an organisation. In essence Jones and Sharp (*ibid*) argued that 'value' should be explicitly linked to the ability of the built asset to support organisational performance and BAM should be viewed as a strategic issue managed within the broader context of an organisation's strategic planning framework to ensure that these added value was delivered.

As a consequence of their work Jones and Sharp (2007) developed a performance-based BAM process model (Figure 2.2) to operationalise their simplified BAM life cycle model. The primary principle behind Jones and Sharp (*ibid*) performance based built asset management model is that the decision to maintain/refurbish a component should be based on the impact that the decision has on the organisation's performance over time. Thus, the key elements to built asset management planning are to understand how built assets and their components impact an organisation's critical success factors. Whilst these will be specific to an individual organisation the generic model will be applicable to all. The following detailed description of the performance-based built asset maintenance process model is a summary of that presented by Jones and Sharp (2007).

The first step of the performance-based BAM process model is to identify an organisation's policy/strategic goals and express these as a series of Critical Success Factors (CSFs). Once these have been established a series of performance toolkits are developed that assess the current level of built asset performance against each of the CSFs. Each toolkit contains a number of metrics (key performance indicators) and benchmarks that reflect the performance expectation (or expectation range) of a specific CSF. While some of the metrics might be individual measures it is more likely that a hierarchy of metrics will be needed to fully reflect each CSF. Where a hierarchy of metrics is required the relative weighting of each metric within the hierarchy needs to be established. Weightings can be derived through either simple comparison or through more complex pairwise (see Saaty, 1980) comparison methodologies. Whichever methodology is used the key aspect of each toolkit is to identify how well a built asset is supporting the business function.

Once the current level of performance is established a series of analysis toolkits can be used to investigate the root cause of any underperformance (note: generally, under-performance is a symptom and not the cause of many problems.). Inquiry toolkits use qualitative analyses (e.g. interviews, focus groups, case study reports etc.) to identify collective reasons for underperformance and establish whether the underperformance is unique (e.g. specific to this built asset) or systemic (e.g. similar underperformance is observed across a number of built assets). Statistical and Experiential toolkits use quantitative analyses (e.g. user satisfaction surveys, factor analysis, competitor analysis etc.) to identify underlying patterns of built asset performance within a built asset over time or across a range of built assets. Finally design toolkits relate the reasons for any underperformance to built asset issues (e.g. problems with construction or in design philosophy).

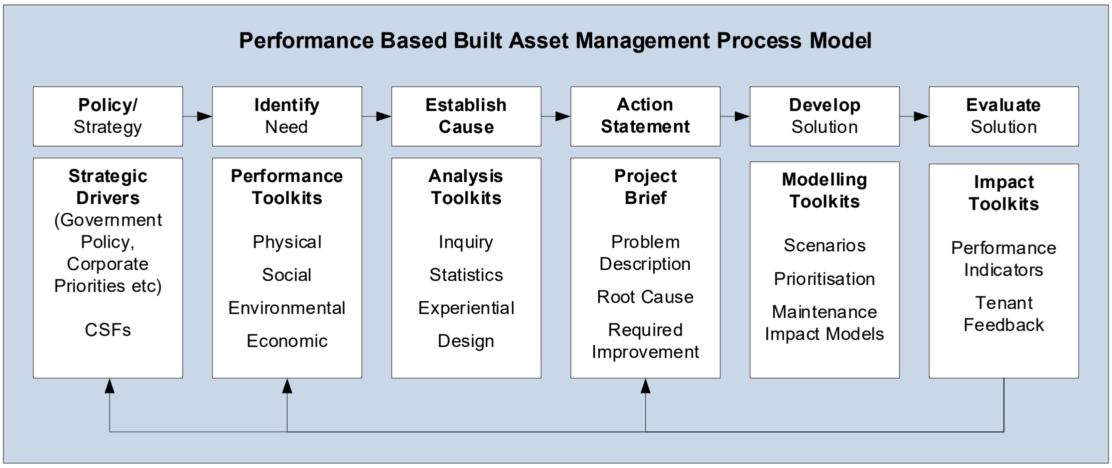

Figure 2.2: Performance based built asset management process model (derived from Jones and Sharp (2007).

Following the analysis of an under-performing built asset an Action Statement is written which clearly articulates the problem and the perceived cause. It also quantifies the improvement in performance (against individual metrics and CSFs) required of any solution. In essence, the Action Statement forms the project brief against which potential solutions can be identified and evaluated.

Modelling toolkits allow alternative solution scenarios to be developed whilst multi-criteria prioritisation methods allow each scenario to be evaluated against the organisations CSFs. The effect of a range of BAM strategies (e.g. preventative action, responsive action, no action) can be identified by the use of impact models which consider the consequences of delay in action (measured against the performance criteria) on business performance (note: business risk will not be consistent throughout an organisation's portfolio but will vary depending on the relative importance of the building/space to the organisation.). Where the business risks are high a preventative strategy would be selected. Where business risks are low a responsive (or no action) strategy would suffice.

Finally a set of Impact toolkits (e.g. Post Completion Evaluations; KPI's etc) allow actual improvements in performance (that result from the BAM interventions) to be compared against the improvement requirements specified in the Action Statement. The results of the feedback in turn inform future problem identification and ultimately organisational strategy. Where BAM interventions cannot be evaluated in 'real-time' a series of future scenarios can be used to test each intervention.

Although Jones and Sharp's model (2007) was developed for commercial organisations to manage their property assets the Royal Institution of Chartered Surveyors (RICS, 2012) released the second edition of their public sector property asset Management guidelines which is very similar to that developed by Jones and Sharp (*ibid*).

The RICS Guidelines were developed following an extensive review of built asset and property management research and represents the current state-of-the-art in academic and practitioner thinking. The guidelines provide practical guidance for facilities/built asset managers as they seek to develop strategies and plans to ensure that their physical assets respond to the changing needs of the occupiers and support service delivery models to satisfy customer demand. The RICS guidelines (*ibid*) define poverty (built) asset management as:

" the process which aligns business and property asset strategies, ensuring the optimisation of an organisation's property assets in a way which best supports its key business goals and objectives".

In this context the role of the facility/built asset manager is to ensure that the assets are aligned with the organisations business needs and that they support service delivery in the most efficient and effective way; both now and over the remaining life cycle of the built assets. The guidelines further suggest that the benefits of effective project management accrue to not only the organisation occupying the assets but also to the wider economic and social well-being of the community(s) that use the services of the organisation.

To ensure effective property/built asset management the RICS guidelines (*ibid*) propose a five stage business process model that positions strategic property/built asset management between an organisation's customers and its suppliers (Figure 2.3).

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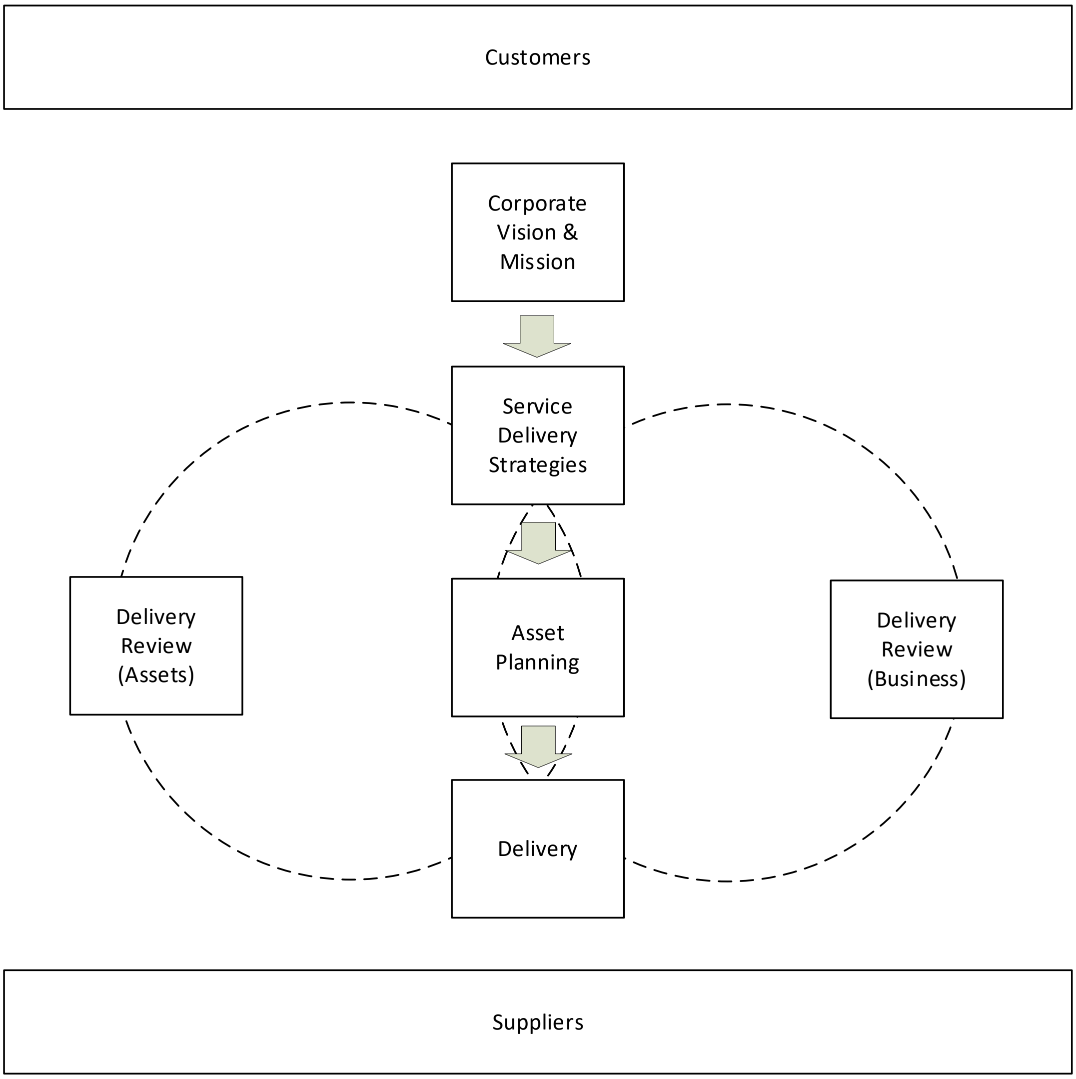

Figure 2.3 RICS process model for effective property asset management (source RICS, 2012)

The first stage the business process model is to identify the corporate vision and mission of the organisation. This is achieved through reference to organisational documents and detailed conversations with the organisation's leaders and, for critical public sector organisations, those politicians responsible for sectoral policy. Once the corporate vision and mission are established they are translated into a series of business/service delivery strategies in consultation with operational managers as the basis of analysing the alignment between the property/built assets and the business/service delivery requirements. Any misalignment between the business/service delivery requirements and the ability of existing property/built assets to support them will form the basis of a series of options appraisals (property/built asset interventions designed to close the performance gap). The options appraisal process will also consider the affordability of each option and from these considerations property/built asset plan can be developed. The property/built asset management plans provide the decision-making framework to support the development of specific (asset by asset) action plans. Whilst each property/built asset management plan will be unique to the organisation that has developed it, such plans typically include some or all of the following:

- a clear statement of the organisation's corporate vision, including the financial and legal context against which property/built asset decisions will be made.
- The development of a series of business focused critical success factors against which performance assessments will be based.
- a clear statement of the expected performance levels required by each asset and an assessment of the baseline performance (current performance levels) and the identification of any 'gaps' in performance that need to be addressed.
- the articulation of clear action statements that articulate the required improvements in performance to close any performance gaps.
- the identification and evaluation of alternative property/built asset interventions (disposal, refurbishment, maintenance, change of use).
- an analysis of the risks associated with each of the interventions, including risk to the business of deferring any actions over time, including a sensitivity analysis considering future scenarios (e.g. technological developments, demographic change, environmental change etc.).
- periodic review of the success of the interventions against the stated expected improvements in performance measured against business objectives.

Once the built asset management plan has been developed it is reviewed against a range of business case scenarios that systematically identify the benefits and dis-benefits (both financial and non-financial) of each property/built asset option against the current performance baseline. The financial assessments of each option are normally considered using a discounted cash flow approach where capital and revenue costs for each intervention are calculated and discounted over a period (normally 20 to 30 years for common built assets). From this a net present value can be calculated. Non-financial benefits and costs can be evaluated using a weighted scoring matrix where importance weightings are assigned against the evaluation criteria outlined in the property/built asset management plan and each intervention is scored on its potential impact on that criteria. The overall weighted score can be derived summing the product of the importance factor and impact factor. A comparison between different property/built asset intervention options can be obtained by considering

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the net present value per benefit point (i.e. by dividing the net present value by non-financial benefits score for an option).

Those options that are selected for implementation are then incorporated into a property/built assets delivery plan where work can be sequenced to address both operational and financial constraints of the organisation (work is likely to be programmed over a period of time to smooth cash flow considerations or provide the opportunity for alternative operational contingencies to be developed to reduce the impact of disruption during any building work). The effectiveness of building work can then be assessed through a series of performance measurements that link to the business/service delivery requirements. The results of these performance reviews, from both a property/asset and business perspective, form the feedback loops that inform business/service delivery strategies over time.

The best practice process model proposed by the RICS (2012) along with that proposed by Jones and Sharp (2007) which have been used to inform the development of the LIQUEFACT RAIF and BAM planning tool.

In developing the RAIF and BAM planning tool the LIQUEFACT project has extended the scope of property/built asset management beyond a narrow consideration of current service performance level to a wider consideration of the impact that an EILD event would have on the ability of the property/built assets to continue to deliver its required service following a disaster event. This work builds on a similar research project undertaken by Prof Jones (LIQUEFACT WP5 lead) to develop a strategic built asset management process model for the planning of mitigation and adaptation interventions to improve flood resilience of a UK social housing provider to future extreme weather events as a consequence of climate change (Hallett, 2013).

2.4 Application the performance-based built asset management process model to developing the business case for mitigations/adaptation interventions to improve flood resilience of a UK social housing provider – The CREW Project

Built asset management models have been applied to the development of disaster risk reduction plans by Jones et al (2017), by Mohammad et al (2014), and Warren (2010). This section presents in detail the work undertaken by Jones as part of the CREW project as this work formed the basis of the approach to BAM planning developed in the LIQUEFACT project.

The performance-based BAM process model described in section 2.3 was applied to the evaluation of the vulnerability and resilience of a major UK social housing provider's building stock to extreme weather events (Hallett, 2013)[9]. In conjunction with this work Jones et al (2017) developed a theoretical approach built asset management planning that could integrate future climate change mitigation interventions into long-term built asset management plans[10].

Jones et al (2017) used a participatory action research methodology to work with a range of stakeholders (internal company representatives ranging from technical operatives to executive officers and external consultants) to operationalise the performance-based built asset management process model (Figure 2.2) to a range of future climate change scenarios (flooding and overheating).

Through a series of workshops and meetings the research team identified the organisations critical success factors (tenant satisfaction and ensuring that future climate change did not cause any of the organisations housing units to fall below its published housing quality standards) against which maintenance and refurbishment (including climate change mitigation/adaptation) would be judged. This procedure confirmed the ability of the key organisational stakeholders to identify performance thresholds (in this case a combination of social, environmental, economic and physical) that could form the basis of a range of key performance indicators.

Once the CSF's were established members of the research team, working in conjunction with the organisations operational staff developed a series of performance toolkits that were used to measure the performance-in-use of each property. Four specific toolkits were developed.

The first toolkit (vulnerability matrix) sought to identify those properties that were located in a potential (current and future) flood zone AND were vulnerable to water ingress. This toolkit involved superimposing the organisation's properties onto flood maps using geo-referenced data and a geographical information system to identify those properties that were at potential risk of flooding (likelihood of exposure to a flood event). Each of the properties that had a likelihood of exposure to a flood event were then examined in more detail (using the organisation's BAM database, Google Street View, and external street surveys) to identify the potential for water ingress into the property assuming a 0.5 m flood in the street immediately adjacent to each property. A combination of the likelihood of exposure to a flood event and the likelihood of water ingress into the property was used to determine each properties level of vulnerability (Figure 2.4).

[9] See https://arcc.ouce.ox.ac.uk/wp-content/pdfs/CREW_Final_Report.pdf for more details
[10] See https://www.arcc-network.org.uk/wp-content/D4FC/D4FC48-Octavia-housing-full-report.pdf for more details.

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		Likelihood of exposure to a flood event			
		No likelihood	Low	Medium	High
Likelihood of water ingress to the property / damage to critical infrastructure	No likelihood	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable
	Low	Not vulnerable	Low vulnerability	Low vulnerability	Low vulnerability
	Medium	Not vulnerable	Low vulnerability	Medium vulnerability	Medium vulnerability
	High	Not vulnerable	Low vulnerability	Medium vulnerability	High vulnerability

Figure 2.4: Vulnerability Matrix

The second toolkit sought to quantify the impact that exposure to a flood event would have on the performance-in-use of 'vulnerable' properties. External surveys of a sample of the organisation's different building typologies identified as highly vulnerable to a flooding event (from Figure 2.4) were undertaken to identify their coping capacity (Figure 2.5) to a flooding event. A combination of the potential damage that a flood event would cause and the recovery time it would take to return the property to its pre-flood performance level was used to categorise each building typology's coping capacity as Low Medium or High.

The vulnerability and coping capacity of each 'at risk' property for flooding was plotted onto a resilience grid (Figure 2.6) and those properties that were highly vulnerable and had low coping capacity to a flooding event were prioritised for early action in the BAM plan. Those properties that were highly vulnerable but had a Medium/Low coping capacity to a flooding event were prioritised for short-medium term action in the asset management plan. Those properties that had a low vulnerability and high coping capacity were identified for periodic review as part of the organisation's ongoing property review procedure.

Two further (similar) toolkits were developed to assess the organisation's vulnerability, resilience and coping capacity to overheating scenarios.

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Failure of a property (or properties) to satisfy a benchmark target triggered a more detailed analysis to identify the underlying cause of the problem and the potential for improvement. Internal surveys of 26 typical properties were undertaken to establish the root cause of both overheating and flooding and to identify potential mitigation solutions. In all cases these solutions were affected by legacy design decisions made when the buildings were newly constructed or underwent major refurbishments.

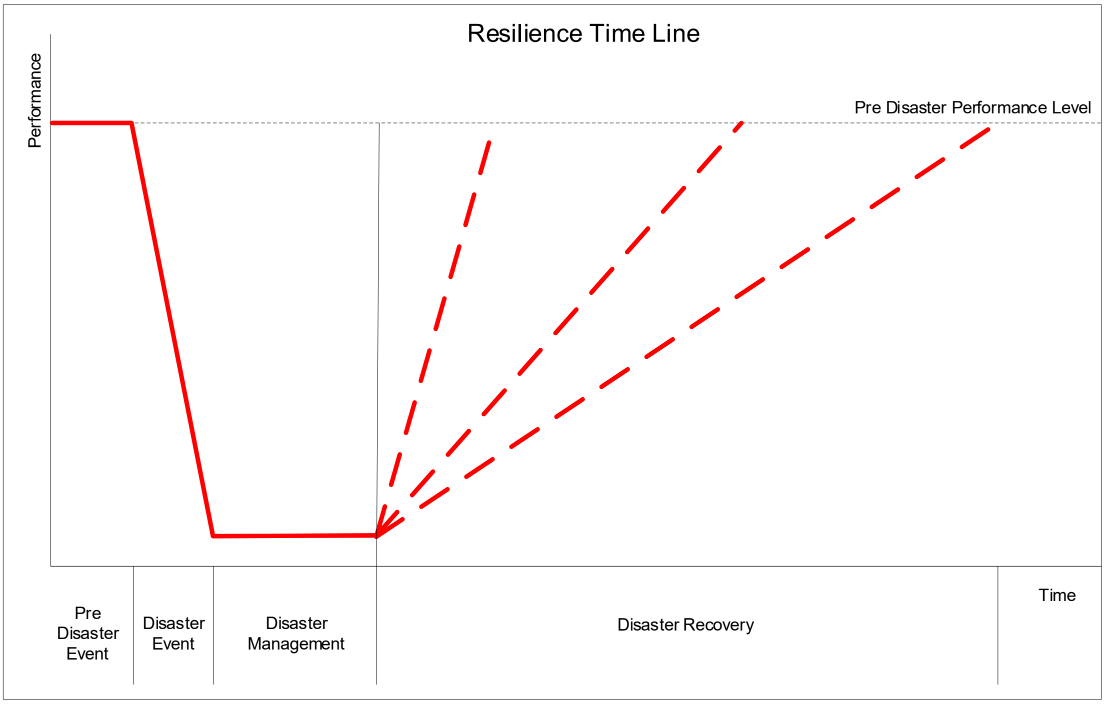

Figure 2.5: Coping Capacity

Adaptation options in the form of resistance (preventing water entering the property) and resilience (increasing speed of recovery once the property has flooded) measures were considered for those properties potentially at risk from flooding. Once the desired improvements in vulnerability and coping capacity were identified researchers worked with the organisation's technical staff to identify and evaluate a range of generic mitigation interventions. The evaluations were made against a series of future scenarios. For flooding it was assumed that a flood had occurred in the street immediately adjacent to the property that had resulted in water ingress into the property. For basement flats it was assumed that up to 1.0m of water would enter the property and would remain in the property for a period of up to 48 hours depending upon the ease at which flood water could be removed once external flooding had receded. For ground floor flats it was assumed that up to 0.5m of water would enter the property and remain in the property for a period of up to 24 hours depending upon ease at which flood water could be removed once external flooding had receded. For street level houses it

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was assumed that up to 0.5m of water would enter the ground floor of the property and remain in the property for a period of up to 24 hours depending upon ease at which flood water could be removed once external flooding had receded (if the house had a basement then the basement flood scenario was used).

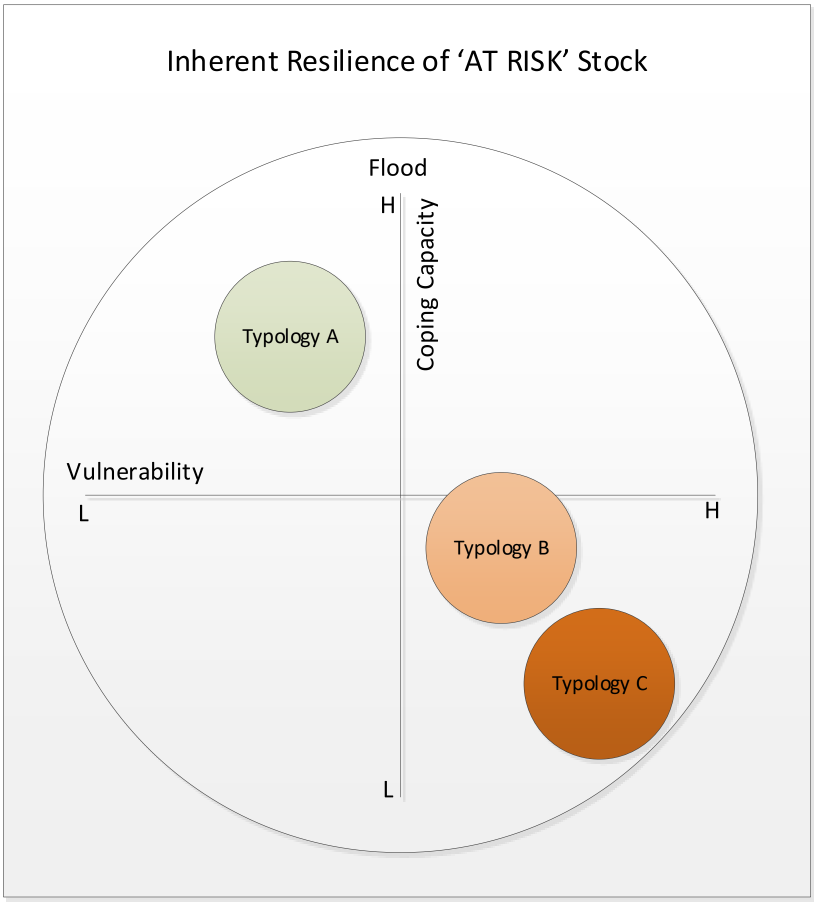

Figure 2.6: Vulnerability and Coping Capacity of properties at risk of flooding

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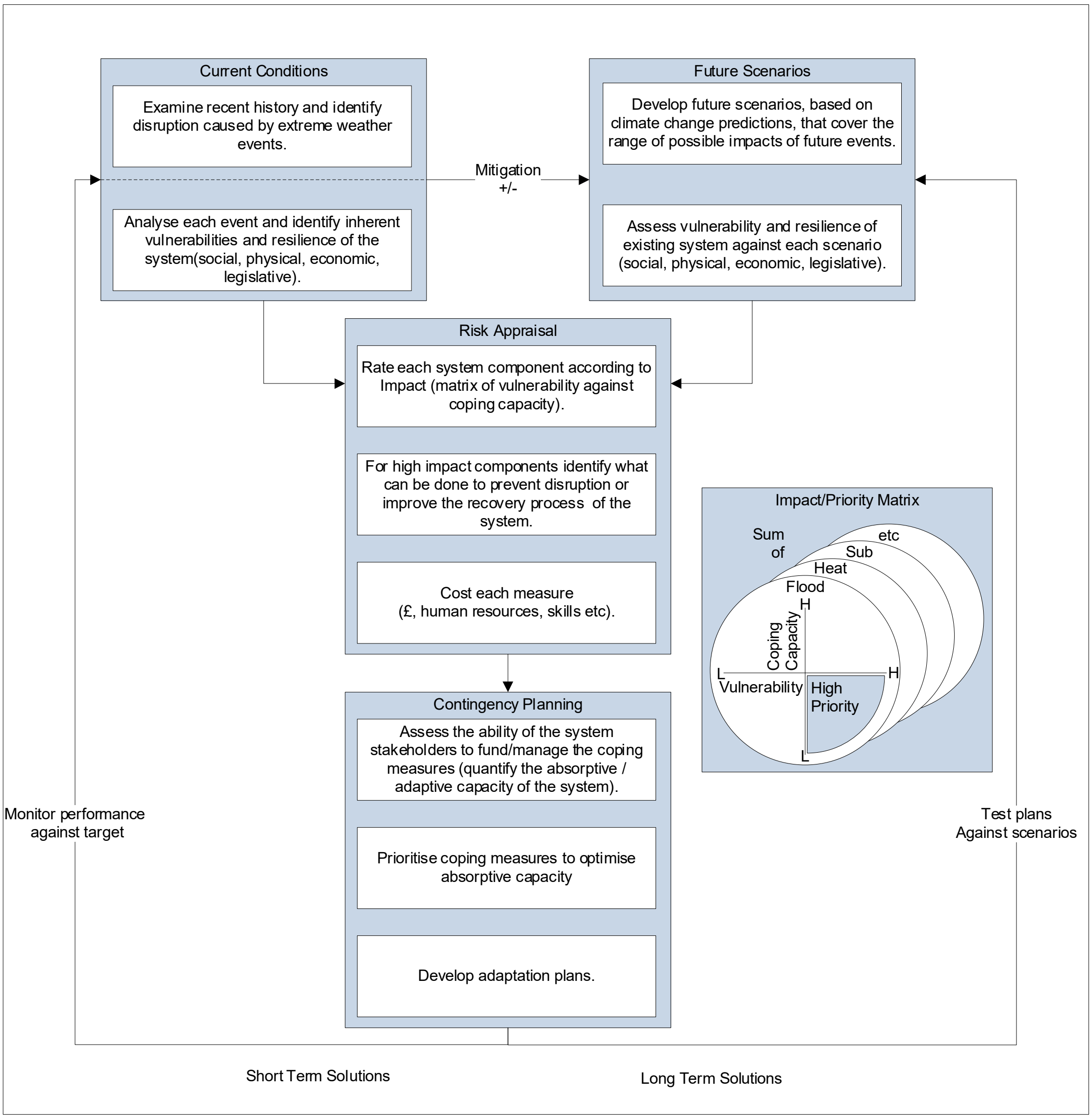

Figure 2.7: CREW Project Resilience Framework

The potential for a range of flood resistance and resilience measures to address these flooding scenarios was assessed for archetype properties using the 26 internal surveys. Mitigation included the retrofitting of technical resistance and resilience measures to buildings and fixtures and fittings as well as tenant (e.g. home use guidance and advice on personal insurance etc.) and landlord (e.g. tenant vulnerability profiling to avoid placing highly vulnerable tenants in highly vulnerable properties, developing and testing organizational business continuity and resilience plans and organisational disaster management plans etc.) operational interventions.

A cost benefit analysis (undertaken by the organisation's financial advisers) was used to prioritise potential interventions and to assign each intervention a priority rating (immediate action, action in the next five years, actions between year 6 and 20) which was then incorporated into a strategic built asset management plan to reduce the vulnerability and improve the coping capacity of the organisation's housing stock to future climate change extreme weather events.

From the surveys it was clear that it would be very difficult (if not impossible) to prevent water entering some types of property (e.g. basement flats). Further, once water had entered the property it was likely to cause significant damage to both building components and fixtures & fittings that significant work would be required in order to return the property to a habitable condition. Thus, the mitigation strategy for this type of property would be to let it flood but to improve the resilience of building components and fixtures & fittings to shorten the time it would take to return the property to a habitable condition.

Where it was possible to prevent water entering a property in all but the most severe flood scenarios the mitigation strategy would be to prevent water ingress wherever possible through the use of temporary resistance measures and include resilience measures to shorten the time it would take to return the property to a habitable condition. The balance between resistance and resilience would be made on a property by property basis to reflect property specific conditions and circumstances.

Finally, all of the organisation's properties that were vulnerable to flooding would be covered by a flood action plan. These plans would provide practical guidance on preparing for a flood and guidance on what to do whilst a flood is in progress. The plans would also provide guidance on how to protect precious items (particularly irreplaceable personal items) from the effects of water damage. The process model described above is shown in Figure 2.7.

The LIQUEFACT project has re-interpreted Prof Jones' performance-based built asset management process model; the building life-cycle model; and the risk framework described above to take account of the changing demands and expectations that will be paced on built assets as a consequence of an organisation's vulnerability and resilience to an EILD event.

The LIQUEFACT project has:

- extended the CREW resilience model to include an assessment of the community's expectations of the level of performance (defined as the ability for the built asset to continue to deliver the level of service expected by the community) to the aftermath of an EILD event.

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- modified (where necessary) the theoretical basis of the performance based built asset management process and building life-cycle models to reflect the wider body of theory associated with community resilience to disaster events; and
- has developed a new range of toolkits (community resilience model, CI resilience model, cost benefit analysis model) that relate specifically to assessing the vulnerability, resilience and coping capacity of built assets to an EILD event.

The remainder of the deliverable describe these tools in more detail and outlines the BAM planning tool that integrates them into RAIF.

3.0 Toolkit for Assessing Community Resilience to EILD Events

The theory pertinent to community resilience to EILD events was critiqued and summarised in LIQUEFACT deliverable D1.1[11] and its application to the development of the LIQUEFACT Community Resilience Assessment Tool was described in LIQUEFACT deliverable D5.1[12]. This section provides a short summary of the key conclusions from D1.1 and D5.1 as a precursor to the presentation of the final beta test version of the LIQUEFACT Community Resilience Assessment Tool.

3.1 A review of the factors affecting community resilience to an EILD event

Attempts to develop practical measures of community resilience to disaster events have resulted in the identification of a wide range of factors that affect community resilience and a number of models that seek to integrate these factors into a range qualitative and quantitative toolkits. In all of the studies three issues repeatedly arise:

- What are the factors that influence community resilience and are these factors consistent across disaster types and context?
- Can reliable, robust and consistent metrics be developed to measure each of the factors?
- What methods can be used to combine the factors into a reliable robust and consistent scorecard that reflects local circumstances and context?

LIQUEFACT deliverable 1.1 reviewed a wide range of academic papers and identified the factors that affect community resilience. These factors are summarised in Table 3.1.

[11] See https://zenodo.org/record/1342684#.XOU2u0xFybV for the full report
[12] See https://zenodo.org/record/1887913#.XOU2-ExFybU for the full report

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Table 3.1: Characteristics/factors known to affect community resilience to disaster events.

Resilience Factor / Characteristic	**Indicator / Expectations**
Robustness	Damage avoidance in lifelines and critical infrastructure (transportation networks, residential housing stock, healthcare facilities, communication networks, commercial and manufacturing establishments etc.); Continuity of service provision; Continuity of functional systems performance; Avoidance of casualties; Avoidance / minimisation of economic losses,
Redundancy	Backup and/or duplicate systems; Backup or access to alternate resources to sustain operations (insurance, alternative sites, robust supply chains etc.); Alternative community logistics (food, water, power etc.); Untapped resources/contingency budgets.
Resourcefulness	Access to money; Information; Technology; Human resources; Household emergency plans; Business continuity plans; Diagnostic and damage detection systems; Contingency plans across stakeholder groups.
Rapidity	Disaster preparedness (Organisational capacities, Early warning systems, Contingency planning, Emergency response planning, etc.); Reduced time of recovery to return systems as close as possible to business as normal.
Personal Factors	Critical awareness; Self-efficacy; Sense of community; Outcome expectancy (positive or negative); Action coping and resource availability; Education and training; Psychological preparedness; Empowerment; Social norms; Trust; Personal responsibility; Social responsibility; Experience; Resources; Adaptive capacity; Cultural attitudes and motivations; Social networks; Property values; Livelihoods; Participation in recovery; Volunteering.
Community Factors	Collective efficacy; Participation; Commitment; Information exchange; Social support; Decision making; Resource availability; Engagement; Leadership; Demographics; Sense of community; Community values-cohesion; Collective efficacy; Place attachment; Adaptive capacity; Local understanding of risk (Hazard assessment, Vulnerability assessment, Impact assessment, Resource management, Mitigation); Counselling services; Health and well-being services; Community organisations (e.g. faith based etc.); Employment;
Institutional Factors	Empowerment; Trust; Resources; Mechanisms for community problem solving, Adaptive capacity, Participation in hazard reduction programmes; Hazard mitigation plans; Zoning and building standards; Emergency response plans; Interoperable communications; Continuity planning; Municipal finance/revenues.

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Governance Factors	Policy & Planning; Legal and regulatory systems; Integration across time and scale; Leadership; Partnerships; Accountability.

Derived from: Ainuddin & Routray (2012); Becker et al (2013); Boon et al (2012); Bruneau et al (2003); Cutter et al (2008); DPRAP (2013); GOAL (2012); Normandin et al (2009); and Paton (2007).

LIQUEFACT deliverable 1.1 concluded that the factors and indicators presented in Table 3.1 should be considered exemplars of the kind of issues that will need to be addressed when assessing community resilience to EILD events.

The general applicability of the range of factors identified from the literature to provide the basis of a community resilience model of EILD events was tested during an external stakeholder workshop held in Bologna in the Emilia Romagna Region (Italy) on October 3rd 2016. The workshop was organised by UNICAS under the auspices of the "Associazione Geotecnica Italiana"; of the "Ordine degli Ingegneri della Provincia di Bologna"; and of the "Ordine dei Geologi della Regione Emilia Romagna. Two hundred and five participants from a range of occupational backgrounds (engineers, architects, geologists drawn from representatives of municipalities, local authorities, governmental institutions; academic institutions, and private consultants) attended the workshop. During the afternoon session they were asked to complete a short questionnaire in which they scored the impact that they thought the range of concepts identified in deliverable D1.1 would have on community resilience to EILD events. In particular respondents were asked to describe the strength of the relationships that they believed existed between the concepts and community resilience using a five-level Likert scale expressed in linguistic terms as "very low", "low", "medium", "high" and "very high". The respondents were also asked to describe the type of influence that they believed each factor has on resilience using the "+" sign to express a positive influence (i.e. as the factor increases/decreases, the resilience increases/decreases) or the "-" sign to express a negative influence (i.e. as the factor increases/decreases, the resilience decreases/increases). If the respondent was confident that no relationship existed between the concept and community resilience they were asked to leave the field blank. The weighting and direction of influence (including the % of respondents who agreed with the direction) for each factor by all the participants are shown in Table 3.2.

From both the mode and arithmetic mean score presented in Table 3.2 it is clear that, whilst all the factors (except political leadership) were considered of some importance to community resilience, those that addressed 'technical' issues were generally considered more important than those associated with 'social', 'economic' and 'organisational' issues. This can be more clearly seen in Figure 3.1. Figure 3.2 shows a breakdown of the importance to each group of factors given by the 4 primary respondent groups (missing data has been excluded from the analysis). Whilst is can be seen that the ranking order of importance weightings is generally consistent across all respondent groups (all group's rank the technical factors as the most important), it does appear that the architects, engineers and geologist groups tend to rate all the factor groups as more important than the manager group. This said, none of the respondent groups exhibited a wide range in weighting factor values and this must be noted when developing any weighting system as part of a community resilience to EILD event toolkit.

One hundred and twelve respondents completed the questionnaire survey.

Table 3.2: Arithmetic mean, modal score and direction of influence of a range of technical, organisational, social and economic factors have on community resilience to an EILD event - all respondents

Factor	Arithmetic Mean	Mode Score	Direction of Influence (% agree)
Poor design and construction (T)	4.06	Very High	Negative (91%)
Unregulated land use planning (T)	3.90	Very High	Negative (91%)
Lack of building codes (T)	3.47	High	Negative (89)
Protection of Cis (T)	3.74	Very High	Positive (90%)
Protection of built assets (T)	3.61	Very High	Positive (81%)
Stock assessment and retrofitting (T)	3.49	High	Positive (94%)
Network redundancy (T)	3.36	Medium	Positive (88%)
Proximity to disaster prone areas (T)	3.94	Very High	Negative (88%)
Early warning (O)	3.18	Medium	Positive (90%)
Risk assessment (O)	3.25	Medium	Positive (94%)
Trained staff (O)	3.72	Very High	Positive (94%)
Emergency response plan (O)	3.68	High	Positive (91%)
Public information (O)	3.14	High	Positive (90%)
Hazard mitigation plan (O)	3.54	High	Positive (92%)
Political leadership (O)	2.18	Very Low	Positive (58%)
Pre-disaster planning (O)	3.45	High	Positive (87%)
Education (S)	3.26	Medium	Positive (91%)
Disaster preparedness (S)	3.34	Medium	Positive (92%)
Social cohesion (S)	3.19	Medium	Positive (93%)
Social support (S)	2.83	Medium	Positive (88%)
Social networks (S)	2.56	Medium	Positive (86%)
Poverty (S)	3.07	Medium	Negative (88%)
Collaboration with research institutes (S)	2.74	Medium	Positive (90%)

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Public participation in decisions (S)	2.80	Medium	Positive (81%)
Empowerment (E)	2.94	Medium	Positive (92%)
Disaster insurance (E)	3.08	Medium	Positive (89%)
Funding mechanism (E)	3.54	Very High	Positive (89)
Business continuity plan (E)	2.97	Medium	Positive (89%)
Ability to mobilize resources (E)	3.87	Very High	Positive (91%)

Note: T-Technical Factor; O-Organisational Factor; S-Social Factor; E-Economic Factor

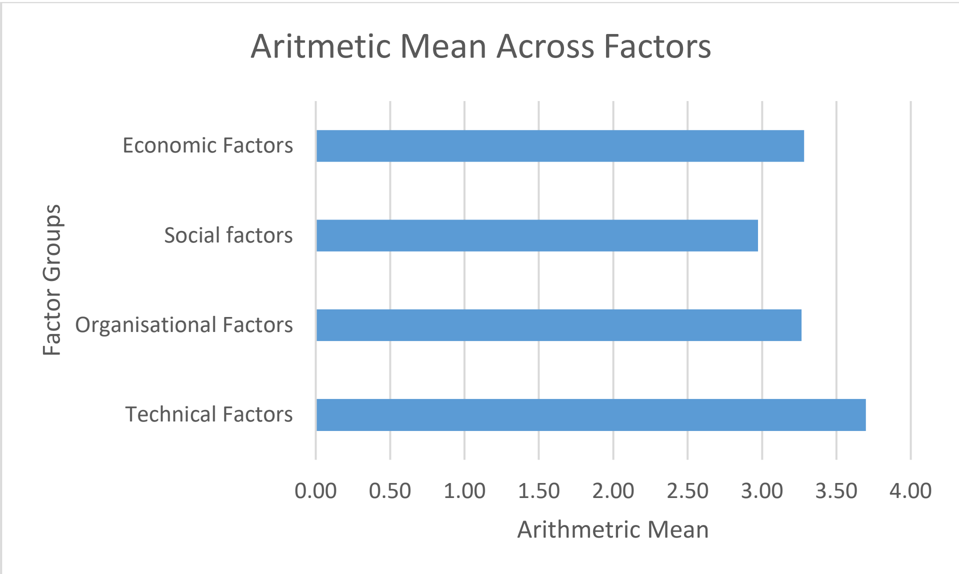

Figure 3.1: Arithmetic mean score of the weights assigned by the respondents by category of factors

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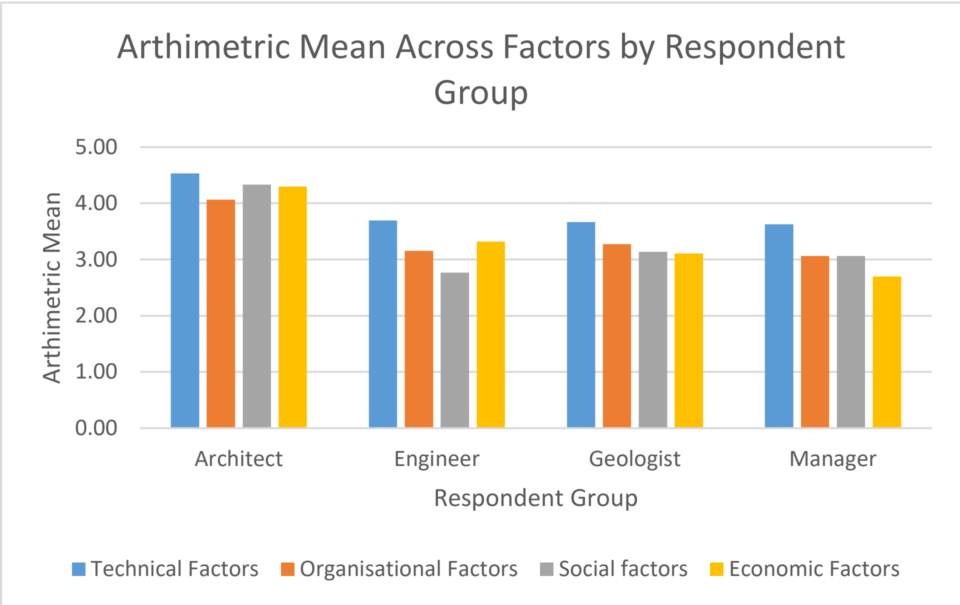

Figure 3.2: Arithmetic mean school of the weights assigned by different respondent groups to technical, organisational, social and economic factors that affect community resilience

The aim of the Bologna workshop was to test whether a group of decision-making stakeholders that had recent experience of an earthquake disaster event that included liquefaction could associate with the generic range of community resilience factors identified from literature and, whether they could assign consistent importance weighting scores to individual factors and across factor groups. From the results of the questionnaire survey it would appear the answer to both of these questions is yes. Whilst initially some respondents asked for clarification of the questionnaire, this was primarily in seeking to understand how to interpret the positive/negative question associated with the direction of influence that each factor would have on community resilience and not on understanding the meaning of each factor. As such, whilst technically the questionnaire was researcher-administered, in the vast majority of cases it can be considered as self-administered and the results demonstrate that community resilience to EILD events based on scoring the impact and importance of a range of factors similar to those presented in Table 3.1 could be developed. Development of the community resilience to EILD events commenced in WP5 Task 5.1 and completed as part of WP5 Task 5.4 (reported here).

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3.2 A review of modelling approaches to community resilience to an EILD event

LIQUEFACT deliverables D1.1 and D5.1 also critically reviewed the range of toolkits and metrics developed to measure community resilience to disaster events (Table 3.3) and the modelling approaches used by the various toolkits to achieve an overall assessment of a community's resilience to a disaster event. The range of modelling approaches included:

- qualitative assessments based on the existence or not of a factor (tick box scorecard);
- linear modelling using simple summation across a range of factors;
- statistical and quasi-statistical approaches to identify critical or dominant factors within a community including factor analysis and structural equation modelling;
- comparative models that reflect resilience before and after a disaster event (normally assessed through reference to future scenarios);
- mapping approaches that group individual metrics against a range of higher-level factors including network models (analytic hierarchy process, analytic network process and policy cognitive maps); and
- complex models, including systems modelling of single and multiple integrated (or nested systems)

Table 3.3: List of toolkits for measuring community resilience to disaster events.

Toolkit	Description
GOAL	This toolkit measures community level resilience through the assessment of a broad range of resilience components in 5 thematic areas. • Governance (6 components) • Risk Assessment (3 components) • Knowledge and Education (3 components) • Risk Management / Vulnerability Reduction (12 components) • Preparedness and Response (6 components) Each component is scored on a 1-5 scale and then aggregated to provide an assessment of the resilience of each key component and the overall level of resilience of the community. The output is in the form of a dashboard radar plot that can compare different communities or the same community before and after interventions https://www.goalglobal.org/images/5101_HN_OP_006_11_Resilience_Toolkit_English_B02.pdf
DPRAP CoBRA	This toolkit was developed to measure the socio-economic and environmental impacts of community based disaster risk reduction to drought across the Horn of Africa. The specific aim of the toolkit is to "design a quantitative impact assessment of interventions at the community or household level". The CoBRA model establishes a baseline assessment of an individual household's resilience to an event and then measures how

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	this might change following a range of interventions. Resilience is measured at a set point in time through a composite of 5 components (human, physical, natural, social and financial) that provide individual and overall resilience score. Measurements are then repeated after a disaster event/interventions and improvements (or reduction) in resilience can be calculated. Although the metrics developed in the toolkit are not directly applicable to earthquake disasters the principles of importance (ranking) and performance (scoring) underpinning the approach are. https://issuu.com/edwintoo/docs/cobra_conceptual_framework_and_meth
Menoni et al	The EU ENSURE (Enhancing resilience of communities and territories facing natural and na-tech hazards) project examined the relationship between flooding vulnerability and resilience in Sondrio (Italy). As part of the project a matrix approach was developed to assess the resilience of the built environment, infrastructure and social systems. The matrix approach provided a framework for assessing the existence (or not) of a range of factors that would affect resilience to a flooding event. http://link.springer.com/article/10.1007%2Fs11069-012-0134-4
Bruneau et al	This framework was developed specifically to measure the seismic resilience of communities. The framework is based around a series of matrices that define at a global level (through performance criteria) the Robustness, Redundancy, Resourcefulness and Rapidity requirements of a community's Technical, Organisational, Social and Economic systems. Further matrices repeat the process (Robustness, Redundancy, Resourcefulness and Rapidity requirements) for critical systems (Power, Water, Health, Emergency Response) from a Technical, Organisational, Social and Economic perspective. This multiple performance metric approach allows community resilience to be broken down into three complimentary measures: reduced failure probabilities; reduced consequences from failures; and reduced time for recovery. http://earthquakespectra.org/doi/abs/10.1193/1.1623497
Kellett et al	The Future Framework for Disaster Risk Reduction: A guide for Decision Makers is a set of guidance for government decision makers on what should be included in a disaster risk reduction framework. Whilst the guidance does not provide specific tools, it does highlight 11 areas (making the case, the architecture, monitoring and accountability, financing, vulnerability and inclusion, disaster risk, environmental and ecosystems, science and technology, conflict and fragility, stakeholders and leadership, sustainable development) that need to be addressed in any disaster risk reduction framework. https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8996.pdf
Resilience Alliance	Provides a framework for assessing resilience in social-ecological systems. Their workbook for practitioners provides guidance on developing and implementing management solutions to improve system resilience. The framework provides tools for describing the system under threat; applying the adaptation cycle; identifying system interactions; understanding governance systems and social networks; and for developing conceptual models and setting threshold criteria. The resilience assessment resulting

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	from enacting the framework can be implemented and integrated into strategic plans and management processes to improve the resilience of the system. http://www.resalliance.org/files/ResilienceAssessmentV2_2.pdf
IFRC	Earthquakes: Guidelines on Preparing, Responding and Recovering. The International Federation of Red Cross and Red Crescent produce guidelines for national societies in preparing, planning and implementing field operations in response to an earthquake event. The guidelines are built on the Hyogo Framework and although this has now been superseded by The Sendai Framework the advice in the guidelines is valid. http://www.preventionweb.net/files/26164_earthquakeguidelinesenweb.pdf
UNISRD Disaster Resilience Scorecard for Cities	The Disaster Resilience Scorecard for Cities consists of 95 disaster resilience evaluation criteria (later increased to 118) grouped by subject/issue, details of the item being measured, a qualitative or quantitative statement of an indicative measurement, an indicative measurement scale (from 0 to 5, where 5 is best practice), and comments to help those applying the item being measured. Each item is assessed against two risk scenarios; a "most probable" scenario and a "most severe" scenario. These scenarios are defined by each city in response to its assumed hazard threat level. Where possible individual assessments are based on objective measures but where these do not exist subjective assessments can be made. Irrespective of which type of assessment is used, full justification for the scores given should be recorded; this will not only allow external validation but will also act as a start point for assessing future revisions. Where items are not under the direct control of a single stakeholder, scoring should be done following consultation with all relevant stakeholders. Finally, not all items listed in the scorecard will apply to all situations and as such the scorecard should be contextualised to reflect city specific circumstances and disaster type. https://www.unisdr.org/we/inform/publications/53349
Ainuddin & Routray	Developed a multiple indices approach to measuring community resilience to earthquake hazards in Baluchistan. Their approach was based on 4 components of (social, economic, physical and institutional) each representing its own domain and measured through 17 individual indicators. Each indicator was expressed in percentage terms and weighted to represent the relative importance of each indicator to each other. Due to lack of data the authors used a subjective assessment of the relative weights and whilst this does not negate the principles behind the approach, it does call into question the robustness of the specific comparisons presented in the paper. The overall community resilience was then calculated by combining the individual component scores. http://link.springer.com/article/10.1007/s11069-012-0201-x

The tools, models and metrics presented in Table 3.3 can be considered exemplars of the kind of issues that will need to be addressed when assessing the resilience to EILD events. Following the detailed consideration of the various toolkits with researchers from the LIQUEFACT project and the LIQUEFACT International Advisory Board, the UNISDR Disaster Resilience Scorecard for Cities was identified as the most appropriate for assessing community resilience to an EILD

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event. The rationale behind this choice was based on a perceived best practice approach demonstrated by the UNISDR scorecard and the fact that many countries/cities were beginning to use the scorecard to assess their antecedent resilience to a range of disaster events, including earthquake events. As by definition, earthquake induced liquefaction phenomenon cannot occur without an earthquake event happening, it seemed logical to the research team that any scorecard it developed to assess resilience to an EILD event should be compatible with, and supplementary to, the UNISDR scorecard. As such, LIQUEFACT researchers have customised the latest version of the UNISDR Disaster Resilience Scorecard for Cities to provide supplementary guidance to ensure that when the Scorecard is applied to an assessment of community resilience to earthquake disaster events it also includes an assessment of the potential for, and antecedent resilience of communities to EILD events.

3.3 Review of the Customised UNISDR Disaster Scorecard for Cities for EILD events

In 2015 the UNISDR (UNISDR, 2015) developed "The Disaster Resilience Scorecard for Cities" as an assessment method to allow cities to better understand how resilient they are to natural and man-made disasters. The Scorecard was developed from the "Ten Essential" for Making Cities Resilient in support of the Sendai Framework for Disaster Risk Reduction 2015-2030.

The "Ten Essentials" seek to provide a better understanding of:

- the disaster risks a city might face;
- how to mitigate the risks; and
- how to respond to disasters in a way that seeks to minimise loss of life, livelihoods, property, infrastructure, economic activity, and the environment.

The "Ten Essentials" are grouped into three sections (Figure 3.3). Essentials 1-3 address governance and financial issues; Essentials 4-8 address planning and disaster preparation; and Essentials 9-10 address disaster response and post-disaster recovery. The Scorecard was developed to enable cities to establish a baseline measurement of their antecedent level of disaster resilience for each "Essential" and to identify opportunities for investment and action (mitigation interventions) to improve their disaster resilience over time.

The UNISDR Scorecard consists of 118 disaster resilience evaluation criteria (Table 3.4) grouped by subject/issue, details of the item being measured, a qualitative or quantitative statement of an indicative measurement, an indicative measurement scale (from 0 to 5, where 5 is best practice), and comments to help those applying the item being measured. Each item is assessed against two risk scenarios; a "most probable" scenario and a "most severe" scenario. These scenarios are defined by each city in response to its assumed hazard threat level. Where possible individual assessments are based on objective measures but where these do not exist subjective assessments should be made. Where items are not under the direct control of a single stakeholder, scoring should be done following consultation with all relevant stakeholders. Finally, not all items listed in the scorecard will apply to all situations and as such the scorecard can be contextualised to reflect city specific circumstances and disaster type. The LIQUEFACT project has developed a customised version of the Scorecard for use alongside the original scorecard by cities/regions assessing the resilience to earthquake events.

In developing the customised Scorecard LQIUEAFCT has taken note of the experience of other users and of the feedback from the Bologna workshop and from the LQIUEFACT International Advisory Board.

Experience from those cities that have completed the scorecard suggests that they have done so at three different levels (UNISDR, 2015). Some cities have adopted a high level survey approach where a one to two day workshop supplemented with a pre-event questionnaire has been used to provide a simple (average or consensus) score for each "Essential" and, if required, an aggregated score across all essentials. Other cities have adopted a more focussed approach, concentrating on specific aspects of resilience (e.g. a selection of the "Essentials") to provide an in depth assessment of that specific aspect of resilience. Some cities have taken the opposite approach and performed an in depth assessment of all of a city's resilience "Essentials" but it was noted that such an approach can be very time consuming. The ability to apply the scorecard at different levels of sophistication provide the opportunity for both a rapid assessment of a cities resilience to a disaster as well as for a detailed assessment of the impact that a range of mitigation/adaptation interventions could have to improve the city's resilience. The LIQUEFACT customised version of the UNISDR Scorecard has been developed to a similar range of assessment levels; in particular, a supplementary Critical Infrastructure Scorecard has been developed to reflect the specific nature of EILD events and the potential impact that such events can have on the performance of critical infrastructure.

Irrespective of which approach is used to complete the Scorecard, the final decision that those using the Scorecard need to make is their approach to aggregating the scores given to the items measured in each "Essential" and between "Essentials". Whilst a simple arithmetic summation or average will provide an overview of a city's resilience, it does assume that all the items are equally important within each "Essential" and that all the "Essentials" are equally important to the city's overall resilience. Such an approach, whilst providing a reasonable basis for general discussions on a city's resilience, as indicated in the Bologna Workshop questionnaire, is probably a little simplistic if the Scorecard is to be used to assess the effectiveness of a range of mitigation interventions to improve resilience (as required in the LIQUEFACT project). The LIQUEFACT customised version of the UNISDR Scorecard has been developed to provide two levels of aggregation using weightings derived from expert opinion and applied through either a balanced scorecard approach, or a multi-criteria approach, that reflect the relative importance of each criteria within each essential, and the relative importance of each essential, to overall community resilience to an EILD event. The aggregated scores from the customised UNISDR Scorecard will be integrated into the RAIF and built asset management plan as part of the mitigation options appraisal process.

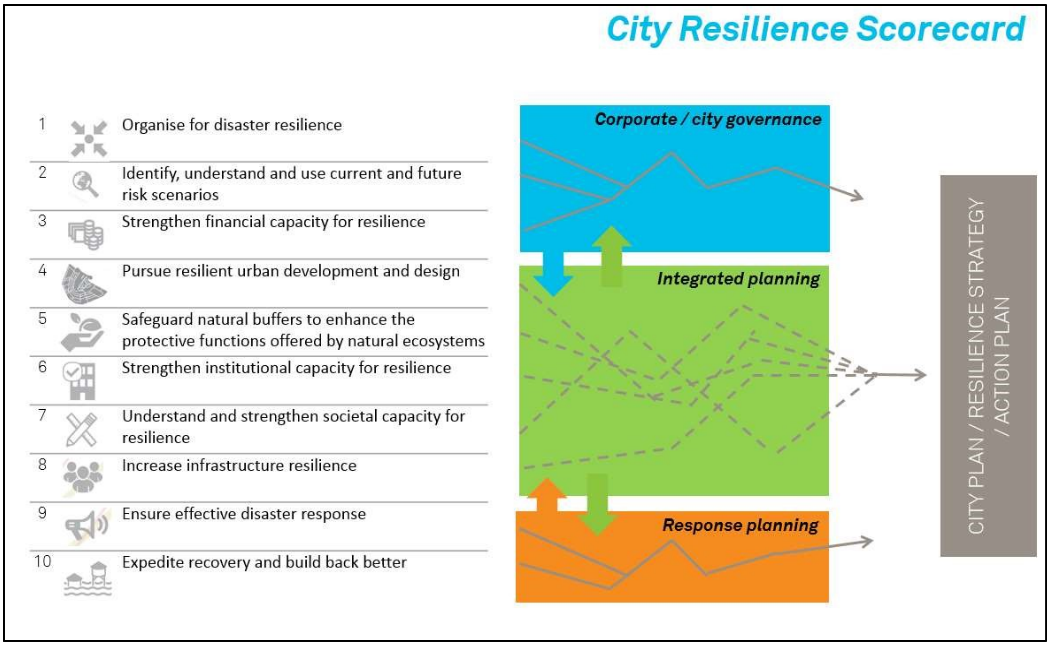

Figure 3.3: The City Resilience Scorecard (source: UNISDR, 2017)

Table 3.4: Summary of the subject/issues addressed in the UNISDR Disaster Resilience Scorecard for Cities (source: Summarised from UNISDR, 2017)

Essential Element	Subject/Issue	Number of Items Measured
Organise for Resilience	Plan making	3
	Organisation, coordination and participation	4
	Integration	1
	Data capture, publication and sharing	1
Identify, Understand and Use Current and Future Risk Scenarios	Hazard assessment	1
	Knowledge of exposure and consequences	2
	Cascading impacts or interdependencies	1
	Hazard maps	1
	Updating of scenario, risk, vulnerability and exposure information	1

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Strengthen Financial Capacity for Resilience	Knowledge of approaches for attracting new investment to the city for DRR	1
	Resilience budgets within the city financial plan including contingency funds	4
	Insurance	2
	Incentives and financing for business, community organisations and citizens	3
Pursue Resilient Urban Development	Land use zoning	4
	New urban development	1
	Building codes and standards	3
	Application of zoning building codes and standards	2
Safeguard Natural Buffers to Enhance Protective Functions Offered by Natural Ecosystems	Existing natural environment and ecosystem health	2
	Integration of green and blue infrastructure into city policy and projects	2
	Transboundary environmental issues	2
Strengthen Institutional Capacity for Resilience	Skills and experience	4
	Public education and awareness	2
	Data capture, publication and sharing	2
	Training delivery	3
	Languages	1
	Learning from others	1
Understand and Strengthen Societal Capacity for Resilience	Community or "grass roots" organisations	3
	Social networks	2
	Private sector / employees	2
	Citizen engagement techniques	3
Increase Infrastructure Resilience	Protective infrastructure	2
	Water sanitation	3
	Energy-electricity	3
	Energy-gas	4
	Transportation	7
	Communication	3
	Healthcare	4
	Education	3
	Prisons (note that law will order, and other first responder assets, are covered in Essential 9)	1
	Administration and operations	1
	Computer systems and data	2
Ensure Effective Disaster Response	Early warning	2
	Event response plans	1
	Staffing / responder needs	2
	Equipment and relief supply needs	2
	Food, shelter, staple goods, and fuel supply	5
	Interoperability and inter-agency working	3
	Drills	2
Expedite Recovery and Build Back Better	Post event recovery planning - pre event	3
	Lessons learnt / l earning loops	1

Since the submission of deliverable 5.1 (May 2017) the UNISDR and AECOM[13] have continued to develop and refine the UNISDR Scorecard based on the feedback from a number of pilot studies, including:

- The need for the Scorecard to support short (1 day) workshops with a range of city stakeholders (e.g. local businesses/civic groups) who could collectively agree a consensus on the impact and scoring mechanisms for each essential based on their experiences and potential response to future scenarios (e.g. most severe and most probable disasters scenarios). The Scorecard also has to differentiate clearly between essentials; identifying those which needed further investigation outside of the workshop. For the LIQUEFACT customised Scorecard this will include the development of a more detailed assessment of the impact that EILD events have on critical infrastructure (CI) assets.
- The need for the Scorecard to provide a level of detail to the analysis that would allow potential improvement to the essentials for a range of mitigation activities to be evaluated as part of the wider Hazard Mitigation Planning process. For the LIQUEFACT customised Scorecard this will include the identification of mitigation interventions that can improve a subject/issues indicative measurement score.
- The need for the scorecard to support individual businesses in assessing the resilience to disaster events including assessing their preparedness and response strategies. This includes the need for the scorecard to be integrated into wider disaster risk management planning. For the LIQUEFACT customised Scorecard will include the integration of the Scorecard into the RAIF, including into an organisation's Business Continuity and Resilience/Disaster Management Plans.
- The need to integrate the Scorecard with more specifically focused disaster resilience tools that focus on particular essentials, or support very localised assessments of disaster impacts, including the ability to apply the Scorecard to a range of businesses (and their supply chains) located within a potential disaster impact region. For the LIQUEFACT customised Scorecard will include the integration of the Scorecard into the RAIF, including into an organisation's Business Continuity and Resilience/Disaster Management Plans and the development of a specific section for a detailed assessment of CI resilience to EILD events.
- The need for the Scorecard to reflect previous local disaster history including a recognition of attitudes to risk amongst different stakeholder groups and the ability to realise coping capacity (e.g. insurance, back-up (out of region) systems, recovery and rebuilding (build back better)). For the LIQUEFACT customised Scorecard this will be achieved through integration with the RAIF and cost benefit analysis tool.

[13] http://www.nafsma.org/sites/default/files/shared-files/UN_Scorecard_Melnar_Chapman_0531_2018.pdf

- The need for a shorter preliminary assessment version of the Scorecard that would allow a rapid screening of potential risks without the need to invest the time and effort you undertaking a full analysis. For the LIQUEFACT customised scorecard this will be achieved through the use of the simple balanced scorecard aggregation method.

Given all of the above a customised version of the UNISDR Disaster Resilience Scorecard for Cities was developed as the basis for measuring a city's antecedent resilience to EILD events and for assessing the improvement in this resilience that could be achieved by applying a range of mitigation interventions. The next section of this report describes the development and validation of the LIQUEFACT customised Disaster Resilience Scorecard for Cities for an EILD event.

3.4 Customisation of the UNISDR Disaster Resilience Scorecard for EILD events

The LIQUEFACT toolbox will use the UNISDR Disaster Resilience Scorecard for Cities as the basis for assessing community resilience to EILD events. The subject/issues; question/assessment area; indicative measurement scale; and comments sections outlined in the Scorecard have been reviewed by the LIQUEFACT project partners, external expert stakeholders and LIQUEFACT International Advisory Board to identify those items that are potentially affected by an EILD event and to rank the relevance of each item to community resilience to an EILD event.

3.4.1 Research Methodology for customising the UNISDR Disaster Resilience Scorecard for EILD events

A series of group interviews were held with LIQUEFACT Partners and External Stakeholders to customise the UN Scorecard for the specific case of EILD events. Community Resilience to liquefaction is a complex phenomenon and using this discursive research methodology enabled the researchers to:

- discover how different groups (LIQUEFACT partners; and external stakeholders involved in disaster management emergency response) viewed community resilience to liquefaction and to explore in detail why they held certain opinions;
- investigate the use, effectiveness and usefulness of the criteria presented in the UNISDR Scorecard in case of and EILD event; and
- generate additional guidance to score each subject/issue to the case of earthquake induced liquefaction.

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Before each group interview all participants were sent the UNISDR Scorecard in order to give them the opportunity to familiarise themselves with the document. However, during the interviews the interviewer reviewed again the subject/issue; question/assessment area; indicative measurement scale; and comments sections for each criterion to ensure that all the group participants understood the reasons for the interviews.

The LIQUEFACT partners were asked to consider and discuss each of the Criteria in the Essentials 1-4 and 6-10. Essential 5 (Safeguard Natural Buffers to Enhance Protective Functions Offered by Natural Ecosystems) was removed from the list of Essential as pre-screening by the research team had deemed this Essential 'not specifically relevant' to community resilience to an EILD event.

After the first round of interviews Essential 8 was also removed (except for criteria 8.1.1 and 8.1.2 as they focus on protective infrastructure and their maintenance) as a review of the wider literature around improving resilience to EILD events (see LIQUEFACT deliverable 5.1) had already identified the need for LIQUEFACT to develop a much more detailed scorecard which could reflect the impact that an EILD event would have on the performance of a range of critical infrastructure systems. The detailed CI scorecard is presented in section 4.

3.4.2 Stakeholder interview protocols

Twelve group interviews were held with stakeholders located in either Italy or Turkey. Anonymized details (to comply with ethics requirements) of the 12 group interviews are given in Table 3.5.

Table 3.5: List of organizations and experts involved in the interviews

Group ID	Number of Participants	Level of Expertise	Area of Expertise
P1	7	Professors, Researchers, PhD students, MSc students	Geotechnical Engineering, Construction Technology,
P2	2	Professor, Researcher	Geotechnical Engineering
P3	3	Professor, Associate Professor, Researcher	Geotechnical Engineering
P4	3	Associate Professor, Senior Research Fellow, Researcher	Geology, Geotechnical Engineering, Structural Engineering

P5	2	Senior Research Engineer, Head of Department of Earthquake Hazard and Risk	Earthquake Hazard and Risk, Earthquake Engineering, Engineering Seismologist
P6	3	Researchers	Geology, Geotechnical Engineering, Emergency Management
P7	3	Practitioner Engineers, Reconstruction and Planning Managers	Engineering, Surveying
P8	7	Practitioner Engineers, Practitioner Geologists	Civil Engineering, Geological Engineering, Disaster Management
P9	2	Professors, politician	Geophysics Engineer,
P10	5	Professors, Associate Professors, Researchers	Civil Engineering, Geological Engineering
P11	4	Practitioner Engineers, Emergency Responder	Geological Engineering, Geophysical Engineering, Search and Rescue, Hazard Training
P12	4	Practitioner Engineers	Civil Engineering, Geophysical Engineering, Geological Engineering

In total 45 individuals participated in 12 group interviews conducted between May and December 2018. Following a general welcome, the interviewer: confirmed that:

- the purpose of the interview was to evaluate the suitability of the UNISDR Scorecard to assess community resilience to an EILD event; and where necessary, to provide modified statements that better reflected the impact that each of the issues addressed by the scorecard would have in the event of an EILD event;
- the interview would be conducted under Chatham House rules where the results from the workshop would be shared but where no individual response would be attributed to any individual participating in the workshop. In other words the interview would be fully anonymized; and
- the procedure that the interview would take and established the ground rules for participation.

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The group interviews were conducted as though they were focus groups. Two interviewers carried out the group interviewers; one did the Italian participants and the other the Turkish participants. Each interviewer was a native speaker of the country in which the interviews were carried out. The interviews were conducted in the participants native language.

Both interviewers used the same standard protocol script and set of questions for the interviews. As these were focus group type interviews, the interviewer:

- kept the discussion moving;
- provided further explanations or examples in case interviewees struggled to understand or contextualise the question;
- kept the discussion focused on the topic being investigated; and
- attempted to bring everyone into the conversation.

All the discussions were recorded and then summarised by the interviewers. A summary of the major topics/comments/points discussed in each interview were reported against each question in an excel spreadsheet.

For each subject/issue the first question was an open question: ***Is this subject/issue of relevance when considering the effect of earthquake induced liquefaction on community resilience?***

Different types of answer where provided to this question based on the level of confidence the participants demonstrated. For all the subject/issues the following answers were registered:

- Yes - it is relevant in case of liquefaction and comments were provided.
- Yes no comments - it is relevant in case of liquefaction but no comments were provided.
- No - it is irrelevant in case of liquefaction.
- Yes/No - in case participants were undecided.
- No Answer - if the participants were not confident: in answering a specific subject/issue, or the entire essential; or in discussing the specific criteria in an Essential but the essential was discussed only in general terms.

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Participants who answered YES (this was a relevant subject/issue for earthquake induced liquefaction) and who felt confident to discuss the subject/issue, were asked to expand on their answer and to provide comments/explanations on whether the subject/issue, question/assessment area, indicative measurement scale, and comments contained in the UNISDR Scorecard were appropriate (in their existing UNISDR scorecard form) and able to effectively address resilience to an EILD event or whether they required amendment, either in part or in whole? Participants who thought that amendments were required were then asked to suggest modifications. After all those who wanted to express an opinion on the subject/issue had been given the opportunity to do so the interviewer moved to the next subject/issue and the process was repeated. Each group interview last about three hours.

3.4.3 Analysis of interview responses

Analysis of the interview responses was carried out at two levels by three independent researchers. For each subject/issue an analysis was carried out on the results of the first question: ***Is this subject/issue of relevance when considering the effect of earthquake induced liquefaction on community resilience?*** Whilst it was acknowledged that this is an insubstantial metric; it did provide a screening tool to assess the relevance of the subject/issue to an EILD events. It also allowed an assessment of any difference in relevance found between the interview groups. This analysis also allowed the identification of those subject/issues that were clearly relevant or clearly not relevant in the case of an EILD event. Those that were identified as definitely relevant and should be considered in the EILD customised scorecard; those which were definitely not relevant and would require no specific consideration from an EILD perspective in the customised scorecard. The following criteria was used to evaluate importance:

- If more than 50% of groups identified an issue "Yes or Yes no comments" it was considered relevant and should be included in the final EILD customised score card.
- If between 40%-49% of groups identified an issue "Yes + Yes no comments" it was considered not relevant but requiring further consideration before a decision was made to include or remove it from the final EILD customised scorecard.
- If more than 50% of groups identified an issue "No" it was considered not relevant and should be removed from the final EILD customised scorecard.
- If between 40% and 49% of groups identified an issue "No" it was considered not relevant but requiring further consideration before a decision was made to remove

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it from the final EILD scorecard. This further consideration sought to examine the degree of confidence demonstrated by the group in answering this specific issue.

- "No Answer" was greater 50%, more than 50% of the interviewees were not confident in answering a specific criterion.
- "No Answer" was equal to 50%, 50% of the interviewees were not confident in answering a specific criterion.

An analysis of the responses from all 12 groups identified all the subject/issues for Essentials 1, 2, 3, 4, 7, 8, 9, and 10 as relevant when evaluating community resilience to an EILD event Table 3.6. As such all the subject/issues would need to be considered in the EILD customised UNISDR Disaster Resilience for Cities scorecard. The subject/issues for Essential 6 were inconclusive and as such these should be considered for inclusion in the EILD customised UNISDR disaster resilience cities Scorecard.

The above said, it should be noted that when the same analysis was carried out for the two subgroupings significant differences were observed between the relevance rankings given by the LIQUEFACT partners/ Italian external stakeholder groups and those given by the Turkish external stakeholder groups. The Turkish external stakeholder groups rated all the criterion/issues as relevant.

Table 3.6: Table showing the guidance on the relevance of each subject/issue for inclusion or rejection from the UNISDR Disaster Resilience Scorecard for Cities when considering community resilience to EILD events.

Essential	Include Definitely	Include Maybe	Reject Definitely
1	1.1.1, 1.1.2, 1.1.3, 1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.3.1, 1.4.1		
2	2.1.1, 2.2.1, 2.2.2, 2.3.1, 2.4.1	2.5.1	
3		3.1.1, 3.2.1, 3.2.2, 3.2.3, 3.2.4, 3.3.1, 3.3.2, 3.4.1, 3.4.2, 3.4.3	
4	4.1.2, 4.1.2.1, 4.1.3, 4.2.1, 4.3.1, 4.3.2, 4.4.1, 4.4.2		4.1.1, 4.3.3
6		6.1.2, 6.1.3, 6.1.4	6.1.1, 6.2.1.1, 6.3.1, 6.3.2, 6.4.1, 6.4.1.1, 6.4.2, 6.5.1, 6.6.1
7		7.1.1, 7.1.2, 7.1.2.1, 7.2.1, 7.2.2, 7.3.1, 7.3.2, 7.4.1, 7.4.2, 7.4.3	

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8 (only ?? considered	8.1.1, 8.1.2	8.2.1, 8.2.2, 8.2.3, 8.3.1, 8.3.2, 8.3.3, 8.4.1, 8.4.2, 8.4.3, 8.4.4, 8.5.1, 8.5.2, 8.5.3, 8.5.4, 8.5.5, 8.5.6, 8.5.7, 8.6.1, 8.6.2, 8.6.3, 8.7.1, 8.7.2, 8.7.3, 8.8.1, 8.8.2, 8.8.3, 8.9.1, 8.10.1, 8.11.1, 8.14.4.1, 4.4.21.2, 8.11.3	
9		9.1.1, 9.1.1.1, 9.2.1, 9.3.1, 9.3.2, 9.4.1, 9.4.1.1, 9.5.1, 9.5.2, 9.5.2.1, 9.5.3, 9.5.4, 9.6.1, 9.6.2, 9.6.3, 9.7.1, 9.7.2	
10		10.1.1, 10.1.2, 10.1.3, 10.2.1	

Note: there were NO Reject Maybe subjects/issues.

The following sections present a summary of the key comments made by the stakeholder groups for each Essential along with detailed additional guidance when considering the impact of EILD events of community resilience.

Essential 1: Organise for Resilience

This Essential was about municipalities organising themselves for resilience; be that from local to national levels. There was a wide range of opinions expressed by the respondents as well as a general feeling of ambivalence towards how to implement this Essential into the LIQUEFACT scorecard. There was some agreement that long term planning is needed but that it requires large financial commitments to enact. There were a few mentions of working with other organisations but too few communication practises currently being put into place to support this. Specific comments made by the groups for each subject/issue comprising Essential 1 are summarised in Table 3.7.

Table 3.7: Specific comments to ensure that EILD events are fully considered in Essential 1: Organise for Resilience

Subject/Issue	Relevance Score	EILD Specific Comments
Risk Consideration in Plan Making	1.0	Plan making needs to include an assessment of the risk of liquefaction using macrozonation maps supplemented with micro-zonation studies and site-specific vulnerability analyses, particularly for key elements of critical infrastructure.
Consultation in plan making	1.0	Consultation needs to include geotechnical associations/engineers who can provide specific advice on liquefaction.

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Review of strategic plans	0.917	Whilst there is a need to review the strategic plan for EILD events the suggested time period of three years is too short. Strategic plan should be reviewed as more detailed macro zonation/micro-zonation studies become available and level of knowledge of liquefaction improves.
Pre-event planning and preparation	0.917	No specific additional (beyond that undertaken general earthquake disasters) planning should be required for EILD events except for assessing the liquefaction impacts on key elements of critical infrastructure.
Coordination of event response	0.792	No specific additional (beyond that undertaken general earthquake disasters) coordination should be required for EILD events except for assessing the liquefaction impacts on key elements of critical infrastructure.
City resources for managing preservation, ordination and participation	0.875	No specific additional (beyond that undertaken general earthquake disasters) consideration should be required for EILD events except for ensuring that those responsible are aware of the liquefaction phenomenon.
Identification of physical contributions	0.792	No specific additional (beyond that undertaken general earthquake disasters) physical contribution should be required for EILD events.
Integration of disaster resilience with other initiatives	0.958	It is important that the impacts of an EILD event on initiatives/projects are evaluated, particularly for critical infrastructure, and that micro-zonation studies and/or site-specific vulnerability analyses are budgeted for.
Extent to which data on the city's resilience position is shared with other organisations involved with the city's resilience	0.833	It is important that micro-zonation studies are made widely available so that other organisations can assess their level of risk to a potential EILD event.

Essential 2: Identify, Understand and use Current and Future Risk Scenarios

This Essential is about adopting future risk scenarios to improve resilience. There were a range of different ideas between the groups and a few contradicting concepts. It was clear that the stakeholders all felt that vulnerabilities are far-reaching and that social factors need consideration (although there was not much knowledge in this area in these stakeholders). Many respondents felt that vulnerabilities need to be considered at a local level. Specific comments made by the groups for each subject/issue comprising Essential 2 are summarised in Table 3.8.

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Table 3.8: Specific comments to ensure that EILD events are fully considered in Essential 2: Understand and use Current and Future Risk Scenarios

Subject/Issue	Relevance Score	EILD Specific Comments
Knowledge of hazards (also called perils, or shocks and stresses) that the city faces, and their likelihood	1.0	Identifying a most severe and most probable liquefaction scenario is very difficult as it requires a combination of an earthquake event and susceptible ground profile. Reference should be made to macro zonation and micro-zonation maps and liquefaction specific diagnostic tools should be used to identify areas at risk. These areas should then be examined in more detail through the use of in-depth tests and specialised expertise. The LRG software can support these type of assessment.
Knowledge of exposure and vulnerability	0.958	Detailed microzonation studies supplemented with site-specific ground investigations should be performed to identify potentially liquefiable soils and to calculate the impact, through the use of fragility curves generated from a range of earthquake scenarios, on built assets. The LRG software can support these types of assessment.
Damage and loss estimation	0.792	Knowledge of exposure and vulnerability to an EILD event should be calculated for each of the cities subsystems (e.g. critical infrastructure, large-scale housing, key business areas etc.) and these analyses used to estimate damage and loss. The LRG software and RAIF can support these types of assessment.
Understanding of critical assets and the linkages between these	0.833	The exposure and vulnerability of each critical infrastructure subsystem needs to be analysed and its interdependency on other subsystems needs to be established. The RAIF can support these types of assessment.
Hazard maps	0.75	Micro-zonation studies supported by liquefaction specific diagnostic analysis should be undertaken.
Update process	0.625	Whilst regular updating processes for an EILD event is important, the three year time period suggested in the scorecard is too short. Updating should take place as and when new micro-zonation studies become available.

Essential 3: Strengthen Financial Capacity for Resilience

Most interviewees did not feel confident in discussing this section. There was a consensus that liquefaction needs to be considered as part of a general assessment of resilience to earthquake events at both local and national levels and for the need to generally strengthen financial capacity for resilience to natural disasters. Specific comments made by the groups for each subject/issue comprising Essential 3 are summarised in Table 3.9.

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Table 3.9: Specific comments to ensure that EILD events are fully considered in Essential 3: Strengthen Financial Capacity for Resilience

Subject/Issue	Relevance Score	EILD Specific Comments
Awareness and knowledge of all possible methods of financing and funding, as required The city is actively pursuing financing and funding, as required Note: If sufficient funds exist these assessment criteria can be omitted	0.583	Predicting the costs associated with an EILD event is very difficult but additional funding, on and above that required to deal with the impacts of earthquake ground shaking is required. The LRG software can provide a high-level assessment of the costs of an EILD event. The city needs to ensure that these costs are covered in the disaster funding plans.
Adequacy of financial planning for all actions necessary for disaster resilience	0.583	Specific funding, on an above that for general earthquake resilience, should be identified to improve the resilience of any critical infrastructure assets that have been identified at risk from an EILD event.
Capital funding for long run engineering and other works that address scenarios and critical assets identified in Essentials 2 and Essential 8	0.417	Specific funding, on an above that for general earthquake resilience, should be identified to improve the resilience of any critical infrastructure assets that have been identified at risk from an EILD event.
Operating funding to meet all operating costs of disaster resilience activities	0.5	Specific funding, on an above that for general earthquake resilience, should be identified to improve the resilience of any critical infrastructure assets that have been identified at risk from an EILD event.
Contingency fund(s) for post disaster recovery (may be referred	0.5	No additional specific issues required (assuming that liquefaction is included as part of general earthquake recovery).

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to as a "rainy-day fund")		
Domestic insurance coverage	0.5	No additional specific issues required (assuming liquefaction is covered by existing insurance)
Non-domestic insurance coverage	0.5	No additional specific issues required (assuming liquefaction is covered by existing insurance)
Incentives to businesses organizations to improve disaster resilience – disaster plans, premises etc	0.583	No additional specific issues required (assuming that liquefaction is considered part of an organisation's general earthquake disaster planning).
Incentives to non-profit organizations to improve disaster resilience – disaster plans, premises etc	0.5	No additional specific issues required (assuming that liquefaction is considered part of an organisation's general earthquake disaster planning).
Incentives to homeowners to improve disaster resilience – disaster plans, premises, etc.	0.583	No additional specific issues required (assuming that liquefaction is considered part of a homeowners general earthquake disaster planning).

Essential 4: Pursue Resilient Urban Development

There was much ambiguity about what was currently being provided to support the pursuit of resilient urban development. However, the groups all agreed on the general importance of implementing resilient urban developments and that regulations, although not fully efficient, were beginning to support this. Specific comments made by the groups for each subject/issue comprising Essential 4 are summarised in Table 3.10.

Table 3.10: Specific comments to ensure that EILD events are fully considered in Essential 4: Pursue Resilient Urban Development

Subject/Issue	Relevance Score	EILD Specific Comments
Potential population displacement	0.625	No additional specific issues required (whilst liquefaction can create major damage to buildings, as it is a localised phenomenon, population displacement is not a significant issue).

Economic activity at risk - % of employment at risk	0.75	No additional specific issues required for % employment at risk (assuming that vulnerability, exposure, damage and loss calculations have been undertaken as part of Essential 2).
Economic activity at risk - % of business output at risk	0.75	No additional specific issues required for either % of business output at risk (assuming that vulnerability, exposure, damage and loss calculations have been undertaken as part of Essential 2).
Agricultural land at risk	0.667	No additional specific issues required (assuming that vulnerability, exposure, damage and loss calculations have been undertaken as part of Essential 2).
Urban design solution that increase resilience	0.917	Liquefaction is primarily a localised phenomenon and as such design solutions need to be at a local scale. Mitigation techniques should be assessed at a local scale.
Existence of building codes designed to address risk identified in Essential 2	0.917	Ensure that local, national and/or international building codes and guidance address earthquake induced liquefaction.
Updates to building codes	0.833	No additional specific issues required.
Sustainable building design standards	0	No additional specific issues required (not relevant to an EILD event).
Application of land use zoning	0.75	Ensure that land use zones reflect the results of micro-zonation studies where available.
Application of building codes	0.625	Ensure that the local, national and/or international building codes and guidance address earthquake induced liquefaction.

Essential 5: Safeguard Natural Buffers to Enhance the Protective Functions Offered by Natural Ecosystems

This essential was deemed not applicable to an EILD event and as such did not form part of the group interview process.

Essential 6: Strengthen Institutional Capacity for Resilience

Respondents felt that many of the subjects/issues were not directly relevant or applicable to liquefaction. Most of the respondents agree that institutional capacity for resilience needs to be strengthened but did not offer suggestions as to how this could be achieved. Additionally, insurance was identified as an important issue that has not generally received enough consideration. Specific comments made by the groups for each subject/issue comprising Essential 6 are summarised in Table 3.11.

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Table 3.11: Specific comments to ensure that EILD events are fully considered in Essential 6: Strengthen Institutional Capacity for Resilience

Subject/Issue	Relevance Score	EILD Specific Comments
Availability of skills and experience in disaster resilience - risk identification mitigation, planning, response and post even response	0.5	No additional specific issues required.
Private sector links	0.583	No additional specific issues required.
Engagement of insurance sector	0.583	No additional specific issues required (assuming that liquefaction is covered under general earthquake insurance).
Civil society links	0.625	No additional specific issues required.
Exposure of public to education and awareness materials/messaging -Coordinated public relations and education campaign exists, with structured messaging, channels, and delivery	0.583	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).
Exposure of public to education and awareness materials/messaging - Exposures per member of public, per month to messaging	0.5	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).
Extent to which data on the city resilience position is shared with other organizations involved with the city's resilience	0.5	No additional specific issues required
Extent to which data on the city resilience position is shared with community	0.5	No additional specific issues required

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organizations and public		
Availability of take-up of training focussed on Risk and Resilience (Professional Training) - Training offered and available to resilience professionals (from government, voluntary or other sources)	0.583	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).
Availability of take-up of training focussed on Risk and Resilience (Professional Training) - % of population trained in last year	0.583	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).
System/process for updating relevant training	0.542	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).
Accessibility of education and training to all linguistic groups in the city - % of population trained in last year	0.542	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials
Effort taken to learn from what other cities, states and countries (and companies) do to increase resilience	0.583	No additional specific issues required (assuming that liquefaction is part of the learning process).

Essential 7: Understand and Strengthen Societal Capacity for Resilience

This Essential is about developing and understanding the societal capacity for resilience to ensure that it can be strengthened in preparation for a disaster. Most respondents felt that this subject/issue was not directly relevant to liquefaction. One interviewee group did identify business continuity planning as important but did not elaborate on how this will be done. Specific comments made by the groups for each subject/issue comprising Essential 7 are summarised in Table 3.12.

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Table 3.12: Specific comments to ensure that EILD events are fully considered in Essential 7: Understand and Strengthen Societal Capacity for Resilience

Subject/Issue	Relevance Score	EILD Specific Comments
Coverage of community or "grass roots" organization(s) throughout the city	0.5	No additional specific issues required.
Effectiveness of community network - Community organization meeting frequency and attendance	0.5	No additional specific issues required.
Effectiveness of community network - Clear identification and coordination of pre post-event roles for communities bodies, supports by training. Roles screed and signed off, preferably via MOU or similar.	0.5	No additional specific issues required.
Social connectedness and neighbourhood cohesion	0.5	No additional specific issues required.
Engagement with vulnerable groups of population	0.5	No additional specific issues required.
Extent to which employers act as a channel with employees	0.2	No additional specific issues required.
Business Continuity Planning	0.5	No additional specific issues required (assuming liquefaction is covered as part of business continuity planning).

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Frequency of engagement	0.5	No additional specific issues required.
Use of mobile and e-mail "systems of engagement" to enable citizens to receive and give updates before and after disasters	0.5	No additional specific issues required.
Validation of effectiveness of education	0.5	No additional specific issues required (assuming that liquefaction is part of the education process).

Essential 8: Increase Infrastructure Resilience

This essential will be replaced with a specific critical infrastructure scorecard that provides a more detailed analysis of each critical infrastructure type. The first two subject/issues were explored in the group interviews as they provide a strategic level assessment of protective infrastructure. Specific comments made by the groups for each subject/issue comprising Essential 8 are summarised in Table 3.13.

Table 3.13: Specific comments to ensure that EILD events are fully considered in Essential 8: Increase Infrastructure Resilience

Subject/Issue	Relevance Score	EILD Specific Comments
Adequacy of protective infrastructure	0.833	Need to assess the degree to which ground improvements mitigations to reduce earthquake induced liquefaction can be provided for key elements of critical infrastructure (e.g. transportation embankments and bridges, dams, critical buildings, etc.). Detailed analysis of mitigation options will form part of the critical infrastructure resilience scorecard
Effectiveness of maintenance	0.833	No additional specific issues required (assuming that any mitigation measures identified above also include routine inspection and maintenance).

Essential 9: Ensure Effective Disaster Response

Most respondents did not think that this was directly relevant to liquefaction. One interviewee group discussed the need for an early warning system for liquefaction but did not expand on how this could be achieved. Specific comments made by the groups for each subject/issue comprising Essential 9 are summarised in Table 3.14.

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Table 3.14: Specific comments to ensure that EILD events are fully considered in Essential 9: Ensure Effective Disaster Response

Subject/Issue	Relevance Score	EILD Specific Comments
Existence and effectiveness of early warning system - Length and reliability of warning - enabling practical action to be taken	0.5	No additional specific issues required (assuming that any early warning systems that exist for earthquakes include EILD events).
Existence and effectiveness of early warning system - Will 100% of population receive it?	0.5	No additional specific issues required (assuming that any early warning systems that exist for earthquakes include EILD events).
Existence of emergency response plans that integrate professional responders and community organizations (For post-event response - see Essential 10)	0.5	No additional specific issues required.
"Surge" Capacity of police also to support first responder duties	0.2	No additional specific issues required.
Definition of other first responder and other staffing needs, and availability	0.5	No additional specific issues required.
Definition of equipment and supply needs and availability of equipment - Equipment and supply needs are defined for "most		No additional specific issues required.

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probable" and "most severe" scenarios in Essential 2		
Definition of equipment and supply needs and availability of equipment - Estimated shortfall in available equipment per defined needs potentially rom multiple sources. MOUs exist for mutual aid agreements with other cities, and also for private sector sources	0.5	No additional specific issues required.
Likely ability to continue feed the population	0.5	No additional specific issues required.
Likely ability to meet needs for shelter/safe places - "Shelter gap" - number of displaced persons minus shelter places available within 24 hours	0.5	Ensure that EILD losses are included in earthquake loss assessments.
Likely ability to meet needs for shelter/safe places - "Shelter gap" - "Shelter gap" - ability of shelters to withstand disaster events and remain safe and usable	0.5	Ensure that EILD damage is included in assessments.
Ability to meet likely needs for staple goods	0.5	No additional specific issues required.

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Likely availability of fuel	0.5	No additional specific issues required.
Interoperability with neighbouring cities/states and other levels of government of critical systems and procedures	0.5	No additional specific issues required.
Emergency operation centre	0.5	No additional specific issues required.
Coordination of post event recovery	0.5	No additional specific issues required.
Practices and rehearsals - involving public and professionals	0.5	No additional specific issues required.
Effectiveness of drills and training	0.5	No additional specific issues required.

Essential 10: Expedite Recovery and Build Back Better

This Essential is about developing and understanding the societal capacity for resilience to ensure that it can be strengthened in preparation for a disaster. Most respondents did not think this subject/issue was directly relevant to liquefaction. One interviewee group identified the need for business continuity planning but did not elaborate on how this will be done. Specific comments made by the groups for each subject/issue comprising Essential 10 are summarised in Table 3.15.

Table 3.15: Specific comments to ensure that EILD events are fully considered in Essential 10: Expedite Recovery and Build Back Better

Subject/Issue	Relevance Score	EILD Specific Comments
Planning for post event recovery economic reboot	0.5	No additional specific issues required (assuming liquefaction assessment is included as part of an earthquake scenario).
Extent to which there has been stakeholder consultation around the "event recovery and economic reboot"	0.5	No additional specific issues required (assuming liquefaction assessment is included as part of an earthquake scenario).

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Shadow financial arrangements for processing incoming aid and disbursing funds	0.5	No additional specific issues required.
Learning loops	0.5	No additional specific issues required.

3.4.4 Discussion of the customisation procedure

Although the stakeholder groups were generally very knowledgeable about EILD events they found it difficult to identify specific issues that needed to be addressed in the UNISDR Scorecard. Participants found it difficult to identify specific EILD attributes for the general/procedural issues. This said, it is clear from the interviews that the key aspect of a city plan/resilience strategy/action plan for an EILD event revolves around those Essentials (1, 2 and 3) that collectively inform corporate/city governance. What was clear from the interviews was the need for these Essentials to explicitly address the potential risks associated with an EILD through the use of the latest macro-zonation maps, micro-zonation analyses, and site-specific investigations. The risk assessment also needs to consider the specific impacts that earthquake induced liquefaction would have on key critical assets through the use of fragility curves. The risk assessment also needs to identify the financial costs that will be needed to improve resilience of key critical assets to an EILD event and ensure that these costs can be covered through prudent financial planning. The tools being developed by the LIQUEFACT project (particularly the LRG and RAIF) should provide the basis for the above analyses.

Essentials 4, 6 and 7 which (along with Essential 8) collectively inform an integrated planning framework for a city plan/resilience strategy/action plan appear to be less influenced by the specifics of an EILD event and as such the generic indicators used by the UNISDR scorecard should cover resilience to an EILD event. Assuming that liquefaction is considered as part of the general resilience to earthquakes very little additional criteria is required to customise the scorecard for an EILD event.

The exception to the above is Essential 8, which in the opinion of the LIQUEFACT project is not detailed enough to provide meaningful assessments of the impact that an EILD event could have on the range of critical infrastructure systems that communities rely on. As such, an alternative critical infrastructure resilience scorecard has been developed in the LIQUEFACT project (see section 4) which can be integrated into the EILD customised UNISDR Scorecard to provide an overall assessment of a city/region's resilience to an EILD event.

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Essentials 9 and 10, which collectively inform the response planning framework for a city plan/resilience strategy/action plan are primarily generic and independent of a specific disaster event and as such no additional information is required to customise the for an EILD event. Again assuming that liquefaction has been recognised earlier in the scorecard as a potential sub-hazard of an earthquake event that the city/region may or may not need to address.

With regards to the appropriateness of using the UNISDR scorecard to assess community resilience to an EILD event, respondents found it very difficult (except for the technical indicators) to separate earthquake induced liquefaction from ground shaking. A number of respondents also commented on the large degree of overlap between indicators that effectively appeared in more than one Essential and they commented on the need to ensure that double (or even triple) counting doesn't occur if the scores from individual essential are aggregated to produce an 'overall' community resilience indicator.

Overall, whilst respondents had some concerns about the applicability of the scorecard to address specific liquefaction issues, and about the potential double counting of issues between essentials, they did agree that a customised version of the scorecard that included an assessment of potential impacts of earthquake induced liquefaction alongside ground shaking would provide a holistic tool to assess community resilience to an earthquake disaster event. As such, a modified version of the UNISDR Disaster Resilience Scorecard for Cities that integrates assessments of the impact of an earthquake induced liquefaction alongside that of ground shaking has been developed in the LIQUEFACT project.

3.4.5 Beta Test version of the EILD Customised Disaster Resilience Scorecard for Cities to be used in the LIQUEFACT validation process in WP7

Version 3 of the LIQUEFACT EILD Customised Disaster Resilience Scorecard for Cities that combines the additional information identified in the interviews along with suggested mitigations is shown in Table 3.16. The Customised Scorecard will be used in conjunction with an assessment of the resilience of a city/region to earthquake disasters to ensure that EILD events are properly accounted for in an earthquake city plan/resilience strategy/action plan.

The customised scorecard will be applied using the same methodology as described by the UNISDR for the application of the standard UNISDR scorecard (see https://www.unisdr.org/we/inform/publications/53349 for full implementation details.

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ESSENTIAL 1: Organise for Resilience

Table 3.16: UNISDR Disaster Resilience Scorecard for Cities Customised to include Earthquake Induced Liquefaction

Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Plan Making							
1.1.1	Risk Consideration in Plan Making	To what extent are risk factors considered within the City Vision / Strategic Plan?	5 – The plan includes a range of actions/priorities (e.g. urban growth and infrastructure projects) that directly respond to current and anticipated future risks. 4 – The plan includes a range of actions/priorities (e.g. urban growth and infrastructure projects) that directly respond to current identified risks. 3 – The plan context is framed around clear presentation of the city risk factors. 2 – A robust risk assessment methodology is integral to the city plan. 1 – There is evidence within the plan that risks (hazards x likelihood) is broadly understood within the City planning team. 0 – Risks are not considered in the plan.	Risk identification and aggregation into scenarios is considered in Essential 2. This assessment criterion (1.1.1) is aimed at the city teams involved in strategic planning / plan making. Does the plan making process use best available science and risk assessment process to inform the order, magnitude and location of major new urban growth or significant infrastructure investment? i.e. is the future spatial vision for the city informed through clear risk assessment processes.	Plan making needs to include an assessment of the risk of liquefaction using macrozonation maps supplemented with micro-zonation studies and site-specific vulnerability analyses, particularly for key elements of critical infrastructure.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - High
1.1.2	Consultation in Plan Making	Is this strategy developed through inclusive, participatory multi-stakeholder	5 – Yes – All relevant groups have been invited and attended. Stakeholders have been fully briefed on the process and receive regular bulletins on the progress of the plan. 4 – At least 8 of the 10 listed groups (right) have been engaged/consulted. 3 – At least 6 of the 10 listed groups have been	• The city emergency services; Other city services and departments (public works, transportation); • The local health sector; Utility providers including telecommunications; • Local businesses;	Consultation needs to include geotechnical associations engineers who can provide specific advice on liquefaction.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			engaged / consulted. 2 – At least 4 of the listed groups have been engaged / consulted. 1 – At least 2 of the listed groups were invited. 0 – Stakeholder engagement has been undertaken.	• NGOs; • Civil society organisations including minority group representation; • Environmental sector; • The wider city population in all neighbourhoods, both formal and informal community groups; • Local universities; • Scientific institutions; Other tiers of government or neighbouring cities, where necessary for the city's resilience; • Industry associations.			
1.1.3	Review of strategic plans	Is the city strategic plan reviewed on a regular basis?	5 – The plan has already been reviewed and there is a published commitment to review the plan at least every 3 years. The plan update process (including capturing lessons learned) is detailed in the plan and stakeholders are clear how they can inform the plan update process. 4 – The plan has already been reviewed and there is a published commitment to review the plan at least every 3 years. Clear processes have been instigated to capture lessons learnt and to ensure these lessons inform plan updates. 3 – The plan has already been reviewed and updated and there is a published commitment to ongoing / regular review (at least every 3 years). 2 – No review has taken place but there is a commitment to undertake a review every 5 years. 1 – No review has happened yet, but a review is		Whilst there is a need to review the strategic plan for EILD events the suggested time period of three years is too short. Strategic plan should be reviewed as more detailed macrozonation / micro-zonation studies become available.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			assumed. No timescale has been set out. The commitment to review is not published. 0 – No review has been undertaken and there are no plans to undertake a review.				
Organisation, Participation and Coordination							
1.2.1	Pre-event planning and preparation	Co-ordination of all relevant prevent planning and preparation activities exists for the city's area, with clarity of roles and accountability across all relevant organizations.	5 - There is a clear coordination of all relevant pre-event planning and preparation activities. All roles and accountability are clearly defined between relevant organizations. 4 - There is some coordination of pre-event planning and preparation in the city. However, overlapping roles exist and accountability is not clearly defined. 3 - The city (or focal point/institution) is currently in process of coordination of pre-event and planning activities, which will clearly identify roles and accountability among relevant organizations. 2 - Coordination of pre-event planning and preparation activities not sufficient. No clear identification of roles and accountability among relevant organizations. 1 - The city is currently discussing to start a process to coordinate all pre-event planning and activities. 0- There are currently no plans to coordinate pre-event and planning activities.	The single point of co-ordination may be a person, or a group or committee (with sub-groups or committees as appropriate). It will coordinate the relevant (see below) activities of: • The city government and, if separate, highways, police, armed forces/civil defence, water, energy, or any other relevant city organizations); • Other tiers of government (e.g. state, ward-level) or neighbouring municipalities); • Private sectors organizations with relevant roles – for example, utilities, phone companies, healthcare, logistics companies, fuel depots, property companies and other relevant organisations. Some cities may have different organizational arrangements for different types of disaster. However, these need at least to work through the same coordination point (person or committee) to ensure consistency in response arrangements; and also to enable management of simultaneous disasters as	No specific additional (beyond that undertaken general earthquake disasters) planning should be required for EILD events except for assessing the liquefaction impacts on key elements of critical infrastructure.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
				applicable. The test of relevance is whether the organization or activity must contribute in any way to preparing for the event scenarios covered below in Essential 2.Coordination of data and systems is covered in Essential 6.			
1.2.2	Coordination of event response	Coordination of all relevant event response activities in the city's area, with clarity of roles and accountability across all relevant organizations	5 - There is a clear coordination of all relevant response activities. All roles and accountability are clearly defined between relevant organizations. 4 - There is some coordination of response activities in the city. However, overlapping roles exist and accountability is not clearly defined. 3 - Coordination of response activities is not sufficient. There is currently no clear identification of roles and accountability among relevant organizations in the city. 2 - The city (or focal point/institution) is currently in process of coordination of response activities, which will clearly identify roles and accountability among relevant organizations. 1 - The city is currently discussing to start a process to coordinate all response activities. 0 - There are currently no plans to coordinate response activities.	See guidance above. Event response coordination arrangements should be regularly tested, if not by real events, at least in simulation exercises - see Essential 9. Coordination of data and systems is covered in Essential 6	No specific additional (beyond that undertaken general earthquake disasters) coordination should be required for EILD events except for assessing the liquefaction impacts on key elements of critical infrastructure.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
1.2.3	City resources for managing organisation, coordination and participation	Ability of the city government to play the critical convening and plan making role for DRR. Do the city	5 – Yes – all lead agency teams are well established properly resourced / funded and have authority to act across all DRR stages – pre, event response and post disaster. 4 – Yes – all lead agency teams are well	It is assumed these assessment criteria most relevant to the city government, but could be applied to other agencies if they take the lead organisational / convening role for DRR. Support can be co-opted (1.2.5) from	No specific additional (beyond that undertaken general earthquake disasters) consideration should be required for EILD events	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low

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Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
		and or other lead agencies have the authority and resources to deliver on their DRR commitments? This assessment criteria relating to resources and funding should be considered for pre-event planning (1.2.1), event response (1.2.2) and post event (1.2.6 together).	established properly resourced / funded and have authority to act, but there is inconsistency in resourcing across the key DRR stages. 3 – City teams have authority, convening power and resource / funding but they do not have proper inter-agency support. 2 – City / lead agencies have authority but are under resourced. They co-opt support with some success. 1 – City / lead agencies have authority but are under resourced. 0 – No. Lead agencies lack proper authority and are under resourced	public and private sectors – this question relates specifically to resource and authority to plan and coordinate activities.	except for ensuring that those responsible are aware of the liquefaction phenomenon.	0 [ ]	LIQUEFACT Score – High
1.2.4	Identification of physical contributions	Co-option of physical contributions by both public and private sectors. Identification of physical contributions for each major organization.	5 – All key contributions fully defined for pre and post-event, underwritten by MOUs. 4 – Most key contributions defined – some minor gaps in coverage. MOUs may not exist. 3 – Some contributions formally defined but full leverage of private sector yet to be achieved. 2 – One or two contributions defined for specific areas – perhaps via informal agreements. 1 – Plans being developed to seek contributions. 0 – No private sector.	Physical contributions refer to plant and equipment, people, premises and accommodation, supplies, data, computer systems, and so on. These will supplement those provided by the city and may come from other agencies or from private sector organizations such as those defined above. The key is to have a clear view of what will be needed to supplement the city's own resources (defined in Essential 9); and then to enter into explicit MOUs with the organizations that will supply those items. Note that the city may also receive contributions to support plan making and risk reduction – see 1.1 above.	No specific additional (beyond that undertaken general earthquake disasters) physical contribution should be required for EILD events.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Integration							
1.3.1	Integration of disaster resilience with other initiatives	Extent to which any proposal in government is also evaluated for disaster resilience benefits or impairments. Explicit stage in policy and budget approval process where disaster resilience side benefits, or impairments, of any city government initiative are identified and counted towards the Return on Investment (ROI) for that proposal.	5 – Explicit decision step, applied to all policy and budget proposals in all relevant functional areas. 4 – Explicit or semi-explicit decision step, applied in most cases and in most functional areas. 3 – No formal process, but disaster resilience benefits are generally understood to be "helpful" to a proposal, in most functional areas. 2 – Decision step sometimes applied, but very likely to be overlooked in most functional areas if a proposal would impair disaster resilience. 1 – Applied ad hoc or occasionally. 0 – Not applied	For example: • Traffic management systems may also help with evacuation, so increasing disaster resilience; • A development approval may locate people in harm's way; • A land use change may reduce benefit of wetlands in preventing floods. Includes, but not restricted to, the functional areas of: land use and zoning; development; water, energy; public safety; transportation; food supply; healthcare.	It is important the impacts of an EILD event on initiatives/projects are evaluated, particularly for critical infrastructure, and that micro-zonation studies and/or site-specific vulnerability analyses are budgeted for.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High
Data Capture, Publication and Sharing							
1.4.1	Extent to which data on the city's resilience position is shared with other organizations involved in city's resilience	Availability of a single "version of the truth" – a single integrated set of resilience data for practitioners.	5 – Full availability of the information listed at right on readiness and risk; fully shared with other organizations. 4 – Some minor gaps, or the information is in more than one place – but it is shared and it is at least linked to enable navigation. 3 – Some more significant gaps, for example on readiness; other organizations may have to "hunt around" to create a complete picture for themselves.	Information to consider making open for public access might include: • A summary of readiness; • The outcomes of this Scorecard; • An explanation of the hazards and perils that the city is thought to face, and probabilities; • A hazard-map based summary (see Essential 2) of at-risk areas;	It is important that micro-zonation studies are made widely available so that other organisations can assess their level of risk to a potential EILD event.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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			2 – Some significant information on readiness and risk is withheld from other organizations or is missing and/or badly fragmented across multiple websites. 1 – Information provision to other organizations on readiness and risk is rudimentary at best. Not possible to for those organizations to derive specific conclusions for themselves. 0 – No information.	• A description of what building codes will protect against, and where these have been applied; • A full set of disaster response plans and known issues; • Key roles and accountabilities; • Planned investments that will affect the city's resilience position; • Further resources and contact details."			

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ESSENTIAL 2: Identify, Understand and use Current and Future Risk Scenarios

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Hazard Assessment							
2.1.1	Knowledge of hazards (also called perils, or shocks and stresses) that the city faces, and their likelihood	Existence of recent, expert-reviewed estimates of probability of known hazards or perils and their extents.	5 – Comprehensive estimates exist, were updated in last 3 years and reviewed by a 3rd party. "Most severe" and "most probable" hazards are generally accepted as such. 4 – Estimates exist but have minor shortcomings in terms of when updated, level of review, or level of acceptance. 3 – Estimates exist but with more significant shortcomings in terms of when updated and level of review or acceptance. 2 – Some estimates exist but are not comprehensive; or are comprehensive but more than 3 years old; or are not reviewed by a 3rd party. 1 – Only a generalized notion of hazards, with no attempt systematically to identify probability. 0 – No estimates. Note: Use of the UNISDR Quick Risk Estimator Tool (QRE) can support assessment against these criteria.	Cities need to have a view of the hazards or perils that they face – what specific hazards (tsunami, hurricane, earthquake, flood, fire etc.) exist and how severe might they be? For each hazard there needs to be identified, as a minimum: • A "most probable" incident; • A "most severe" incident. Hazards may be identified from probability distributions, specifically conducted for the purpose of assessing disaster resilience: "most probable" would be at the midpoint of the range of hazards that need to be addressed and "most severe" would be from the top 10% of the probability range. Alternatively, they may be approximated from such sources as: • General hazard assessments for the region; • Assumptions created as an input to land zoning, planning discussions or permitting; • Insurance industry risk assessments; • Expert opinion as to "typical" hazards; • Prior experience or historical records of disasters in the region.	Identifying a most probable and most severe liquefaction scenario is very difficult as it requires a combination of an earthquake event and a susceptible ground profile. Reference should be made to macro zonation and micro-zonation maps and liquefaction specific diagnostic tools should be used to identify areas that risk. These areas should then be examined in more detail through the use of in-depth tests and specialised expertise. The LRG software can support these type of assessment.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - High

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				However, if these levels of knowledge are not available, cities should still try to assemble a picture from prior experiences and/or estimation of the general level of hazard that they face. Sophisticated cities may also attempt to estimate the impact of multiple consecutive smaller hazards, or combinations of hazards (a hurricane and accompanying storm surge, for example).It is important to note that hazards may change over time as a consequence of urbanization and land use (for example where deforestation increases propensity for flash flooding), climate change (for example, changing rainfall or storm patterns), or better knowledge (for example, understanding of seismic threats or likely storm tracks). Thus, hazard estimates need to be updated regularly (See 2.5).			
Knowledge of Exposure and Consequences							
2.2.1	Knowledge of exposure and vulnerability	Existence of scenarios setting out city-wide exposure and vulnerability from each hazard level (see above).	5 – Comprehensive scenarios exist city-wide, for the "most probable" and "most severe" incidence of each hazard, updated in last 18 months and reviewed by a 3rd party. 4 – Scenarios have minor shortcomings in terms of coverage, when updated, level or thoroughness of review. 3 – Scenarios have more significant shortcomings in terms of coverage, when	Exposure may be thought of as who or what (people, land, ecosystems, crops, assets, infrastructure, economic activity) is potentially in harm's way as a result of a hazard. Vulnerability may be thought of as the potential consequences of that exposure (loss of life, property or service; physical damage; health impact, economic impact; environmental impact and so on).	Detailed microzonation studies supplemented with site-specific ground investigations should be performed to identify potentially liquefiable soils and to calculate the impact, through the use of fragility curves generated from a	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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			updated, level of review, thoroughness. 2 – Partial scenarios exist but are not comprehensive or complete; and/or are more than 18 months old; and/or are not reviewed by a 3rd party. 1 – Only a generalized notion of exposure and vulnerability, with no attempt systematically to identify impacts. 0 – No risk assessment. Note: Use of the UNISDR Quick Risk Estimator Tool (QRE) can support assessment against these criteria.	Different exposures and/or vulnerabilities may combine, for example where the tsunami generated by the Tohoku earthquake in Japan in 2011 (also known as the Great East Japan Earthquake) badly damaged the Fukushima nuclear power plant – generating a whole additional set of exposures and vulnerabilities. Exposures and vulnerabilities may be assessed from sources such as regional flood maps or earthquake hazard maps, or from expert estimation. Hazards, exposures and vulnerabilities need to be assembled into "scenarios". Scenarios are comprehensive pictures of the total impact of the hazard (if any) across all neighbourhoods and all aspects of the city, and will include: • Exposure and vulnerability of neighbourhoods and economic zones; • Exposure and vulnerability of critical infrastructure items, with and without alternatives (see below); • Benefit from, and status of ecosystem services, where applicable; • Estimates of recovery time, given estimated benefit of mitigation measures, if any. Scenarios will ideally have been for reviewed for thoroughness and plausibility by a 3rd party and updated in last 18	range of earthquake scenarios, on built assets. The LRG software can support these types of assessment.		

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				months. This is more frequently than the reviews of hazards, above, as land use and development that may affect exposure and vulnerability happens on a faster time-scale.			
2.2.2	Damage and loss estimation	Do risk assessments identify business output and employment at risk, populations at risk of displacement, housing at risk, agricultural land and ecosystems at risk, cultural heritage at risk for key identified scenarios?	5 – Risk assessments identify multiple risk points including socio-economic, spatial and physical, and environmental assets at risk from "most probable" scenario in current development and future urban and population growth; any knowledge gaps and uncertainties are summarized and made explicit. 4 – Risk assessments identify multiple risk points according to current urban development. 3 – Risk assessments focus mostly on spatial, physical assets at risk. Data is limited in sector/subject areas. 2 – Risk assessments currently focus mostly on spatial, physical assets at risk. There are plans to update risk assessments once other data is available. 1 – There are plans to develop risk assessments to identify on all sectors/subjects at risk. 0 – Risk assessments do not identify all risk areas and there are no plans to update them as such.		Knowledge of exposure and vulnerability to an EILD event should be calculated for each of the cities subsystem (e.g. critical infrastructure, large-scale housing, key business areas etc.) and these analyses used to estimate damage and loss. The LRG software and RAIF can support these types of assessment.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
Cascading Impacts or Interdependencies							
2.3.1	Understanding of critical assets and the linkages between these	All critical assets are identified (see Essential 8) and relationships	5 – Critical assets are identified city-wide and systematically linked into failure chains as applicable. The city and appropriate partners have a retrofit and triage strategy that allows it	As identified above, critical assets are equipment, facilities, infrastructure or computer systems/data that are critical to the functioning of the city, maintenance of	The exposure and vulnerability of each critical infrastructure subsystem needs to be analysed and its	5 [ ] 4 [ ] 3 [ ] 2 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low

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		between them are identified in the form of potential "failure chains". This is used to frame disaster plans and triage (se Essential 9) and also retrofits and upgrades to improve the capability of the infrastructure to withstand disasters.	to prioritize upgrades and repairs. 4 – Critical assets and failure chains are generally identified with some minor gaps and omissions. A retrofit and triage strategy exists but it may also have gaps. 3 –5 – Critical assets and failure chains identified to some degree but some significant known omissions. 2 – Critical assets are identified but failure chains are not. No triage or strategy is therefore possible and retrofits are prioritised, if they happen at all, by individual city departments. 1 – Identification of critical assets is patchy at best – significant gaps exist by area, or by infrastructure system. No triage strategy. 0 – No identification of critical assets	public safety or disaster response. While many cities will identify these, at least to some degree it is much rarer to identify how they are linked and the "failure chains" that may exist. A failure chain is a set of linked failures spanning critical assets in multiple infrastructure systems in the city. As an example – loss of an electricity substation may stop a water treatment plant from functioning; this may stop a hospital from functioning; and this in turn may mean that much of the city's kidney dialysis capability (say) is lost. This is a failure chain that spans energy, water and healthcare systems. The following ISO 37120 indicators, especially where mapped spatially, can be helpful to understand the city baseline, and to potential cascading impacts: • ISO 37120 indicator 7.2. Electrical connectivity; • ISO 37120 indicator 21.1. Potable Water Supply; • ISO 37120 indicator 21.3. Sanitation; • ISO 37120 indicator 15.1. Informal Settlement; • ISO 37120 indicator 19.1. Quantifies extent to which the natural environment has been protected and maintained;	interdependency on other subsystems needs to be established. The RAIF can support these types of assessment.	1 [ ] 0 [ ]	[ ] Low LIQUEFACT Score – High

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				• ISO 37120 indicator 19.2. Trees Planted			
Hazard Maps							
2.4.1	Hazard maps	Presence of hazard maps (for example, flood or seismic risk maps).	5- Hazard maps for current urban development and future urban growth are developed based on available risk- assessments. Relevant guidelines exist including multiple benefits of tackling cross cutting issues in an integrated way (such as benefits of addressing adaptation, mitigation interface opportunities within (built environment). 4 – Hazard maps exist for current urban development and relevant guidelines exist. 3- Hazard maps are available for current urban development but there are no guidelines to guide risk sensitive urban planning and development. 2- Hazard maps and relevant guidelines to guide risk sensitive urban planning and development are currently being developed. 1 – There are plans to develop hazard maps and relevant guidelines to guide risk-sensitive urban planning and development. 0 – There are no plans to develop hazard maps and / or relevant guidelines to guide risk-sensitive urban planning and development.	For availability / access and publication of hazard, vulnerability and risk maps to other organizations and to the public – see Essential 1. Training in risk, vulnerability and exposure see Essential 6. Note that cities may wish to think about the frequency of updates to risk maps. Urban conditions and risks frequently vary. Smart sensing and controls are shifting focus towards more dynamic updating of hazard maps.	Micro-zonation studies supported by liquefaction specific diagnostic analysis should be undertaken.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
Updating of Scenario, Risk, Vulnerability and Exposure Information							
2.5.1	Update process	Process ensuring frequent and complete updates of scenarios.	5 – Update processes exist, are proven to work at required frequency and thoroughness, and are accepted by all relevant agencies. 4 – Processes exist with some minor flaws in	Updates are Essential because hazards may change over time (especially if weather or sea-level related); and because land use, population and economic activity patterns	Whilst regular updating processes for an EILD event is important, the three year time period suggested in the	5 [ ] 4 [ ] 3 [ ] 2 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low

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		Existence of a process agreed between all relevant agencies to: Update hazard estimates every 3 years or less; Update exposure and vulnerability assessments and asset inventory every 18 months or less.	coverage, date slippage or less important agencies being bought in. 3 – Processes exist, but with at least 1 major omission in terms of frequency, thoroughness or agency buy-in. Risk identification may be compromised in some areas, accordingly. 2 – Processes have some major flaws to the point where overall value is impaired and original risk assessments are becoming significantly obsolete. 1 – Processes are rudimentary at best. A complete risk assessment – even if elderly – has yet to be achieved. 0 – No processes.	may also change as cities grow. Updates need to address: • Hazard patterns; • Dwellings; • Businesses; • City infrastructure and facilities (see Essential 8), including critical assets and failure chains; • Critical computer systems and data (see Essential 8); • Schools and healthcare facilities (see Essential 8); • Ecosystem services (see Essential 5). The focus here is on the process itself and its ability to ensure continued and complete updating of scenarios. Updates may be by means of a regular updating exercise that captures all changes for the preceding period, or by means of an incremental update process that reliably captures changes as they occur. Many countries update their risk data on a 5 year cycle. This is unlikely to be adequate to keep pace with urban boundary or land use changes.	scorecard is too short. Updating should take place as and when new micro-zonation studies become available.	1 [ ] 0 [ ]	[ ] Low LIQUEFACT Score – Medium High

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ESSENTIAL 3: Strengthen Financial Capacity for Resilience

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Knowledge of approaches for attracting new investment to the city for DDR							
3.1.1	Awareness and knowledge of all possible methods of financing and funding, as required The city is actively pursuing financing and funding, as required Note: If sufficient funds exist these assessment criteria can be omitted	Where a city has outstanding resilience expenditure needs (revenue or capital) – the extent to which it has researched and understands all available routes / options to close any funding shortfalls. The extent to which the city is actively trying to meet funding needs and has a clear responsibility for this. This may include the use of external funding or management consultants. This may include the systematic identification of "resilience dividends" (see right	5 - Yes there is dedicated responsibility within the city authority to access available financing at international and national levels. 4 – Yes there is dedicated responsibility within the city authority to access those funding streams known to the city, but awareness of all available funds is incomplete or accessing such funds can be too resource intensive. 3 - There is no dedicated responsibility within the city authority, however there are plans to discuss and implement this to gain full awareness of available funds and how to access them. 2 - There is no dedicated responsibility within the city authority to access the funds; there is a low/partial awareness of available funds for response and recovery. 1 – No dedicated responsibility within the city authority to access such funds and no awareness of which finds to access/ no plans to do so. 0 – Response and recovery funding not considered whatsoever.	(If no additional financing needs apply, omit this assessment). Many cities do not have a fully developed "atlas" of where all possible sources of resilience funding may lie. As a result improvements to resilience may go un-funded. Alternative financing methods and sources may include, but are not restricted to: • Leasing; • Government grants, including matching grants; • Social impact or resilience bonds (payment for results achieved); • Development banks and aid organizations; • Foundations that may have a direct interest in some aspect of resilience – for example where a conservation NGO might support restoration of ecosystem services, or an education NGO might support awareness and training; • Other government agencies that may have a direct interest in some aspect of resilience – for example where a transportation agency finances a new	Predicting the costs associated with an EILD event is very difficult but additional funding, on and above that required to deal with the impacts of earthquake ground shaking is required. The LRG software can provide a high-level assessment of the costs of an EILD event. The city needs to ensure that these costs are covered in the disaster funding plans.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium

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		– also known as co-benefits).		bridge that may also improve evacuation capacity; • Crowd-funding; • Development fees; • Public-private partnerships; • Taxes and surcharges. "Resilience dividends" – sometimes called co-benefits - arise in two ways: Inbound" dividends arise where investments elsewhere in the city have additional resilience benefits – for example where advanced meter infrastructures make water and energy systems more able to report damage from a flood or earthquake. Inbound dividends will tend to reduce the visible costs of resilience. "Outbound" dividends, where an investment in resilience also provides an additional, non-resilience benefit- for example where a flood zone doubles as a park during times of normal weather. Outbound dividends serve to increase the visible benefits of resilience.			
Resilience budgets within the city financial plan including contingency funds							
3.2.1	Adequacy of financial planning for all actions necessary for disaster resilience	Presence of financial (capital and operating) plan(s) with a reasoned set of priorities, based on disaster resilience impact achieved, and	5 – A coherent city-wide set of priorities exists that covers all identified needs, is argued coherently and assembled into a coherent set of 5 year financial plans (there may be multiple responsible agencies). Plans are protected from political change. 4 – Single 5 year set of priorities and financial	If (as is likely) funding comes from several sources, the combined funding needs to be adequate for the city's disaster resilience needs, and also coherently deployed "as if" there was a single source and a single plan. Thus, if there are separate subsidiary plans (for example, transportation or	Specific funding, on an above that for general earthquake resilience, should be identified to improve the resilience of any critical infrastructure assets that	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low

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		linked to "most probable" and "most severe" scenarios in Essential 2. Priorities for disaster resilience investment $$ are clear and defensible, based on a view of most beneficial impact. Priorities are assembled into 5-year plan that integrates spending by all key organisations and will meet scenarios in Essential 2.	plans exist but with some minor omissions and inconsistencies. Political continuity may be an issue. 3 – Financial plans exist but longer than 5 years and may have some gaps and inconsistencies. Political continuity is a known issue. 2 – Multiple financial plans from different agencies – these have never been coordinated and it is unclear whether they are consistent or not or will together deliver the required level of disaster resilience. 1 – Plans exist but with substantial gaps. 0 – No prioritization – spending, if any, is haphazard. No plan.	sustainability plans), these need also to be coordinated, complete and mutually consistent. Plans also need to persist, even if changed or updated, through changes in the political leadership of the city.	have been identified at risk from an EILD event.		LIQUEFACT Score – Medium
3.2.2	Capital funding for long run engineering and other works that address scenarios and critical assets identified in Essentials 2 and Essential 8	% funding for capital elements of plan(s) relative to estimated cost. Degree of protection ("ringfencing") from cuts or from being taken away to be used for other purposes.	5 – Projects are 100% funded and protected. 4 –Projects are 75-100% funded and protected. 3 – Projects are 50-75% funded, and may be liable to funds being diverted for other purposes. 2 – Projects are 25-50% funded, and liable to funds being diverted for other purposes. 1 – Projects are 0-25% funded, and routinely diverted for other purposes. 0 – No Projects.	If capital funds are spread across separate sources and/or organizations, the deployment of the combined funding needs to be coordinated and mutually consistent in line with the plan above.	Specific funding, on an above that for general earthquake resilience, should be identified to improve the resilience of any critical infrastructure assets that have been identified at risk from an EILD event.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
3.2.3	Operating funding to meet all operating	Funding for operating expenses relative to estimated costs:	5 – Budget exists, is 100% adequate and is protected. 4 – Budget exists, is 75-100% adequate, and is	If operating funds are spread across separate sources and/or organizations, or separate budget line-items, the deployment	Specific funding, on an above that for general earthquake resilience, should be	5 [ ] 4 [ ] 3 [ ]	[ ] High [ ] Medium High [ ] Medium

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	costs of disaster resilience activities	presence of separately delineated budget line item(s). Degree of protection ("ringfencing") from cuts or from being taken away to be used for other purposes.	protected. 3 – Budget exists, is 50-75% adequate but is liable to diversion for other purposes. 2 – Budget exists, is 25-50% adequate but is liable to diversion for other purposes. 1 – Budget exists, but is only 0-25% adequate and is routinely diverted for other purposes. 0 – No budget.	of the combined funding needs to be coordinated and mutually consistent in line with the financial plan above.	identified to improve the resilience of any critical infrastructure assets that have been identified at risk from an EILD event.	2 [ ] 1 [ ] 0 [ ]	[ ] Medium Low [ ] Low LIQUEFACT Score – Medium
3.2.4	Contingency fund(s) for post disaster recovery (may be referred to as a "rainy-day fund")	Existence of fund(s) capable of dealing with estimated impacts from "most severe" scenario (See Essential 2). Degree of protection ("ringfencing") of contingency fund(s) from being taken away to be used for other purposes.	5 – Contingency fund (and insurance as applicable) exists to rectify impacts from "most probable" scenario, is 100% adequate and protected. 4 – Fund exists, is 75-100% adequate and protected. 3 – Fund exists, is 50-75% adequate but may be liable to funds being diverted for other purposes. 2 – Fund exists, is 25-50% adequate, and liable to funds being diverted for other purposes. 1 – Fund exists is only 0-25% adequate, and routinely diverted for other purposes. 0 – No fund.	Include impact of insurance coverage where applicable (see below). Include money also available from other agencies, different levels of government etc.	No additional specific issues required (assuming that liquefaction is included as part of general earthquake recovery).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Insurance							
3.3.1	Domestic insurance coverage	Extent of coverage of domestic housing. (Personal or life coverage is not assessed).	5 – 75 – 100% of likely housing losses from "most severe" scenario is covered city-wide by insurance. 4 – 75-100% of likely losses from "most probable" scenario is covered city-wide. 3 – 50-75% of likely losses from "most probable" scenario is covered city-wide. 2 – 25-50% of likely losses from "most probable"	This assessment covers insurance on domestic dwellings. Personal or life coverage is excluded. Governmental, industrial and commercial insurance is covered below. Insurance may come from multiple public or private providers.	No additional specific issues required (assuming liquefaction is covered by existing insurance)	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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			scenario is covered city-wide. 1 – 0-25% of likely losses from "most probable" scenario is covered city-wide. 0 – No cover.				
3.3.2	Non-domestic insurance coverage	Extent of insurance coverage of non-domestic property, infrastructure and assets.	5 – 75 – 100% of likely losses from most severe scenario is covered city-wide by insurance. 4 – 75-100% of likely losses from "most probable" scenario is covered city-wide. 3 – 50-75% of likely losses from "most probable" scenario is covered city-wide. 2 – 25-50% of likely losses from "most probable" scenario is covered city-wide. 1 – 0-25% of likely losses from "most probable" scenario is covered city-wide. 0 – No cover.	This question covers insurance to commercial, industrial property and assets, as well as to NGO-, government- or city-owned buildings, assets and infrastructure. Domestic insurance is covered above. Insurance may come from multiple providers. Some governments and agencies and some businesses may self-insure. It will be necessary to confirm that funds exist to meet the likely needs.	No additional specific issues required (assuming liquefaction is covered by existing insurance)	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Incentives and financing business, community organisations and citizens							
3.4.1	Incentives to businesses organizations to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help business owners take steps to improve disaster resilience to a standard to deal with the "most severe" scenario (Essential 2).	5 – Incentives are visibly achieving (or have achieved) required results evenly with businesses across the city. 4 – Incentives are generally effective but with some minor shortcomings perhaps in some areas. 3 - Incentives have larger gaps in coverage of the economic base. 2 - Incentives have larger gaps in coverage of the required issues. 1 – Incentives have major weaknesses and have so far failed to achieve their purpose. 0 – No incentives.	Incentives and financing may come from multiple sources.	No additional specific issues required (assuming that liquefaction is considered part of an organisation's general earthquake disaster planning).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
3.4.2	Incentives to non-profit organizations to	Existence of incentives to help non-profits take steps	5 – Incentives are visibly achieving (or have achieved) required results evenly with nonprofits across the city.	Incentives and financing may come from multiple sources. Non-profits may be directly concerned with	No additional specific issues required (assuming that liquefaction is considered	5 [ ] 4 [ ] 3 [ ]	[ ] High [ ] Medium High [ ] Medium

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Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
	improve disaster resilience – disaster plans, premises etc	to improve disaster resilience to a standard to deal with the "most severe" scenario (Essential 2).	4 – Incentives are generally effective but with some minor shortcomings perhaps in some areas. 3 - Incentives have larger gaps in coverage of the non-profit base. 3 - Incentives have larger gaps in coverage of the required issues. 1 – Incentives have major weaknesses and have so far failed to achieve their purpose. 0 – No incentives.	disaster resilience issues (for example, emergency response groups, neighbourhood watch, food kitchens); or indirectly (for example, churches, environmental watch groups or similar).	part of an organisation's general earthquake disaster planning).	2 [ ] 1 [ ] 0 [ ]	[ ] Medium Low [ ] Low LIQUEFACT Score – Medium
3.4.3	Incentives to homeowners to improve disaster resilience – disaster plans, premises, ect.	Existence of incentives to help homeowners take steps to improve disaster resilience to a standard to deal with the "most severe" scenario (Essential 2). Ideally means-tested, to ensure that funds go to those most in need.	5 – Incentives are visibly achieving (or have achieved) required results evenly with householders across the city. 4 – Incentives are generally effective but with some minor shortcomings perhaps in some areas. 3 - Incentives have larger gaps in coverage of householders. 2 - Incentives have larger gaps in coverage of the required issues. 1 – Incentives have major weaknesses and have so far failed to achieve their purpose. 0 – No incentives.		No additional specific issues required (assuming that liquefaction is considered part of a homeowners general earthquake disaster planning).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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ESSENTIAL 4: Pursue Resilient Urban Development

Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Land use zoning							
4.1.1	Potential population displacement	% of population at risk of displacement.	5 – No population displacement from "most severe" scenario. 4 – No population displacement from "most probable" scenario. 3 – <2.5% population displacement from "most probable" scenario. 2 – 2.5-5% population displacement from "most probable" scenario. 1 – 5-7.5% population displacement from "most probable" scenario. 0 – >7.5% population displacement from "most probable" scenario.	Displacement for 3 months or longer as a consequence of housing being destroyed or rendered uninhabitable, or the area in which it is located being rendered uninhabitable. This assessment also needs to cover informal and unplanned settlements. Effectiveness of zoning should ideally be independently validated (see also Essential 2).	No additional specific issues required (whilst liquefaction can create major damage to buildings, as it is a localised phenomenon, population displacement is not a significant issue).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
4.1.2	Economic activity at risk	% of employment at risk	5 – No loss of employment from "most severe" scenario. 4 – No loss of employment from "most probable" scenario. 3 – <2.5% of employment at risk from "most probable" scenario. 2 – 2.5-5% of employment at risk from "most probable" scenario. 1 – 5-7.5% of employment risk from "most probable" scenario. 0 – >7.5% of employment at risk from "most probable" scenario.	Employment is at risk from damage to farmland, factories, offices, and so on. Loss is for 1 month or longer. Effectiveness of zoning should ideally be independently validated (see also Essential 2).	No additional specific issues required (assuming that vulnerability, exposure, damage and loss calculations have been undertaken as part of Essential 2).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
4.1.2.1	Economic activity at risk	% business output at risk.	5 – No loss of business output from "most severe" scenario. 4 – No loss of business output from "most probable" scenario. 3 – <2.5% of business output at risk from "most probable" scenario. 2 – 2.5-5% of business output at risk from "most probable" scenario. 1 – 5-7.5% of business output risk from "most probable" scenario. 0 – >7.5% of business output at risk from "most probable" scenario.	Business output measured in financial terms. This assessment also includes loss through business being forced to relocate elsewhere, even if only temporarily, due to loss of premises or facilities, loss of markets, loss of services from the city or loss of workforce through inability to reach their place of work. Loss is for 1 month or longer. Effectiveness of zoning should ideally be independently validated (see also Essential 2).	No additional specific issues required (assuming that vulnerability, exposure, damage and loss calculations have been undertaken as part of Essential 2).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
4.1.3	Agricultural land at risk	% of agricultural land at risk.	5 – No loss of agricultural land from "most severe" scenario. 4 – No loss of agricultural land from "most probable" scenario. 3 – <2.5% of agricultural land at risk from "most probable" scenario. 2 – 2.5-5% of agricultural land at risk from "most probable" scenario. 1 – 5-7.5% of agricultural land at risk from "most probable" scenario. 0 – >7.5% of agricultural land at risk from "most probable" scenario.	Note: Some elements of land use zoning / strategic planning are covered under Essential 1. Further detail is included here. This assessment is intended to focus on agricultural land required to feed the city, excluding imported food from other regions or countries. Loss is for 6 months or longer. Effectiveness of zoning should ideally be independently validated (see also Essential 2).	No additional specific issues required (assuming that vulnerability, exposure, damage and loss calculations have been undertaken as part of Essential 2).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
New urban development							
4.2.1	Urban design solution that increase resilience	Use of urban design solutions to improve resilience; often by maximizing the extent and benefit of ecosystem services	5 – Systematic use of design solutions to improve resilience throughout the city, enforced by codes. Assumed to be "the norm". 4 – Widespread use of urban design features but some missed opportunities. Proposals to use urban design solutions are likely to be favourably	Urban design solutions that can improve resilience will include, but are not limited to: • soakaways and porous pavement used to deal with urban storm-water run-off and replenish ground water;	Liquefaction is primarily a localised phenomenon and as such design solutions need to be at a local scale. Mitigation techniques should be assessed at a local scale.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low

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Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
		within the city (see also Essential 5).	received but not mandated. 3 – Some use of urban design features – perhaps in some areas, or perhaps concentrating on one or two solutions. Their use is not assured but the argument for using them can be made depending on each case. 2 – Scattered use of urban design solutions, but interest in expanding this. 1 – Little use and little interest. 0 – No use and no interest.	• underground parking garages used as holding tanks for storm water, and parks that function as flood zones; • green roofs to help cool buildings and reduce storm run-off; • trees and greenery to reduce heat-island effects, or stabilize hillsides; • neighbourhood micro-grids or roof-top generation as back-up to the main energy supply.			LIQUEFACT Score – High
Building codes and standards							
4.3.1	Existence of building codes designed to address risk identified in Essential 2	Existence of applicable codes to all physical assets.	Codes exist that will ensure: 5 – Zero damage. All physical structures and assets remaining usable in the "most probable" scenario. 4 – >75% of all physical structures and assets remaining usable in the "most probable" scenario. 3 – >50% of all physical structures and assets remaining usable in the "most probable" scenario. 2 – >20% of all physical structures and assets remaining usable in the "most probable" scenario. 1 – >10% of all physical structures and assets remaining usable in the "most probable" scenario. 0 – 0-10% of all physical structures and assets remaining in the "most probable" scenario.	Building codes should be specifically evaluated for ability to deal with "most probable" and "most severe" scenarios in Essential 2. It may make sense to subdivide the city by region or neighbourhood. Effectiveness of codes should ideally be independently validated (see also Essential 2).	Ensure that local, national and/or international building codes and guidance address earthquake induced liquefaction	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
4.3.2	Updates to building codes	Codes exist that will ensure:	5 – Codes are or will be reviewed for suitability for "most severe" scenario and updated every 5 years or more frequently. They embody the latest standards in building practice. 4 – Codes are or will be reviewed for suitability for the "most probable" scenario every 10 years. They may not embody the very latest standards in building practice. 3 – Codes are or will be reviewed for suitability for the "most probable" scenario every 10 years. They probably do not embody the very latest standards in building practice. 2 – Codes are or will be reviewed for suitability for the "most probable" every 15 years or longer. They are known to be obsolete in significant respects. 1 – Codes exist, but are not reviewed at all, and no there are no plans for this. They are wholly obsolete. 0 – No codes.	Codes may be updated as building practice evolves or as new needs (for example an increased storm risk) dictate.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High
4.3.3	Sustainable building design standards	Use of sustainable building design standards such as REDi, LEED, GreenStar and BREEAM to improve resilience.	5 – Systematic specification of meaningful green building standards for all new-build or retrofit, enforced by codes. Assumed to be "the norm". 4 – Widespread use of green building standards, but some missed opportunities. Proposals to use such standards are likely to be favourably received but not mandated. 3 – Some use of green building standards – perhaps in the downtown area. Their use is not assured but the argument for using them can be made depending on each case.	Sustainable building designs can improve resilience by: • Reducing demand for energy and water; • Dealing better with heat events; • Incorporating features such as green roofing that also helps to control storm water runoff. United Nations Office for D Disaster Resilience Scorecard for Cities disaster Risk Reduction	No additional specific issues required (not relevant to an EILD event).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Low

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			2 – Scattered use of green building standards developing on the developer's interest, but interest in expanding this. 1 – Little use and little interest. 0 – No use and no interest.				
Application of zoning building codes and standards							
4.4.1	Application of land use zoning	Extent to which land use zoning is enforced.	5 – Zoning is 100% implemented and all settlement and economic activity is compliant. 4 – Zoning is 90-200% implemented and enforced. 3 – Zoning is 80-90% implemented and enforced. 2 – Zoning is 70-80% implemented and enforced. 1 – Zoning is 50=70% implemented and enforced. 0 – Zoning is <50% implemented and enforced.	By definition, it will be difficult for cities with informal settlements to score highly on this measure, unless it so happens that they are safely located, and unless separate steps have been taken to make these more resilient.	Ensure that land use zones reflect the results of micro-zonation studies where available.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High
4.4.2	Application of building codes	Implementation of building codes on relevant structures.	5 – Codes are 100% implemented on applicable structures and certified as such by a 3rd party. 4 – Codes are 90-100% implemented on applicable structures and 3rd-party certified. 3 – Codes are 80-90% implemented on applicable structures. They may or may not be 3rd party certified. 2 – Codes are 70-80% implemented on applicable structures. They may or may not be 3rd party certified. 1 – Codes are 50-70 % implemented on applicable structures. No 3rd party certification. 0 – Codes are <50% implemented on applicable structures. No 3rd party certification.	Effectiveness of codes should ideally be independently validated (see also Essential 2). Application of codes will be a particular issue in unplanned or informal settlements. Codes and standards will include those for the supply of basic infrastructure services to informal settlements, without which the ability of those settlements to recover from disasters will be severely compromised.	Ensure that the local, national and/or international building codes and guidance used address earthquake induced liquefaction.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium High

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ESSENTIAL 5: Safeguard Natural Buffers to Enhance the Protective Functions Offered by Natural Ecosystems

This is not relevant to liquefaction and no modifications have been made to the UNISDR scorecard.

ESSENTIAL 6: Strengthen Institutional Capacity for Resilience

Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Skills and experience							
6.1.1	Availability of skills and experience in disaster resilience - risk identification mitigation, planning, response and post even response	Known (i.e. inventoried in last 1 year) availability of key skills, experience and knowledge.	5 – Skills inventory carried out in last year and all key skills and experience are available in required quantities for all organizations relevant to city disaster resilience. 4 – Inventory carried out - shows with minor gaps in quantity or skill type in some organizations. 3 – Inventory carried out but each organization has at least one skill or experience type in short supply. 2 – Inventory may not have complete coverage, but known widespread lack of multiple skill or experience types in many organizations. 1 – Rudimentary and partial inventory. Suspicion of complete or almost complete lack of skills available across the city. 0 – No inventory.	Skills will include: land planning, energy, environmental, water and structural engineering, logistics, debris disposal, healthcare, law and order, project planning and management. Knowledge refers to operating knowledge of city government and city infrastructure(s): the energy, water, sanitation, traffic and other critical city systems at risk. (see Essential 8). Experience refers to direct experience of the types of perils the city faces (see Essential 2) and the capabilities of the city's infrastructure to withstand and/or recover from these. Some skills, knowledge or experience may be purchased from specialist consultancies, or supplied on a one-time basis by aid agencies. (First responders – see Essential 9).	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium
6.1.2	Private sector links	To what extent does the city utilise and	5 – City DRR stakeholders have in place comprehensive MOU agreements with private		No additional specific issues required.	5 [ ] 4 [ ]	[ ] High [ ] Medium High

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		engage the private sector?	companies to co-opt resources such as food, warehousing, data centres and vehicles, and perhaps skilled employees such as engineers, in an emergency situation. There are regular meetings between DRR stakeholders and local companies updating on local risks. 4 – The city has MoUs and fairly regular meetings but these could be improved. 3 – The city has some formal MOUs and meetings with the private sector but these could be improved. 2 – Some agreements exist but these are not formal / coordinated. Meetings are rare. 1 – The city DRR stakeholders have started to engage the private sector but this is at an early stage. 0 – No agreements or meetings.			3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
6.1.3	Engagement of insurance sector	Is the city engaging with the insurance sector to assess, mitigate and manage risk and stimulate a market for insurance products?	5 – Very substantial engagement for some years, city is actively collaborating. 4 – Some engagement but missing a thorough process for cross sector engagement. 3 – Engagement is happening, but only for the cities critical assets. 2 – Discussions have been initiated. 1 – The need for engagement with the insurance has been recognised, but no discussions have taken place yet. 0 – No engagement, no insurance.	As society's traditional risk manager, the (re) insurance industry has significant expertise in the quantification and evaluation of complex risks and can play a highly constructive role in assisting cities identify and respond to risks and build their resilience. The widespread availability of insurance within cities represents a crucial component of resilience due to insurance's critical role in helping economies and communities 'bounce back' quickly from disasters and extreme events. Promoting urban resiliency is also a strategic imperative of the (re) insurance industry as	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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				it can help catalyse market growth, address underinsurance, reduce losses, enhance 'license to operate', and present opportunities for innovative risk transfer and insurance solutions. (Ref: WCCD and UNISDR, Towards Standardized City Indicators for Insurability & Resilience, July 2016).			
6.1.4	Civil society links	To what extent does the city utilise and engage civil society organisations?	5 – City DRR stakeholders have in place comprehensive MOU agreements with various NGOs with NGO role defined in providing support in response, relief and meeting resource demands. High volunteer capacity as required. Regular planning and coordination meetings. 4 – The city works with NGOs and/or volunteers in various DRR capacities but this could be utilised even further. High volunteer capacity as required. 3 – The city works with NGOs and/or volunteers in some DRR capacities but this could improve. Modest volunteer capacity relative to the city needs. 2 – Some agreements exist but these are not formal / coordinated. Need for greater volunteer capacity. 1 – The city DRR stakeholders have started to engage NGO organisations and/or volunteers but this is at an early stage. 0 – No agreements / arrangements.	Engagement with volunteers is also an important way of enabling social capacity to respond (see Essential 7).	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Public education and awareness							

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
6.2.1	Exposure of public to education and awareness materials/messaging	Coordinated public relations and education campaign exists, with structured messaging, channels, and delivery	5 – Systematic, structured campaign exists using at least 6 of the media at right, via neighbourhood mobilization (see Essential 7), and schools outreach. 4 – Campaign uses at least 5 of the media/channels above, including 1 of neighbourhood mobilization and schools outreach. 3 – Campaign uses at least 4 of the media/channels above; also, weighted to least informative such as radio and poster ads. 2 – Campaign uses 3 of the media/channels above; also weighted to least informative such as radio and poster ads. 1 – Ad hoc – no structured education and awareness campaign as such. 0 – No education work.	Likely to be based on information made public – see Essential 1. Media may include: • Print – books, newspapers, leaflets, fliers; • School and college teaching material; • TV – advertisements. Documentaries, news features; • Radio – as for TV; • Web – websites, advertisements, content on city websites; • Mobile – as for web but also social media - Twitter, Facebook, Web etc.; Possibly also create specialist app for city's disaster resilience information; • Posters – on buildings, buses, trains, city offices. Material may come from multiple agencies and sources, but should have coordinated messages. Schools and colleges may be an especially important channel; also churches, neighbourhood groups, libraries.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
6.2.1.1	Exposure of public to education and awareness materials/messaging	Exposures per member of public, per month to messaging	5 – Average 1 or more exposures per person per week, citywide. 4 – Average 1 exposure per person per two weeks, city-wide. 3 – Average 1 exposure per person per month, city-wide. 2 – Average 1 exposure per person per quarter, city-wide.	Exposures established, for example, via traffic counts (web sites, mobile), audience figures (TV, radio), road traffic counts (i.e., road traffic past posters), and so on. If funds permit exposures could also be validated via survey.	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			1 – Average 1 exposure per person per six months, city-wide. 0 – Average 1 exposure per person per year or worse.				
Data capture, publication and sharing							
6.3.1	Extent to which data on the city resilience position is shared with other organizations involved with the city's resilience	Availability of a single "version of the truth" – a single integrated set of resilience data for practitioners.	5 – Full availability of the information listed at right on readiness and risk; fully shared with other organizations. 4 – Some minor gaps, or the information is in more than one place – but it is shared and it is at least linked to enable navigation. 3 – Some more significant gaps, for example on readiness; other organizations may have to "hunt around" to create a complete picture for themselves. 2 – Some significant information on readiness and risk is withheld from other organizations or is missing and/or badly fragmented across multiple websites. 1 – Information provision to other organizations on readiness and risk is rudimentary at best. Not possible to for those organizations to derive specific conclusions for themselves. 0 – No information.	Information to consider making open for other organizations to access might include: • A summary of readiness – perhaps the outcomes of this Scorecard; • An explanation of the hazards and perils that the city faces, and probabilities; • A risk-map based summary (see Essential 2) of at-risk areas; • A description of what building codes will protect against, and where these have been applied; • A description of what businesses and other organizations should expect by way of disaster impacts, the city's likely response and the implications for business continuity; • A description of what businesses and other organizations need to do for themselves; • Key roles and accountabilities in the city; • Planned investments that will affect the city's resilience position; • Further resources and contact details.	No additional specific issues required	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
6.3.2	Extent to which data on the city resilience	Availability of a single "version of the truth"	5 – Full availability of the information listed at right on readiness and risk; fully shared with	Information to consider making open for public access	No additional specific issues required	5 [ ] 4 [ ]	[ ] High [ ] Medium High

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	position is shared with community organizations and public	– a single integrated set of resilience data for citizens and community organizations containing at least the items shown at right.	other community organizations and available to the public via website, mobile device etc. 4 – Some minor gaps, or the information is in more than one place – but it is shared and it is at least linked to enable navigation. 3 – Some more significant gaps, for example on readiness; other organizations or citizens may have to "hunt around" to create a complete picture for themselves. 2 – Some significant information on readiness and risk is withheld from other organizations or is missing and/or badly fragmented across multiple websites. 1 – Information provision to other community organizations and to citizens on readiness and risk is rudimentary at best. Not possible to for those organizations or citizens to derive specific conclusions for themselves or their neighbourhoods. 0 – No information.	might include: • A summary of readiness – perhaps a summary of the outcomes of this Scorecard; • An explanation of the hazards that the city is thought to face, and probabilities; • A hazard-map based summary (see Essential 2) of at risk areas; • A description of what building codes will protect against, and where these have been applied; • A description of what citizens should expect by way of disaster impacts, the city's likely response and the implications for daily life; • A description of citizens need to do for themselves and their families; • Key roles and accountabilities in the city; • Planned investments that will affect the city's – or a neighbourhood's - resilience; • Further resources and contact details.		3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Training delivery							
6.4.1	Availability of take-up of training focussed on Risk and Resilience (Professional Training)	Training offered and available to resilience professionals (from government, voluntary or other sources)	5 – Full training curriculum is available for all, derived from known or anticipated needs. 4 – Full training curriculum is available across the city. 3 – Training curriculum available but is not fully deployed across the city. 2 – Ad hoc training classes address some issues for some area of the city.	Training for professionals is covered here in Essential 6. Community training is covered in Essential 7 and Disaster Drills are covered in Essential 9.	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			1 –Training courses are under development. 0 – No training.				
6.4.1.1	Availability of take-up of training focussed on Risk and Resilience (Professional Training)	% of population trained in last year	5 – 5% or better in all neighbourhoods. 4 – 2.5-5% in all neighbourhoods. 3 – 1-2.5% in all neighbourhoods. 2 – 0.5-1% in all neighbourhood's. 1 – <0.5% in all neighbourhood's. 0 – No training.	Effectiveness of training validated via drills – see Essential 9.	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
6.4.2	System/process for updating relevant training	Frequency of repeat training	5 – 6 monthly refreshers and emergency drills city-wide for all trained participants. 4 – Annual refreshers and emergency drills city-wide for all trained participants. 3 – Annual refreshers and emergency drill cycle but may not be city-wide or reach all participants. 2 – Two-yearly refreshers and emergency drill cycle but may not be city-wide or reach all participants. 1 – Ad hoc refreshers and emergency drills – timing, attendance and content depends on enthusiasm of local organization. 0 – No refreshers or emergency drills.	See also Essential 9.	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Languages							
6.5.1	Accessibility of education and training to all linguistic groups in the city	Availability of all education and training in all languages spoken in the city.	5 – Available for 100% of linguistic groups and 100% of the population. 4 – Available for 95% of the population irrespective of language. 3 – Available for 90% of the population	Cities with high numbers of different languages may need to settle for a selection of languages that reaches everyone has a first or second language.	No additional specific issues required (assuming liquefaction is covered by the education and awareness materials	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			irrespective of language. 2 – Available for 85% of the population irrespective of language. 1 – Available for 80% of the population irrespective of language. 0 – Available for <80% of the population irrespective of language.	Validation will be required that 100% of population is being reached in this way.		0 [ ]	LIQUEFACT Score – Medium
Learning from other							
6.6.1	Effort taken to learn from what other cities, states and countries (and companies) do to increase resilience	Learning activities executed with other cities and other practitioners.	5 – Regular (say, annual) exchanges with other cities and regions, specifically to share understand and capture resilience best practices, issues, responses; and examples exist of changes made in the city as a result. Supplemented by regular peer-to-peer contacts with practitioners in other organizations. 4 – Regular exchanges but may be in the context of other meetings with sharing of best practices as a side-effect. Outcomes are captured and some impact may be identified on how the city prepares for disasters. 3 – Reliance only on networking by individual practitioners in the organization with their peers in other organizations. These can be frequent, and there will be some attempt to capture and implement learnings. 2 – Occasional exchanges of a more one-off or ad hoc nature. Impact on/benefit for the city is diffuse and harder to identify.1 – Even networking is limited and learning potential is therefore also limited. 0 – No attempt to learn from others.	These activities are focused on learning and improving – actual coordination of response management and resilience planning is covered in Essential 1. Learning might be via a direct exchange with peer cities, or through industry groups, national resilience and emergency management forums, city groups such as 100RC, C40, ICLEI and others, or NGOs such as the UN.	No additional specific issues required (assuming that liquefaction is part of the learning process).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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ESSENTIAL 7: Understand and Strengthen Societal Capacity for Resilience

Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Community or 'grass roots' organisations							
7.1.1	Coverage of community or "grass roots" organization(s) throughout the city	Presence of at least one nongovernment body for pre and post event response for each neighbourhood in the city.	5 – Community organization(s) addressing full spectrum of disaster resilience issues exist(s) for every neighbourhood, irrespective of wealth, demographics etc. 4 – >75% of neighbourhoods covered. 3 – >50 -75% of neighbourhoods covered. 2 – >25-50% of neighbourhoods covered. 1 – Plans to engage neighbourhoods and maybe one or two initial cases. 0 – No engagement.	Community organizations may include: • Those set up specifically for disaster resilience management (for example, community emergency response teams – CERT – in the US). • Those serving some other purpose but willing and able to play a disaster resilience role: for example, churches, business Round Tables, youth organizations, food kitchens, neighbourhood watch, day centres and so on. Community organizations should be willing and able to contribute to disaster resilience plans for their area based on the input of their members. They need to be seen as legitimate, and to cooperate with each other and the city government. (Event response element is regularly tested at least in simulation exercises – see Essential 9).	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium
7.1.2	Effectiveness of community network	Community organization meeting frequency and attendance	5 – For >75% of neighbourhoods, one meeting per month, all personnel roles staffed and 10x formal role-holder numbers in regular attendance. 4 – For 50-75% of neighbourhoods, one meeting per quarter – all roles staffed and 5 x role-holder numbers in attendance. No meetings in the rest. 3 – For 25-50% of neighbourhoods, semi-annual	Community organizations defined as above.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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			meetings, but with some gaps in roles and less than 3x role-holders in attendance. No meetings in the rest. 2 – For 25-50% of neighbourhoods, annual meetings but with significant gaps in roles and less than 3x formal role-holders in attendance. No meetings in the rest. 1 – Ad hoc meetings in less than 25% of neighbourhoods, of a few "enthusiasts". 0 – No meetings.				
7.1.2.1	Effectiveness of community network	Clear identification and coordination of pre post-event roles for communities bodies, supports by training. Roles screed and signed off, preferably via MOU or similar.	5 – For >75% of neighbourhoods, roles are defined and filled, coordination is effective within and between community bodies, and full training is both provided and attended. 4 – For 50-75% of neighbourhoods, roles are defined and agreed, but some minor deficiencies in these or in training, or incomplete staffing in some cases. Coordination generally good but some lapses. No roles defined in the rest. 3 – For 25-50% of neighbourhoods, most roles defined, but with more significant omissions; some training but with gaps in coverage; coordination adequate but could be improved. No roles defined in the rest. 2 – For 25-50% of neighbourhoods, a few key roles defined, but coordination is absent or poor and training notably incomplete. No roles defined in the rest. 1 – Plans in place to define roles and develop coordination mechanisms. 0 – No roles defined and no coordination.	One key issue is ensuring that there is a clear differentiation of roles between community organizations and between them and other entities such as city government – who is responsible for what? See also information sharing framework in Essential 6.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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Social networks							
7.2.1	Social connectedness and neighbourhood cohesion	Likelihood that residents will be contacted immediately after an event, and regularly thereafter to confirm safety, issues, needs etc.	5 – Sufficient volunteers are available from community organizations to give "reasonable confidence" that 100% of residents will be contacted within 12 hours of an event. 4 – 90% of residents within 12 hours. 3 – 80% of residents. 2 – 70% of residents. 1 – 50% or less of residents. 0 – No volunteers.	Social connectedness has been shown to have a major impact in reducing fatalities from disasters, and also in reducing opportunistic crime following an event. Connectedness is however difficult to measure directly. This assessment is written in terms of specifically identified volunteers and grass-roots organizations, taking these as a proxy measurement for connectedness. In addition, the "reasonable confidence" standard is inherently subjective. As well as this proxy measurement, therefore, other factors that you may also wish to take into account will include: • A history of people in each neighbourhood meaningfully helping each other after previous events. A strong fabric of community organizations in general, even if not focused on disaster resilience in the first instance.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
7.2.2	Engagement with vulnerable groups of population	Evidence of disaster resilience planning with or for the relevant groups covering the span of the vulnerable population. Confirmation from those groups of	5 – All vulnerable groups are regularly engaged on disaster resilience issues and they or their representatives confirm as such. 4 – All major groups (measured by membership % of those defined as vulnerable in the city as a whole) are engaged – some minor gaps. 3 – One or more major gaps in coverage or effective engagement. 2 – Multiple gaps in coverage or effective	Vulnerable groups of the population might include, as examples: • Those in areas of high poverty; • Transient or nomadic communities; • The elderly; • Physically or mentally sick or disabled; • Children; • Non-native language speakers. Engagement may be through	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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		effective engagement.	engagement. 1 – Generalized failure to engage with vulnerable groups. 0 – No vulnerable groups specifically identified.	neighbourhood organizations or via specialist government organizations, charities, NGOs etc. These may also function as "grass roots" organizations (see above). (Public awareness, education and training materials – see Essential 7).			
Private sector employees							
7.3.1	Extent to which employers act as a channel worth employees	Proportion of employers that pass resilience communications to employers, and allow limited time off for resilience volunteer activities.	5 – 50% of employers with more than 10 employees take part in communicating with their workforce about resilience issues/ 10% take part in resilience training and allow small amounts of time off for resilience volunteer activities. 4 – 40% / 8%. 3 – 30% / 5%. 2 – 20% / 3%. 1 – 10% / 1%. 0 – 0% / 0%.	Employees can act as an important communications conduit to employees on resilience issues, especially in the area of hazards faced and preparation – which are also likely to benefit them in the form of better continuity of operations after an event.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
7.3.2	Business Continuity Planning	Proportion of business with a solid business continuity plan	5 – All employers with more than 10 employees have some form of business continuity plan based on a planning assumptions validated by the city. 4 – 80%. 3 – 50%. 2 – 30%. 1 – 10% or less. 0 – 0% or don't know.	While business continuity plans are the concern of each business, their presence and effectiveness will play a major role in how rapidly the city's economy restarts after a disaster. Therefore cities need to be proactive in persuading businesses to undertake continuity plans, based on a shared view of the hazards and issues likely to arise.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Citizen engagement techniques							
7.4.1	Frequency of engagement	Use of regular overlapping modes of engagement to create repeated and	5 – 100% of population likely to receive at least 5 resilience related messages per year from all sources. 4 – 80% of population likely to receive at least 4	PR and organization change best practice shows that people need to receive messages multiple ways and ideally from different channels to internalize them. The	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low

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		reinforcing message delivery	messages. 3 – 70% of population likely to receive at least 3 messages. 2 – 50% of population likely to receive at least 1 message. 1 – More than 50% of population do not receive any messages at all. 0 – No resilience messaging.	same rule seems likely to apply to social awareness. The level of message penetration that is achieved could be tested by surveys each year (which are also a form of messaging!).		1 [ ] 0 [ ]	[ ] Low LIQUEFACT Score – Medium
7.4.2	Use of mobile and e-mail "systems of engagement" to enable citizens to receive and give updates before and after disasters	Use of mobile and social computing-enabled systems of engagement (supported by e-mail).	5 – All information before, during and after an event is available on mobile devices; this is supported by alerts on social media; this is also used to enable an in-bound "citizen to government" flow allowing crowd sourcing of data on events and issues. 4 – Extensive use is made of systems of engagement, with a few minor omissions. 3 – Some use is made, but there are larger gaps in the information available by this means and the in-bound flow works only via direct communication rather than mining of data generally. 2 – As for 3 but with no inbound flow. 1 – Only rudimentary use of systems of engagement – perhaps only via mobile access to the existing website which may not have been optimized for smartphones etc. – but interest in expanding this. 0 – No use of systems of engagement.	"Systems of engagement" is the term given to mobile device/social media and e-mail-based systems to pass information to individuals and also to capture information from them. They are usually paired with "systems of record" which are back-office and enterprise systems (such as the emergency management system). Data capture may be directly, where a citizen directly contacts the city government, or via a data-mining – for example where some governments in Australia mine data from Twitter and SMS to gain an extra source of intelligence on wildfire outbreaks and status.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
7.4.3	Validation of effectiveness of education	Knowledge of "most probable" risk scenario and	5 – "Most probable" scenario, and applicable response and preparation, appears to be generally known by >90% of respondents as	Will require on-line or face-to-face surveys to validate.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ]	[ ] High [ ] Medium High [ ] Medium

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		knowledge of key response and preparation steps is widespread throughout city. Tested by sample survey.	verified by opinion poll. 4 – 75–90% known. 3 – 50-75% known. 2 – 25-50% known. 1 – 10-25% known. 0 – <10% known, or no poll.			2 [ ] 1 [ ] 0 [ ]	[ ] Medium Low [ ] Low LIQUEFACT Score – Medium

ESSENTIAL 8: Increase Infrastructure resilience

A separate scorecard has been developed to measure the impact that specific critical infrastructure has on resilience. In this section only Protective Infrastructure is considered here.

Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Protective infrastructure							
8.1.1	Adequacy of protective infrastructure	Protective infrastructure exists or is in the process of construction – capabilities known to match hazards envisioned in "most probable" and "most	5 – Protective infrastructure fully in place designed to deal with "most severe" scenario with minimal economic or humanitarian impact. 4 – Protective infrastructure has some deficiencies relative to "most severe" scenario but designed to deal with "most probable" scenario. 3 – Protective infrastructure would mitigate most of "most likely" scenario but some impacts would	Examples of protective infrastructure: • Levees and flood barriers; • Flood basins; • Sea walls (where used); • Shelters, such as tornado/hurricane shelters; • Storm drains and storm water holding tanks; • Wetlands and mangroves (see Essential 5);	Need to assess the degree to which ground improvements mitigations to reduce earthquake induced liquefaction can be provided for key elements of critical infrastructure (e.g. transportation embankments and bridges, dams, critical	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - High

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		severe" scenarios in Essential 2.	be felt; deficiencies relative to "most severe" are more serious. 2 – Protective infrastructure would allow significant damage/impact from "most possible", and potentially catastrophic damage from "most severe". 1 – Protective infrastructure would mitigate some impacts but would still allow potentially catastrophic damage from "most probable" scenario. 0 – No protection in place.	• Shock absorption capabilities fitted to infrastructure to deal with earthquakes.	buildings, etc.). Detailed analysis of mitigation options will form part of the critical infrastructure resilience scorecard		
8.1.2	Effectiveness of maintenance	Processes exist to maintain protective infrastructure and ensure integrity and operability of critical assets.	5 – Audited annual inspection process and remediation of issues found. 4 – Audited inspections but remediation of minor items may be delayed by funding issues. 3 – Audited inspections every 2 years or more; remediation may be delayed by funding issues. 2 – Non-audited inspections every 2 years or more – backlog of remediation issues. 1 – Haphazard inspections in response to incidents or reports from the public. Significant known backlog of maintenance issues such that effectiveness of infrastructure may be impaired. 0 – No regular inspections and backlog / maintenance status is unknown.	Examples of processes: • Levee maintenance; • Clearing storm drains; • Maintenance of emergency response equipment; • Maintenance of back up and stand-by power or communications systems or other critical assets.	No additional specific issues required (assuming that any mitigation measures identified above also include routine inspection and maintenance).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – High

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ESSENTIAL 9: Ensure Effective Disaster Response

Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Early warning							
9.1.1	Existence and effectiveness of early warning system	Length and reliability of warning - enabling practical action to be taken	5 – Warnings exist for all hazards known to be relevant to the city, and will allow time for reaction (as far as technology permits). Warnings are seen as reliable and specific to the city. 4 – Warnings exist but warning time maybe less than technology currently permits. Warnings are seen as reliable and specific. 3 – Some hazards, especially earthquakes, are excluded and warning time may be less than technology permits. (If earthquakes are the only hazard for your city, score 0). 2 – Warning time is less than technology permits and there may also be some false positives: reliability of warnings may therefore be perceived as questionable. 1 – Warnings seen as ad hoc and unreliable. Likely to be ignored. 0 – No warnings.	The technology of disaster warnings is rapidly evolving, both in the long-term assessment of risk (for example weather risk in the coming season) and the notification period and update frequency for a specific event (for example the progress of a flood crest down a river, or landslide risk, or tornado warnings). Improved warning may enable an improved risk assessment in Essential 2, for example, by enabling better preparation or enabling more people to move from harm's way. However, while they are the focus of much research currently, meaningful earthquake warning systems do not currently exist for practical purposes. If earthquakes are the only hazard for your city, omit this assessment.	No additional specific issues required (assuming that any early warning systems that exist for earthquakes include EILD events).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium
9.1.1.1	Existence and effectiveness of early warning system	Will 100% of population receive it?	5 – 100% reached. 4 – 90-100% reached. 3 – 80-90% reached. 2 – 70-80% reached. 1 – 50-70% reached. 0 – <50% reached (or no warnings – see above).	This assessment refers to the specific warning of the imminent event. Other pre-event, and post event communications are dealt with in Essential 7. Warnings should be delivered over the maximum possible notice period via multiple media, including phone, TV, radio, web, as well as sirens.	No additional specific issues required (assuming that any early warning systems that exist for earthquakes include EILD events).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low

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							LIQUEFACT Score – Medium
Event response plans							
9.2.1	Existence of emergency response plans that integrate professional responders and community organizations (For post-event response - see Essential 10)	Existence of plans formulated to address "most likely" and "most severe" scenarios, shared and signed off by all relevant actors (including citizen organizations	5 – Complete plans exist, keyed to scenarios referenced in Essential 2. They have been tested in real emergencies. 4 – Complete plans exist as above, but may not have been fully tested. 3 – Plans exist but are not keyed to scenarios referenced in Essential 2. 2 – Plans exist are known to be incomplete or otherwise deficient. 1 – Plans exist but are known to have major shortcomings. 0 – No plans.	Note – more strategic planning is covered in Essential 1 and Essential 10. Emergency response plans will need to cover: • Command and control - coordination with other agencies and cities, roles, responsibilities (see Essential 1); • Evacuations (including hospitals, jails, etc.); • Communication systems; • Critical asset management (including likely "failure chains" – see Essential 8); • Integration of private sector utilities covering energy, water / sanitation, trash collection, communications etc.; • Medical response; • Law and order response; • Fire and rescue response; • Public information; • Triage policies. Incorporation of contributions from citizen / grass roots organization. Elements of emergency response plans may be linked to, and tested through, plans for "regular" events such as sporting fixtures, carnivals or parades (see below).	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Staffing / response needs							

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9.3.1	"Surge" Capacity of police also to support first responder duties	Sufficient back-up or para-professional capacity to maintain law and order in "most severe" and "most probable" scenarios, in addition to supporting burden of first responder duties.	5 – Surge capacity exists and is tested either via actual events or practice drills for scenarios in Essential 2 – coverage of all neighbourhoods will be possible within 4 hours. 4 – Adequate surge capacity nominally exists but is untested. 3 – Surge capacity exists but is known or suspected to have minor inadequacies, perhaps in location, numbers. Coverage of all neighbourhoods within 4-12 hours. 2 – Coverage of all neighbourhoods within 12-48 hours. 1 – Coverage of all neighbourhoods within 48-72 hours. 0 – No surge capacity identified.	This capacity may come from other agencies such as the Army or civil defence force but needs to be confirmed via MOU or similar.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
9.3.2	Definition of other first responder and other staffing needs, and availability	Staffing needs are defined for "most probable" and "most severe" scenarios.	5 – Needs defined, either from actual events or from practice drills for scenarios in Essential 2, taking into account the role of volunteers. 4 – Needs defined independently of latest scenarios. 3 – Some needs defined but with some gaps for specific professions or for specific areas of the city. 2 –Needs definition has more serious shortcomings. 1 –Needs definition is Essentially nominal or guesswork. 0 – No needs defined (or no plan – see above).	Different national response standards may apply in this area. The category includes fire, ambulance, healthcare, neighbourhood support, key communications, energy and water utility staff and key highway staff. Parts of this capacity may come from other agencies such as the Army or civil defence force.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Equipment and relief supply chains							
9.4.1	Definition of equipment and	Equipment and supply needs are	5 – Needs defined, keyed to scenarios from Essential 2, and take into account the role of	Equipment includes: • Police, fire and ambulance vehicles, and	No additional specific issues required.	5 [ ] 4 [ ]	[ ] High [ ] Medium High

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	supply needs and availability of equipment	defined for "most probable" and "most severe" scenarios in Essential 2	volunteers. 4 – Needs defined independently of latest scenarios. 3 – Some needs defined but with some gaps for specific professions or for specific areas of the city. 2 –Needs definition has more serious shortcomings. 1 –Needs definition is Essentially nominal or guesswork. 0 – No needs defined (or no plan).	fuel; • Helicopters, planes as applicable, and fuel; • Rescue equipment; • Medical supplies; • Bulldozers, excavators, debris trucks (may be supplied by private organizations); • Pumps and generators; • Hand equipment – chainsaws, winches, shovels, etc.; • Local emergency response IT systems, hand-held devices. (Medical/hospital needs – see Essential 8).		3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
9.4.1.1	Definition of equipment and supply needs and availability of equipment	Estimated shortfall in available equipment per defined needs potentially rom multiple sources. MOUs exist for mutual aid agreements with other cities, and also for private sector sources	5 – Equipment known to be available in line with defined needs for "most severe" scenario. 4 – Equipment known to be available in line with defined needs for "most probable" scenario. 3 – Shortfall of <5% of ideal equipment numbers for key items. 2 – Shortfall of 5-10% of ideal equipment numbers for key items. 1 – Shortfall of >10% of ideal equipment numbers for key items. 0 – No definition of needs – see above.	Equipment defined as above.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Food, shelter, staple goods and food supply							
9.5.1	Likely ability to continue feed the population	"Food gap" - # of days that city can feed all segments of its population likely to be affected minus # of days' disruption	Under "most severe" scenario: 5 – Positive outcome – days of emergency food available exceeds estimated days disruption to regular supply. 4 –Neutral outcome – days of food available equals estimated days' disruption to regular supply.	Food = food and water. Needs to include certainty that food from other agencies is available, via MOU or similar.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
		estimated under those scenarios.	3 – Negative outcome – estimated food gap is 24 hours. 2 – Negative outcome – estimated food gap is 48 hours. 1 – Negative outcome – estimated food gap is 72 hours. 0 – Negative outcome – estimated food gap is more than 72 hours.				LIQUEFACT Score – Medium
9.5.2	Likely ability to meet needs for shelter/safe places	"Shelter gap" - number of displaced persons minus shelter places available within 24 hours	Under "most severe" scenario: 5 – Positive outcome – shelter places available within 12 hours exceeds estimated need. 4 – Neutral outcome – shelter places available equal to estimated need. 3 – Negative outcome – shelter places available less than estimated need (shelter gap) by 5%. 2 – Negative outcome – estimated shelter gap is 10%. 1 – Negative outcome – estimated shelter gap is 15%. 0 – Negative outcome – estimated shelter gap is 20% or more.	Shelter may include existing structures likely to resist the disaster in question, by virtue of their strong construction and/or their location – sports stadia, school halls, shopping malls, parking garages and so on. Shelters need to take account of separate needs of men, women, children, disabled. Signage to, and for use within, shelters is also likely to be required. Third-party owners of shelter facilities/safe places should be engaged via MOUs or similar.	Ensure that EILD losses are included in earthquake loss assessments	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
9.5.2.1	Likely ability to meet needs for shelter/safe places	"Shelter gap" - ability of shelters to withstand disaster events and remain safe and usable	Under "most severe" scenario: 5 – All designated shelter places are assessed as likely to safely withstand a "most severe" event. 4 – 90% of shelter places are assessed as likely to safely withstand a "most severe" event. 3 – 80% of shelter places are assessed as likely to safely withstand a "most severe" event. 2 – 70% of shelter places are assessed as likely to protect users in "most severe" event. 1 – 50% of shelter places are assessed as likely to	This applies to shelters in which people may have taken refuge prior to an event (for example a hurricane, where there will be some hours warning); or shelters to which people may be directed after the event.	Ensure that EILD losses are included in earthquake loss assessments	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			safely withstand a "most severe" event. 0 – Less than 50%, are assessed as likely to withstand a "most severe "event.				
9.5.3	Ability to meet likely needs for staple goods	"Staples gap" - % shortfall in supply within 24 hours relative to demand	Under "most severe" scenario: 5 – Positive outcome – supply of staples available within 12 hours exceeds estimated demand. 4 –Neutral outcome – supply equals estimated demand. 3 – Negative outcome – supply of five or more critical staples less than estimated demand (staples gap) by 5%. 2 – Negative outcome – estimated staples gap is 10%. 1 – Negative outcome – estimated staples gap is 15%. 0 – Negative outcome – estimated staples gap is 20% or more.	Cities will need to compile lists of critical staple items, as these are to some extent culturally or population dependent. But they are likely to include: • Sanitation; • Personal sanitary supplies and diapers; • Medications and first aid supplies; • Batteries; • Clothing; • Bedding; • Bottled gas for cooking, heating; • Materials for immediate repairs or weather-proofing of housing. In some countries these may be provided via private sector retailers, operating under MOU with the city or other government agency.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
9.5.4	Likely availability of fuel	"Fuel gap" - # of days that city can meet fuel requirements, minus # of days' disruption to regular supply.	Under "most severe" scenario: 5 – Positive outcome – days of fuel available exceeds estimated days' disruption to supply. 4 –Neutral outcome – days of fuel available equals estimated days' disruption to supply. 3 – Negative outcome – estimated disruption exceeds days of fuel available (fuel gap) by 24 hours. 2 – Negative outcome – estimated fuel gap is 48 hours. 1 – Negative outcome – estimated fuel gap is 72	Fuel – gasoline, diesel, as required for emergency vehicles, back up equipment, and personal and business transportation.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
			hours. 0 – Negative outcome – estimated fuel gap is more than 72 hours.				
Interoperability and inter-agency working							
9.6.1	Interoperability with neighbouring cities/states and other levels of government of critical systems and procedures	Ability to cooperate at all levels with neighbouring cities and other levels of government.	5 – Proven interoperability of all key systems and procedures. 4 – Interoperability in theory of all key systems but yet to be tested in practice. 3 – Some minor incompatibilities exist but are being addressed. 2 – Major incompatibilities but plan exists to address them. 1 – Major incompatibilities but no plan. 0 – Interoperability never assessed.	Critical first response systems and procedures will include those in the areas of communications, law and order, fire, first responder, food distribution, etc.). Interoperability needs to be assessed at multiple levels, including: • Communications systems; • Data; • Emergency management applications; • Assumptions, rehearsed procedures and priorities; • Accountabilities (see Essential 1); • Territorial coverage. Physical asset characteristics (for example, fire hose widths for neighbouring fire departments; fuel compatibility for vehicles).	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
9.6.2	Emergency operation centre	Existence of emergency operations centre with participation from all agencies, automating standard operating procedures specifically designed to deal with "most	5 – Emergency operations centre exists with hardened communications and camera-enabled visibility of whole city, and with SOPs designed and proven to deal with "most severe" scenario; all relevant agencies participate. 4 – Emergency operations centre exists with hardened communications and camera-enabled visibility of whole city, and with SOPs designed and proven to deal with "most probable" scenario; all relevant agencies participate.	Operations centre needs itself to be highly disaster resilient! SOP = Standard operating procedures – pre-rehearsed processes and procedures for emergency response.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
		likely" and "most severe" scenarios.	3 – Emergency operations centre exists with SOPs designed for "most probable" scenario (but may not be proven), most agencies participating but incomplete camera visibility or communications. 2 – Emergency operations centre exists but SOPs unproven, participation incomplete and poor camera visibility. 1 – Emergency operations centre designated but with significant generalized shortcomings. 0 – No emergency operations centre.				
9.6.3	Coordination of post event recovery	Coordination arrangements identified in advance for all post-event activities in the city's area, with clarity of roles and accountability across all relevant organizations. Does an organizational chart documenting structure and role definitions at each relevant agency exist, to achieve a single overall point of co-ordination?	5 - There is a clear coordination of all relevant post-response activities. All roles and accountability are clearly defined between relevant organizations. 4 - There is some coordination of post-response activities in the city. However, overlapping roles exist and accountability is not clearly defined. 3 - Coordination of post-response activities is not sufficient. There is currently no clear identification of roles and accountability among relevant organizations in the city. 2 - The city (or focal point/institution) is currently in process of coordination of post-response activities, which will clearly identify roles and accountability among relevant organizations. 1 - The city is currently discussing to start a process to coordinate all post-response activities. 0 - There are currently no plans to coordinate post-response activities.	Also addressed in Essential 9. As for 1.2.1 / 2 – the single point may be a person or a group. Key activities will be: • Day to day government (especially if provided by a stand-in entity such as the armed forces, a neighbouring state etc.); • Longer term management of rebuilding process– an organizational arrangement is needed for including all stakeholders including citizen groups. One major issue will be the speed with which this organization can be assembled and begin operation. The post event organization should in effect be mobilized at the same time as the event response organization.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
Drills							

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
9.7.1	Practices and rehearsals - involving public and professionals	Testing of plans annually, by reference to simulated emergency and actual non-emergency events.	5 – Annual suite of drills validated by professionals to be realistic representation of "most severe" and "most probable" scenarios. 4 – Annual suite of drills broadly thought to be realistic. 3 – Annual suite of drills but not realistic in some significant respects. 2 – Less than annual drills. 1 – Ad hoc partial exercises – not all scenarios tested, not realistic. 0 – No exercises (or no plans – see above).	Drills to include use of/response to education and healthcare facilities. Drills linked to public engagement and local training – see Essential 6. Specific emergency drills may be supplemented by use of sporting events, rallies, parades and other local activities, and also minor versions of the disaster event (e.g. minor flooding, weaker earthquakes) to: • Practice aspects of emergency response such as crowd management; • Test carrying capacity of potential evacuation routes; • Evaluate response and access times, etc. (These may also be used for disaster awareness).	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium
9.7.2	Effectiveness of drills and training	Level of effectiveness of drills	5 – All professional and public participants in drills show strong evidence of having absorbed training. 4 – Most participants show evidence of having absorbed training, with some minor issues. 3 – One or more issues with training evident from outcome of drills. 2 – Several significant skills or knowledge gaps revealed. 1 – Drills indicate that city is broadly unprepared for disaster in terms of training and skills. 0 – No drills.	Requires evaluation of every drill after completion. Training delivery and level of participation – see Essentials 6 & 7.	No additional specific issues required.	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score – Medium

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ESSENTIAL 10: Expedite Recovery and Build Back Better

Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
Post event recovery planning – pre event							
10.1.1	Planning for post event recovery and economic reboot	Existence of comprehensive post event recovery and economic reboot plans.	5 – Fully comprehensive plans exist addressing economic, infrastructure and community needs after "most probable" and "most severe" scenario. 4 – Fully comprehensive plans exist addressing economic, infrastructure and community needs after "most probable" scenario. 3 – Plans exist for post "most probable" event but with some shortfalls. 2 – Plans exist for post "most probable" event but with more significant shortfalls. 1 – Plans exist for post "most probable" event but with generalized inadequacy. 0 – No plan.	Comprehensive post event recovery plans will need to detail (not an exhaustive list): • Interim arrangements for damaged facilities and homes anticipated from "most probable" and "most severe" scenarios; • Locations and sources of temporary housing (if different from emergency shelters – see Essential 9); • Triage policies for inspection, repairs and debris removal and preferred contractors; • Counselling and personal support arrangements; • Community support arrangements – re-initiation of social security, food and other benefits payments; • Economic "re-boot" arrangements – interim tax relief, incentives, etc; • Improvements to city layout and operations sought as rebuilding takes place, to reduce future risk; • Arrangements to ensure social equality – equality of attention, inputs, funding, priority across all neighbourhoods; • Code updates so that rebuilding can be immediate and to better standards than before; • Directory of inspectors trained /	No additional specific issues required (assuming liquefaction assessment is included as part of an earthquake scenario).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium

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Standard UNISDR Scorecard					**Additional Considerations for EILD events**		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
				accredited to assess building damage (particularly relating to red-flagging or red-tagging buildings after floods, storm damage or earthquakes); • Directory of insurance loss adjustors. Plans may be from several organizations, but these should be reviewed for consistency of assumptions and priorities. (Post event organization structures – see Essential 1). (Funding – see Essential 3).			
10.1.2	Extent to which there has been stakeholder consultation around the "event recovery and economic reboot"	Stakeholder involved in build back better plan.	5 – Yes – All relevant groups have been invited and attended. Stakeholders have been fully briefed on the process and receive regular bulletins on the progress of the plan. 4 – At least 8 of the 10 listed groups (right) have been engaged / consulted. 3 – At least 6 of the 10 listed groups have been engaged / consulted. 2 – At least 4 of the listed groups have been engaged / consulted. 1 – At least 2 of the listed groups were invited. 0 – No stakeholder engagement has been undertaken.	The city emergency services; • The local health sector; • Utility providers including telecommunications; • Local businesses and scientific institutions; • NGOs; • Civil society organisations including minority group representation; • Environmental sector; • Business interests; • Other relevant government tiers or agencies; • The wider city population in all neighbourhoods, both formal and informal; • Local universities; • Scientific institutions / industry associations.	No additional specific issues required (assuming liquefaction assessment is included as part of an earthquake scenario).	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium
10.1.3	Shadow financial arrangements for processing	Post event arrangements exist for dealing with incoming financial	5 – Arrangements exist and are believed to be workable. 4 – Arrangements have some minor gaps but are believed to be workable.	May be provided by national government, if still functional, or by a private sector organization such as an accounting firm.	No additional specific issues required	5 [ ] 4 [ ] 3 [ ] 2 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low

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Standard UNISDR Scorecard					Additional Considerations for EILD events		
Ref	**Subject / Issue**	**Question/ Assessment Area**	**Indicative measurement scale**	**Comments**	**Specific Comments for Liquefaction**	**Indicative Score**	**Importance Score**
	incoming aid and disbursing funds	aid and disbursements.	3 – Arrangements have one or more significant gaps that may compromise aspects of workability. 2 – Arrangements have more significant shortfalls that place overall workability in doubt. 1 – Partial or incomplete arrangements only. Unlikely to be workable. 0 – No plan.			1 [ ] 0 [ ]	[ ] Low LIQUEFACT Score - Medium
Lessons learnt / learning loops							
10.2.1	Learning loops	Existence of a process and format for "post-mortems" on what went well and less well in the event response and post-event phases.	5 – Comprehensive plans exist that are shared by all stakeholders they have in fact been used after a disaster – changes have been made to plans and practices. 4 – Comprehensive plans exist but have not been used in live situations – only after drills. 3 – The need to learn is acknowledged and there is some attempt to share learnings, but it is not systematic - there are gaps. 2 – Post event learning is planned by some stakeholders, but to varying degrees and it is not planned to be shared. 1 – Any provision for post event learning is rudimentary at best. 0 – No plans.	This process could be the process used for usual learning and review after drills and practices – the difference being that this is "for real". This learning is critical in helping a city understand how it can 'build back better' and also in improving comprehension of risks. New risks, learning from real events can be reincorporated into to city risk management framework, as outlined under Essential 2.	No additional specific issues required	5 [ ] 4 [ ] 3 [ ] 2 [ ] 1 [ ] 0 [ ]	[ ] High [ ] Medium High [ ] Medium [ ] Medium Low [ ] Low LIQUEFACT Score - Medium

3.4.6 Review of weighting methodologies that could be applied to the subjects/issues contained in the Customised UNISDR Scorecard

The primary aim of this review is to evaluate alternative methods of weighting and aggregation that can be applied to the Customised UNISDR Disaster Resilience Scorecard for Cities. In reviewing alternative methods specific consideration has been given to:

- the semi quantitative nature of the Scorecard (i.e. both the indicative score and relative importance of each subject/issue is assessed using an ordinal scale) which need to be aggregated to provide an assessment of the resilience of each Essential within the Scorecard and of the overall resilience across all the Essentials in the Scorecard; and
- to account the fact that the stakeholders completing the scorecard are likely to come from a range of disciplines who each have different levels of expertise when assessing the impact of earthquakes and earthquake induced liquefaction disaster scenarios.

In order to achieve this aim, an extensive review of literature of existing mathematical methods used to weight and aggregate data was performed and their advantages and disadvantages identified. An initial search through the SCOPUS database using the search terms identified in Table 3.18 (a) identified 433 papers of potential interest to the review. A supplementary search through SCOPUS using the search term (b) identified an additional 22 papers of potential interest to the review. The 455 papers identified were then screened on their title and 375 were removed from further consideration as they were deemed to be not directly relevant to the review. The abstracts of the remaining 80 papers were read and a further 28 were removed from further consideration. Full text copies of the remaining 52 papers were obtained and each of these papers was read in detail. Of these 52 papers, 18 were directly relevant to this review (i.e. they critically reviewed scales of measurement used in community resilience research) and these. These 18 articles were then comprehensively reviewed again where they were segregated of their aims, methodology, key findings, key words, mathematical formulas and relevance. Even though all were relevant in their content, only five articles contained details of mathematical formulations used to appoint a weighting to an indicator and aggregate scores for resilience.

Table 3.18: Search criteria used for SCOPUS study

(a) Initial Search Strategy	
Search Number	***Search Term***
1	"Community Resilience" AND Indicators AND Weighting
2	"Community Resilience" AND Indicators AND Aggregation

3	{Community Resilience} AND Indicators OR Aggregation OR Weighting OR Normalisation OR Mean
4	{Community Resilience} AND Measure
5	{Community Resilience} AND Quantify
(b)	***Further Search Strategy***
Key Words	Quantitative Methods Resilience Mathematical Formulation Numerical Analysis of Qualitative Data Weighting Formulas Aggregation Formulas Quantitative Assessment of Community Resilience Quantitative Frameworks measuring Resilience

Analytical Hierarchy Process

Introduced by Thomas Saaty (Saaty, 1980), the analytical hierarchy process (AHP) is a common and effective tool for dealing with often complex decision making. It allows for a problem being decomposed into a hierarchy and aids the decision maker to set priorities and make the best decision. The hierarchy transforms empirical data into numerical values which makes them further processable and comparable. The numerical transformation also allows the allocation of a weighting to each criterion.

The first step is to translate a complex problem into a hierarchal structure consisting of an overall goal (e.g. resilience assessment), several criteria contributing to his goal (e.g. resilience dimensions like community, socio-economic, critical infrastructure etc.) and then a number of attributes, which are the indicators for each dimension. Then, a pairwise comparison of each cluster pertaining the same level of importance in the hierarchy is performed by experts, who answer two questions: Which of these two elements is more important? and by how much? The preference is expressed on a semantic scale of 1 to 9 where a preference of 1 indicates equality between 2 individual indicators, whilst 9 indicates that the individual indicator is 9 times more important than the one its being compared to. The final step is establishing a weighting, which in this case is a relative weighting of the individual indicator using an eigenvector (OECD, 2008).

A fairly simple but flexible approach makes AHP a widely used comprehendible process for stakeholders. It allows the addition of further analysis methods such mathematical programming and entropy weighting to help better the results of both qualitative and quantitative data. For the AHP to be effective, it requires a high number of pairwise comparisons meaning that smaller data sets may not be able to use this method but on the other hand, if there are too many indicators and comparisons to be made, the addition of cognitive stress may exist invalidating some of the decisions being made. As well as this, the consistency of beliefs and decisions of the experts must be considered as they are not necessarily consistent, making the results less trustworthy. In order to vindicate these from the results, a further process of measuring the degree of inconsistency can be applied in order to help validate the results for their application to the public. Taking this into account, the selection of the expert's panel has to be carefully considered as the judgement is affected by experience, depth of knowledge, relative intelligence, personal involvement, etc. (Saaty, 1980).

Saaty (1996) extended the AHP approach to accommodate a more complicated modelling arrangement in which a number of inter-related hierarchies co-exist within a system. To model these multiple hierarchies, and to account for feedback between the hierarchies Saaty (*ibid*) developed the analytic network process (ANP) (Saaty, 1996)

Benefit of the doubt approach

The benefit of the doubt approach (BOD) is another statistical technique, which originally was proposed to evaluate macroeconomic performance, but has recently been adapted for the evaluation of composite indices. With regards to weighting, BOD assigns higher weights to the indicators that have more beneficial impacts towards the goal (e.g. community resilience) and vice versa with lower impacting indicators. Secondly, indices used in BOD are relative to a benchmark value acquired endogenously through optimisation. Lastly, if no unit has the highest score, then the benchmark will be unit dependant meaning no unique benchmark will exist for all the units under analysis.

BOD is a sensible method to be adapted for national policies, as the weights are determined by the individual observed performances that are relative in that area. Also, the benchmark that is set is also a function of the observed performances rather than a theoretical calculation that is universal for all geographical areas. It also has the ability to integrate the process of weighting and aggregating results, taking away the difficulties of using different methods for an overall score. Saying this, each BOD construction then becomes independent for each area and non-transferrable. Unfortunately, the application of different normalisation methods can lead to multiple potential results and low transparency (Nardo, et al., 2005).

Dependence Tree Analysis

Dependence Tree Analysis (DTA) captures the correlation between a component and its sub-components in a quantitative manner, enabling the computing of the effect that each component has on each other. The first step in building the dependence tree is to identify all the components that are capable of influencing the main output. The tree is constructed of three components;

(1) The main component which is located on the top of the tree (e.g. Community Resilience)
(2) Intermediate component which are the essential components required for the successful achievement of the main component (e.g. Preparedness, Recovery)
(3) Primary components which refer to those that cannot be further split into sub-components (e.g. Risk Assessment, Redundancy).

The value 1 is the highest output that can be obtained by the main component and it means that the components accomplishment is strictly dependent on the accomplishment of its sub-components where the value 0 implies that the component cannot be accomplished even though its sub-components may be deemed as accomplished. (Kammouth, et al., 2016).

Equal Weighting Method

Equal weighting method is the implication of the recognition of an equal status for all sub indicators. It is one of the simplest strategies of weighting that exist and can be easily replicated by others. This type of weighting can be used in situations where all the indicators are considered equally as important as each other, or when there is no statistical or empirical evidence that supports a substitute scheme. Alternatively, it could be the result of the lack of knowledge of the relationships that exist between sub-components and their importance whilst ignorance towards the correct or other method could be another reason as to why equal weighting is chosen (Nardo, et al., 2005).

Factor Analysis

Based on the Common Factor Model, factor analysis (FA) is a collection of statistical techniques used to examine how underlying constructs influence the responses on a number of measured variables (DeCoster, 1998). FA aims to reduce the dimensionality of the data without significant information loss by using linear transformation techniques to reduce the size of the original data set variables into smaller correlated and uncorrelated variables that still depict the original data. By doing this, the data set becomes easier to read and understand as well as being easier to use for further analysis (Dunteman, 1989). Assuming that correlation exists between data items, FA can be used to identify common shared factors and identify weighting values that can be applied to the data items. Statistical techniques are used to select and rank factors and develop a common factor model of the problem being investigated (OECD, 2008). Most commonly, FA is used to examine the interrelationships between indicators. When weighting is concerned, FA is used as an intervention to correct overlapping information between two or more correlated indicators meaning it isn't an actual measure of theoretical importance, reducing the validity of the results when compared to their importance in the real world. Trying to deduce weights using factor analysis requires the data set to contain a high number of indicators with a certain level of correlation to help reduce the number of factors. Unfortunately, this method is also sensitive to modification of its original data set which questions its transferability between different cities and states.

Regression Analysis

Multiple regression models have the ability to handle large number of indicators (Nardo & Saisana, 2008). It is a multivariable technique that assesses the relationship among a set of variables. When there is a single output, the weight of an indicator can be determined by evaluating the relationship the indicator has with it. This approach is suitable for a large number of variables of all different types and can be very useful to verify and adjust weights, or when interpreting sub-indicators as possible policy actions. Because of the interdependencies and complex resilience systems, there may be a need to build multiple models which, however, can lead to poor and invalid results.

Subjective Assessment

The interpretation of community resilience used in the Hyogo Framework (Sendai Framework predecessor) is based on four components (Social, Economic, Physical and Institutional) that each provide a contribution towards the overall community resilience. Each component contains a range of indicators that are scored (1-100% -the higher the score the more resilient the indicator) and then aggregated to provide an assessment of resilience of the four components which in turn are aggregated to provide an assessment of the overall resilience of the community (Ainuddin & Routray, 2012).

Unobserved Component Models (UCM)

Established in the world of economics, UCM is another method that can combine the processes of weighting, aggregation and index construction. The core assumption of this approach is that resilience is difficult to observe directly or that an indicator is an imperfect signal of an unobserved resilience component (Gan, et al., 2017). What UCM does is that firstly, it isolates the informative signal that is common to each indicator to develop the best possible index by optimally combining the data available. The indicators generated by UCM are expressed as a linear function of the unobserved component that has an attached random error term. The whole process can then lead to the generation of indicator weighting using a series of decreasing functions of variance of indicators. One of the most interesting characteristics of this methodology is that it can provide interval estimated of a resilience index instead of a final valuation based on the aggregation of the observed indicators. Also, the UCM's ability to placing data in common units has the advantage of maintaining some of the fundamental information of the underlying data with the ability of being less sensitive to extreme outliers in the data set. Another advantage of the UCM is that the data-driven precision-weighting approach can improve the precision of the overall aggregating indicators. Contrary to this, the model needs enough data to ensure the results are deemed reliable and robust. The data itself, if highly correlated, means the model will not work as it may perform poorly due to identification problems. (Kaufmann, et al., 2010).

Additive Aggregation Method

A widely used linear method of aggregation, additive aggregation uses functions that sum up the normalised values of indicators, calculated through weighting, to form a resilience index. In order for this aggregation technique to be employed, sub-indicators must be independent and simply will be added together to yield a total value of resilience for the particular indicator. Additive aggregation is deemed very transparent and for a non-mathematician it is probably the only concept for averaging a set of numbers (Bullen, 2003). A final resilience index can additionally be calculated and precisely defined once a measurement of error is known. Furthermore, secondary methods like sensitivity analysis and uncertainty quantification can be used to add precision to the calculated index. A drawback of using this method is that it implies there is no interaction, dependency or conflict between different indicators, an assumption that seems so unrealistic as resilience frameworks are known for their interdependencies between factors (Nardo, et al., 2005). Therefore, this method cannot be used in the presence of these indicator interactions or when the interactions are too substantial. One of the major disadvantages of this method is that it is fully compensatory, such that an indicator with a poor performance can be compensated by an indicator with a sufficiently higher performance. When assessing two different indicators, one with the score of 21,1,1,1 and the other with 6,6,6,6 would have equal results if additive aggregation was to be used, not reflecting the very different conditions present (OECD, 2008).

Geometric Aggregation

Used as an in-between solution in a multi-criterion framework, geometric aggregation methods utilise multiplicative functions. Additive aggregation is deemed as fully compensatory but geometric aggregation only allows for compensability between indicators with certain limitations. These types of methods limit the ability of low scoring indicators to be fully compensated by high scoring indicators. What it also does is highlight indicators with relatively low scores to stakeholders allowing a better chance of improving its position in the ranking by the addressing of the issues within that area (OECD, 2008). It must be considered that geometric aggregation methods are not fully non-compensatory thus allowing some sort of trade-offs between indicators resulting in not having a true reflection of the indicator performance. Unlike additive aggregation techniques, further sensitivity and uncertainty cannot be analysed.

Non-Compensatory Aggregation

Multi Criteria Decision Making (MCDM) deals with decision making in the presence of a number of decision criteria with the aim to elicit clear subjective preferences. Quite rightly then a resilience assessment is a very complex multi-criteria problem. Non-Compensatory methods are based on linear aggregation function and the perspective of MCDM. There, the non-compensatory multi-criteria approach is based on decision maker preferences and is centred around the fact that a general objective of most indices is to create rankings. It constructs a ranking algorithm that is more consistent than linear aggregation rules by (1) comparing pairwise indicators according to the whole set of sub-indicators to form a ranking matrix and (2) ranking the indicators in a complete pre-order according to the ranking matrix. (Munda & Nardo, 2005). Unlike the other methods, there are no restrictions on the types of variables or indicators that can be used allowing interdependencies that are often found in MCDM frameworks. The two possible drawbacks of this method are computational limitations and the loss of information on the intensity of resilience (OECD, 2008); (Munda & Nardo, 2005).

Implications for the EILD customised UNISDR Scorecard

The purpose of this review was to compare alternative approaches to weighting and aggregation that can be applied to the Customised UNISDR Disaster Resilience Scorecard for Cities. The primary aim of the scorecard is to evaluate the antecedent resilience of a city/region community to an EILD event. To this end, the scorecard comprises 10 Essentials grouped into three Domains (corporate/city governance, integrated planning and response planning). Each of the 10 Essentials into comprise a number of subjects/issues, again grouped into a series of factors, that are scored using a 0-5 scale to reflect the cities/regions compliance against a range of quality indicators and a 1-9 scale (1-low; 3-medium low; 5-medium; 7-medium high; 9-high) to reflect the relative importance of the subject/issue to the city/region. Thus, a baseline measurement of the city/regions level of disaster resilience can be calculated for: each Factor (by aggregating the subject/issue scores across the Factor); for each Essential (by aggregating the factor scores across the Essential); for each Domain (by aggregating the Essential scores across the Domain); and for the overall city/region (by aggregating the Domain scores).

With regard to the most appropriate way of aggregating the scores at each level, as the scorecard is naturally organised into a series of hierarchies it would appear that applying a hierarchical model, either AHP or ANP would be the most appropriate. This said, the operational difficulties (both in terms of time taken to complete pairwise comparisons and the level of inconsistency that such comparisons can generate) might well render both AHP and ANP approaches impracticable for most city/regions. As such, a simplified approach, using a simple weighted average aggregation procedure where the subject/issue score is multiplied by the relative importance indicator and then simply summed across Factors, Essentials and Domains may prove more robust and reliable approach.

Both the hierarchical and simplified summation approach will be evaluated when the customised scorecard is validated as part of LIQUEFACT WP7.

3.4.7 Applying the customised UNISDR Scorecard for EILD Events as part of the RAIF

The customised UNISRD Scorecard will be validated through a series of use-cases in WP7. The customised scorecard will be applied to a hypothetical simulation of a city/region that is susceptible to EILD events. A series of workshops will be held with proxy stakeholders (experts who will play the role of different stakeholder groups in the hypothetical simulation) who will apply the scorecard to the hypothetical city/region:

- providing indicative scores is for each subject/issue;
- developing relevance and importance weightings for each subject/issue within each Essential and across Essentials using both a subjective methodology and pairwise comparison; and
- identifying potential mitigation interventions that would be needed to improve the resilience score of that subject/issue.

Following the workshop researchers from LIQUEFACT will calculate antecedent and post mitigation community resilience scores for the hypothetical city/region using both the subjective methodology and pairwise comparison methods. Indicative costs associated with the potential mitigation interventions will be calculated using the CBA methodology presented in this deliverable to provide a cost benefit score that can be used to prioritise the different mitigation intervention options. The use-cases will be reported as part of WP7.

4.0 Critical Infrastructure Resilience Tool

LIQUEFACT deliverable D5.1 (Bartolucci and Jones, 2017a) presented a critical review of the theory pertinent to assessing critical infrastructure resilience to EILD events and LIQUEFACT deliverable D5.2 (Bartolucci and Jones, 2017b) described its application to the development of the LIQUEFACT Critical Infrastructure (CI) Resilience Assessment tool. The first version of the tool proposed in D5.1 was refined through a further comparison with previous tools for resilience assessment proposed in literature. The second version of the tool was presented in Morga and Jones (2019). This chapter presents an overview of the previous versions of the tool introduces the third and final version of the tool together with the beta version of the scorecard proposed to apply the tool.

4.1 Identification of the approach for resilience assessment of Critical Infrastructures to an EILD event

CIs are composed by several elements and their functionality depends on several factors. In 2004 the European Council defined "Critical Infrastructure" as "'those facilities and networks, services and assets the destruction or disruption of which would have a serious impact on the health, safety or security or economic well-being of citizens or the effective functioning of government in the Member States" (European Council, 2008). The Green Paper of the European Programme for Critical Infrastructure Protection (Commission of the European Communities, 2005) identifies the following sectors as Critical Infrastructures:

1. Energy,
2. Information, communication technologies,
3. Water,
4. Food
5. Health
6. Financial
7. Public and legal order and safety,
8. Civil administration,
9. Transport
10. Chemical and nuclear industry.
11. Space
12. Research.

It defines also two additional concepts: interdependencies and National CIs. The second ones must be identified within the Member States (MS) and their protection is interest of all MS. This strategic document indicates reduction of single points of failure, planning for recovery arrangements and testing the infrastructures as the strategy to protect them and increase

their security; finally, it identified MS, infrastructures owners and operators as responsible for protecting CIs (Commission of the European Communities, 2005).
According to this definition of CI in LIQUEFACT D5.2 (Bartolucci and Jones, 2017b), a tool including indicators that affect the CI resilience was presented. The set of indicators were defined through a compared study of the results of few European research projects dealing with resilience of CIs to natural hazards. LIQUEFACT CI resilience tool classifies those indicators in Factors and Sub-factors, which are partially related to the European Council's definition of CI. In fact, it defines "facilities and networks, services and assets" as CIs and LIQUEFACT tool classifies the indicators in "Organization & management", "Technical systems" and "Operational Delivery systems" factors. While the first and the third categories are related to "services", the second one refers to "assets". Moreover, the classification in "assets" and "services" is related to the literature well-known classification of "hard infrastructures" and "soft infrastructures" (Aradau, 2010). Indeed, the expression "hard infrastructure", or lifelines, identifies physical CIs and "soft infrastructure" indicates CIs based on organizational foundation. However, none of CIs classified as hard excludes the presence of an organizational foundation that guaranties the functionality of the physical components; as well, none of the soft infrastructures does not have any physical component, such as buildings or networking assets. The international standard on business continuity management systems (ISO 22301:2014) supports this statement as it defines resources "all assets, people, skills, information, technology", "premises, and supplies and information that an organization has to have available to use". Therefore, the indicators collected in LIQUEFACT CI resilience tool are suitable for all kinds of infrastructures.

The CIs complexity is represented satisfactory by system (of systems) models and it can be analysed through empirical, theoretical, or judgement-based approaches. The analysis method defined as the most suitable depends on the category to which they belong. Empirical and theoretical analysis methods are applied to hard CIs, while soft CIs are easily analysed through judgement-based approaches. Taking into account the complexity of CIs composed by both hard and soft components, LIQUEFACT CI resilience tool was developed to apply a judgement-based approach. In fact, also the uniqueness of CI systems including soft components makes difficult the use of empirical approaches, while theoretical approaches are difficult to apply because of mathematical functions to use to model the soft components.

The complexity of CIs is increased further by the vagueness of the boundaries of their service and their management and their imperfect overlapping. This is clear by looking at the complexity of the community boundary in geographical and administrative terms and the interrelationships existing among the different levels of the community (EDUCEN, 2019). The geographic aspect of the hazard, the infrastructural asset and the urban and rural development pattern has also an important role. In particular, the localized occurrence of soil liquefaction phenomena respect to the more diffused earthquake events causes a lower vulnerability of infrastructure assets either horizontal or localized in small areas to the first threat than the second one. However, whilst for horizontal infrastructures the redundancy is critical to reduce the vulnerability to localized threat, but it requires a considerable effort in terms of organization and hazard and vulnerability assessment; for infrastructures localized in small areas, risk assessment and strengthening require less effort in term of hazard and vulnerability assessment. This highlights that the resilience assessment to EILD is strongly influenced by different elements/indicators for each kind of CI. This is a further reason to select resilience indicators suitable for all kinds of CIs to include in LIQUEFACT CI resilience tool.

4.2 LIQUEFACT CI resilience tool: version 1

The first version of LIQUEFACT CI resilience tool was proposed in D5.1 (Bartolucci and Jones, 2017b) and included around 50 indicators (see Figure 4.1). Those indicators were selected across tools proposed in other FP7 or H2020 European projects (Bartolucci and Jones, 2017a) and in particular from the CI-RAT of the project ResiLENS (ResiLENS, 2016) and the tool of the project EU-CIRCLE (EU-CIRCLE, 2016).
Some of the indicators included in the first version of Liquefact tool are related to the primary health care scenario presented in D1.3 of Liquefact (Bartolucci and Jones, 2016). In fact, the indicators in the sub-factor “Physical asset” refer to buildings and those in the sub-factor “Asset infrastructures” clearly refers to building services.
The indicators were organised hierarchically in order to apply the Analytical Hierarchic Process (AHP) and the Analytical Network Process (ANP). This allows the identification of the system elements measured through an indicator that should be modified in order to enhance the CI resilience.
In this document, a complete analysis of the first version of LIQUEFACT CI resilience tool is neglected, as it was presented in a previous deliverable of the project.

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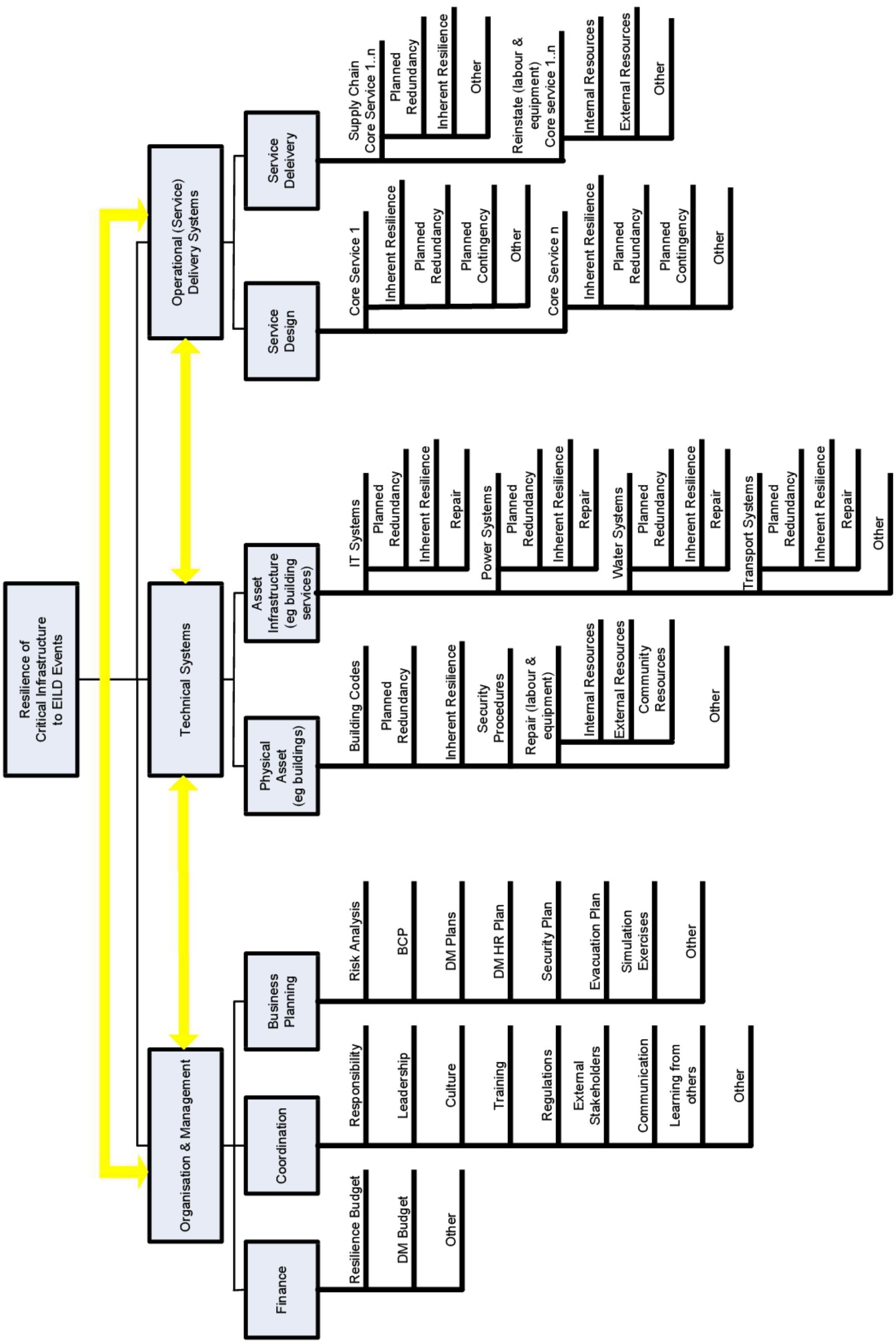

Figure 4.5 LIQUEFACT CI resilience tool: version 1 (Bartolucci and Jones, 2017a)

4.3 LIQUEFACT CI resilience tool: version 2

The second version of LIQUEFACT CI resilience tool (figure 4.2) was developed by critically reviewing the definition of CI resilience for both hard and soft infrastructure and the suitability of the selected indicators to EILDs. Moreover, the temporal evolution of CI resilience is introduced in the tool by a reorganization of its tools.

The CIs resilience is defined as the capacity of the infrastructure system to withstand to a threating event and recover from it. This implies the system is characterised by robustness and rapidity. Whilst the robustness is described as the system capacity to operate after a disrupting event; the rapidity measures how fast the system recover and spring back to its performance ex-ante the event (McDaniels et al., 2008). The first of those capacities is related to the hard components of the CI; whereas the second characterizes its organizational components (McDaniels et al., 2008). Both CI characteristics inform the system preparedness to the disaster; however, only the organizational components are strongly involved in the ex-post phase of a disaster (McDaniels et al., 2008). A new preparation phase to a next similar disaster is permeated by the capacity of the CI socio-organizational components to learn from the past events and adapt themselves. The identification of a social component within CIs highlights the necessity to clarify the connection between community and CIs.

A large number of studies about community resilience were proposed in the past decades. Some of them presented assessment frameworks and identified four aspects of community resilience: robustness, redundancy, resourcefulness and rapidity (Tierney and Bruneau, 2007; Bruneau et al., 2003). Other studies stated the importance of CIs as subsystems for the community and highlighted the impact of CI resilience on community's recovery speed (Bruneau et al, 2003). In further studies, different dimensions of the community resilience were identified: technical, organizational, social and economic (Bruneau et al., 2003). As highlighted in a previous work, among those dimensions only the social one appear to be not related to CI resilience (Morga and Jones, 2019). In fact, the technical dimension identifies the physical asset and services related to the infrastructures, while the economic and organizational dimensions contain elements related to operational and organizational parts of CIs. However, both the social and organizational dimensions of the community system are linked to the institutional subsystem, which is linked to the infrastructures. Moreover, the social subsystem of community is part of the infrastructure, as people manage and direct CI operational level. A further framework identified five dimensions of the community resilience: environmental, infrastructure and physical, social, economic and institutional (Sharifi and Yamagata, 2016). The infrastructure and physical dimension clearly are connected to CIs, while the economic and organizational dimensions can be linked to the organizational dimension of CIs (Sharifi and Yamagata, 2016). The identification and definition of the CI factors and sub-factors was defined in the first version of LIQUEFACT CI resilience tool. In the

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second version of the tool factors and sub-factors were called dimensions and sub-dimensions in accordance to the reviewed literature frameworks about community resilience.

The second version of the tool introduces a dynamic prospective of CI system resilience. As the disaster temporal development overlaps upon the CI life-cycle, phases within the CI resilience could be identified. Previous studies about the community resilience distinguish four different phases of the community resilience: planning, absorption, recovery and adaptation (Larkin et al., 2015). In accordance to these phases as many aspects or abilities of the resilience are identified:

- Preparedness,
- Absorption,
- Recovery,
- Adaptivity.

According to other studies, the phase of system adaptation is part of its response to the disaster, while the recovery occurs together with adjustment (Bhamra et al., 2011; Ponamarov and Holcomb, 2009). However, those studies are based on the hypothesis that the system is complex and not informed by operational rules, rather than by adaptive organizational links. This is the case of the DROP model proposed by Cutter et al. (2008). In CIs, operations are rugulated by standards, plans and courses of actions; this limits their adaptive ability. Thus, the adaptation process occurs only during or after the recovery phase. Moreover, the adaptation phase informs the preparation phase to the next disrupting event to reduce the disaster risk.

The second version of LIQUEFACT CI resilience tool proposed the same resilience indicators of the first version but classified according to the four aspects distinguished for the CI resilience (Figure 4.3) to understand which mostly affects the resilience of a selected CI.

The adaptivity of a system is an aspect of its resilience and it generally indicates the system ability to cope with the adverse conditions by implementing prospective or reactive adaptive actions (Scholz et al., 2011). Those actions can be implemented by the system while it copes with the disaster and reacts to it or after the recovery from the disaster as preparation to withstand to similar disasters. In LIQUEFACT CI resilience tool, it characterizes what occurs after the recovery from a disaster and the preparation to the next disaster. In fact, codes, plans and processes regulate infrastructures, which are not “agile” systems, as the “community”. Hence, the risk management informing the resilience is plan-based for “infrastructure” system, whilst it is “decision”-based (Scholz et al., 2011) for the “community” system.

For the second version of the tool the suitability of the selected resilience indicators to IELDs was tested through a comparison analysis of one of the framework used to define the tool and two other frameworks put forward for the CI resilience appraisal (Morga and Jones, 2019). In particular, those frameworks are respectively the CI-RAT proposed in ResiLENS project (ResiLENS, 2016), and the CI Resilience tool proposed by the National Infrastructure Advisory Council in US (Berkeley and Wallace, 2010) and the tool for a-priori assessment of CI resilience proposed by the Risk and Resilience Group (Prior, 2015) at ETH, Zurich. The comparison shown in Tables 4.1, 4.2 and 4.3 highlights that most of the indicators developed for the assessment of CI resilience to other hazards are suitable for IELD events. However, it is worth of mention that worldwide design guidelines or standards do not number earthquake induced soil liquefaction hazard amongst threats to consider for a robust design of lifelines. This is clear from the matrix proposed by the American Lifeline Alliance for USA (American Lifelines Alliance). In fact, in that matrix the earthquake cascade hazards, such as tsunami, earthquake induced landslide and earthquake induced soil liquefaction, are missing among the possible threats. As consequence, lifelines could result vulnerable to those cascade hazards.

Table 4.4 CI resilience components included in CI-RAT tool ResiLENS, 2016; Morga and Jones, 2019)

Requisite (ResiLENS, 2016)	Elements (ResiLENS, 2016)	Applicable to EILDs (Morga and Jones, 2019)	Dimensions and indicators of Liquefact CI resilience toolkit (Morga and Jones, 2019)
Preparedness, prevention, protection	Organization and coordination	Y	Management (Responsibility, Disaster Management (DM) HR plan)
	Organization dynamics including leadership, culture, decision making, internal and external relationship	Y	Management (Leadership, culture, external stakeholders)
	Budget and financial capacity including budget for protection, redundancy, financial capacity to realize allocated budget	Y	Management (Disaster M budget and Resilience budget, Business Contingency Plan (BCP))
	Risk management	Y	Management (Risk analysis, security plan, regulations) and Technical (Security procedures)
	Safeguarding CI assets with electronic and physical means	N	-
	Safeguarding mission critical systems	N	-
Mitigation, absorption and adaptation	Building codes and infrastructure hardening	Y	Technical (Building codes, redundancy planning, repair)
	Early warning and information management systems	Y	None – Element not considered in Liquefact project

	Robustness, redundancy and backup	Y	Technical and Operational (Planned redundancy, inherent resilience)
	Immediate actions	Y	Management (Evacuation plan, BCP)
Response, recovery and learning	Education and learning including training, education, openness and improvement	Y	Management (Training, learning from others)
	Responsiveness including business continuity planning and exercises	Y	Management (Simulation exercises, BCP)
	Resource provision	Y	Management, Technical and Operational
	Learning from others, i.e. actions and information sharing	Y	Management (Learning from other, communication)

Table 4.5 CI Resilience framework proposed by the National Infrastructure Advisory Council (Berkeley and Wallace, 2010; Morga and Jones, 2019)

Category (Berkeley and Wallace, 2010**)**	**Indicator (**Berkeley and Wallace, 2010**)**	**Applicable to EILDs** (Morga and Jones, 2019)	**Dimensions and indicators of Liquefact CI resilience toolkit** (Morga and Jones, 2019)
A-priori	Probability of failure	Y	Management (Risk analysis)
	Quality of infrastructure	Y	Technical
	Pre-event functionality of the infrastructure	Y	Technical (Repair)
	Substitutability	Y	Technical (Redundancy)
	Interdependence	Y	Service (Supply chain)
	Quality/extent of mitigating features	Y	Technical (Repair)
	Quality of disturbance planning/response	Y	Technical (Inherent resilience)
	Quality of crisis communications/information sharing	Y	Management (Communication and external stakeholder)
	Security of infrastructure	N	-

Table 4.6 CI Resilience indicators collected in the tool for the a-priori appraisal (Prior, 2015; Morga and Jones, 2019)

Category (Prior, 2015)	**Factor (Prior, 2015)**	**Applicable to EILDs (**Morga and Jones, 2019**)**	**Dimensions and indicators of Liquefact CI resilience toolkit (**Morga and Jones, 2019**)**
Infrastructure design and asset characteristics	Interconnectedness	Y	Service (Inherent resilience)
	Asset profile	Y	Technical (Repair)
	Product/Service profile	Y	Service (Reinstate)
	Design limitations		
	Cyber dependence	Y	Service (Inherent resilience)
Supply chain vulnerability	Availability of critical components	Y	Service (Reinstate)
	Domestic sources	N	-
Sector interdependencies	Dependencies	Y	Service (Reinstate)
	Co-location	N	-
Sector risk profile	High-profile target	N	-
	Strategic assets	N	-
Markets and regulatory structure	Regulatory constraints	Y	Coordination
	Market structure	N	-
Public-private roles and responsibilities	High-impact, Low frequency risks	Y	Management (Responsibility, culture)
	Disaster coordination	Y	Management (Communication, external stakeholder)
Standards	Standard bodies	Y	Management (Regulation)
Information sharing	Threat information	Y	Management (Communication)
	Clearances	N	-
Workforce issues	Capabilities	Y	Management (Training, leadership)

By the definition proposed in of the European Programme for Critical Infrastructure Protection (Commission of the European Communities, 2005), CIs are interdependent, i.e. one supplies a service to another. This makes the resilience assessment of single CIs complicate. The relation among different organizations operating in a region had been investigated by studies, such as the one carried out after the 2010/11 earthquake in Canterbury (Brown et al., 2014), which showed that among all CIs the road network had been the one with the outage lasting longer and affecting most of the organizations. Water, sewage, electricity, phone networks and data network caused very disruptive consequences, whereas the road network outage had catastrophic consequences because it lasted more than few days. Despite this and other evidences of consequences of CIs interdependency, LIQUEFACT CI resilience tool neglected part of interdependencies among CIs and proposes the hierarchic organization of resilience indicators. However, the interaction with “upstream” and the “downstream” infrastructures or services of each CI (i.e. respectively those providing a service to the analysed infrastructure and those to which the analysed infrastructure provides a service) is considered not as an interdependency among infrastructures but as part of the infrastructure itself. The “upstream” infrastructures and services are modelled both as physical elements through the indicators in “infrastructure services” sub-dimension and as service provided to the analysed infrastructure, through the “planned redundancy” indicators in the service design. The interaction with “downstream” infrastructures or services is modelled through the “external stakeholder” indicator included in the coordination “sub-dimension”.

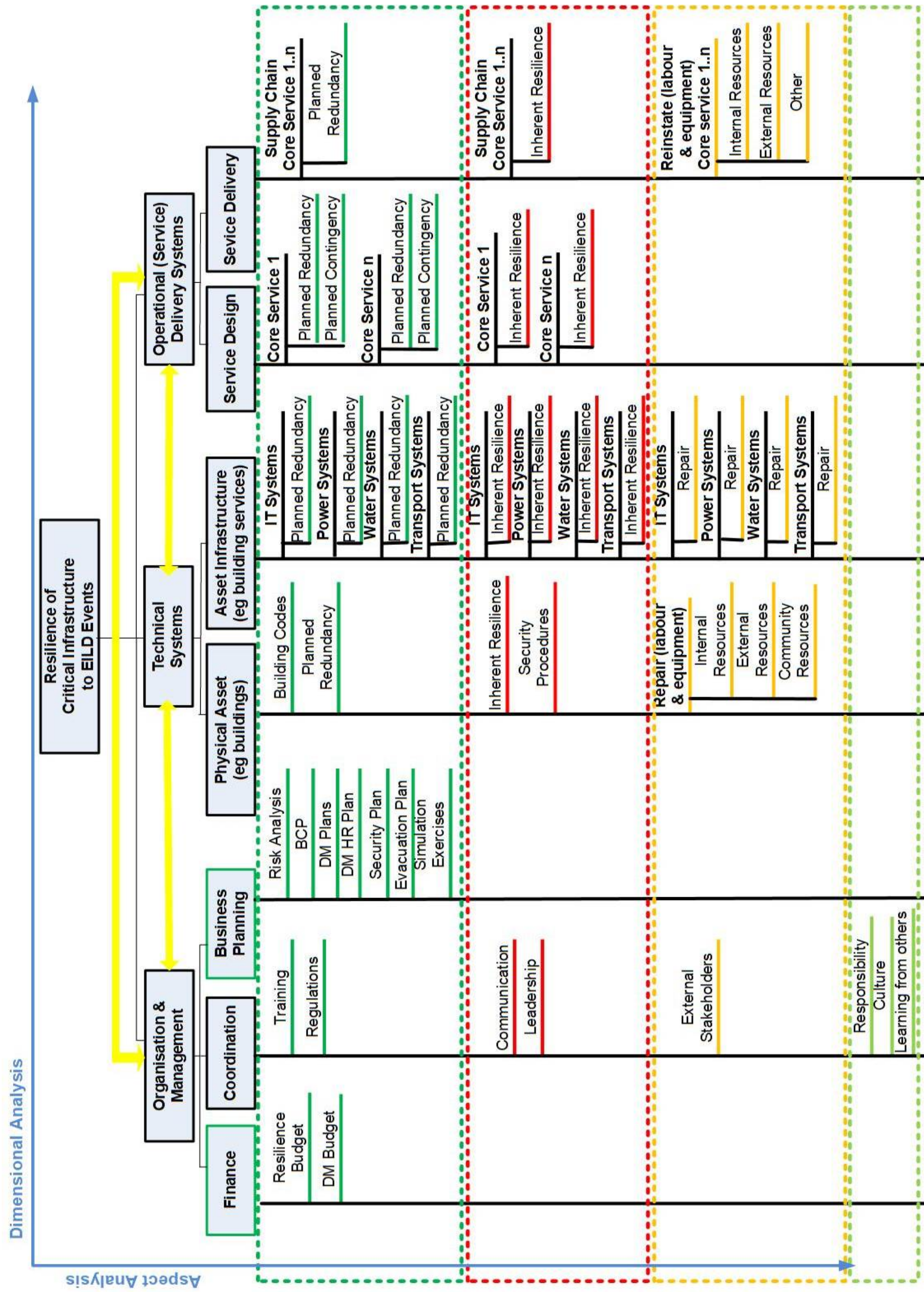

Figure 4.6 Second version of LIQUEFACT CI resilience tool (Morga and Jones, 2019)

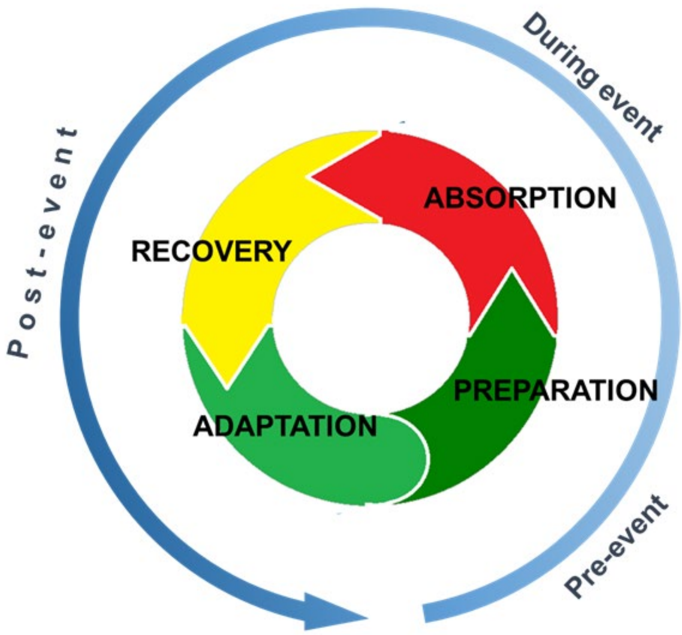

Figure 4.7 CI resilience phases and disaster phases (Morga and Jones, 2019)

4.4 Third and final version of Liquefact CI tool

In this deliverable, the final version of LIQUEFACT CI resilience tool is proposed. An additional aspect of the CI resilience is introduced: institutional and lawmaking (Figure 4.4). In the resilience temporal evolution, this aspect is equivalent to the lawmaking phase and it is part of the preparation phase to the disaster. This aspect affects all indicators of the CI preparation to EILDs. Thus, a further critical review of the indicators included in the tool is carried out and three temporal sub-phases of CI preparation to disaster are recognised: lawmaking, actions planning and plans implementations. During the first sub-phase standards and guidelines are formulated through procedures occurring at institutional level with direct or indict participation of the community; whereas during the second and third phase action plans are developed and implemented by each CI.

The management and development of organizations is promoted by plans. According to ISO 22301:2014(ISO, 2014), organizations should have three different plans:

- Strategic,
- Management,
- Contingency.

Similarly, some scholars distinguished strategic, tactical and emergency plans as levels of the infrastructure preparedness to disasters (Rossi et al., 2008). Whilst the strategic plan numbers sources suited to overcome a disaster; the tactical (or management) plan refers to resource and infrastructures management strategy; finally, the emergency (or contingency) plan collects all operations and resources needed in case of emergency.

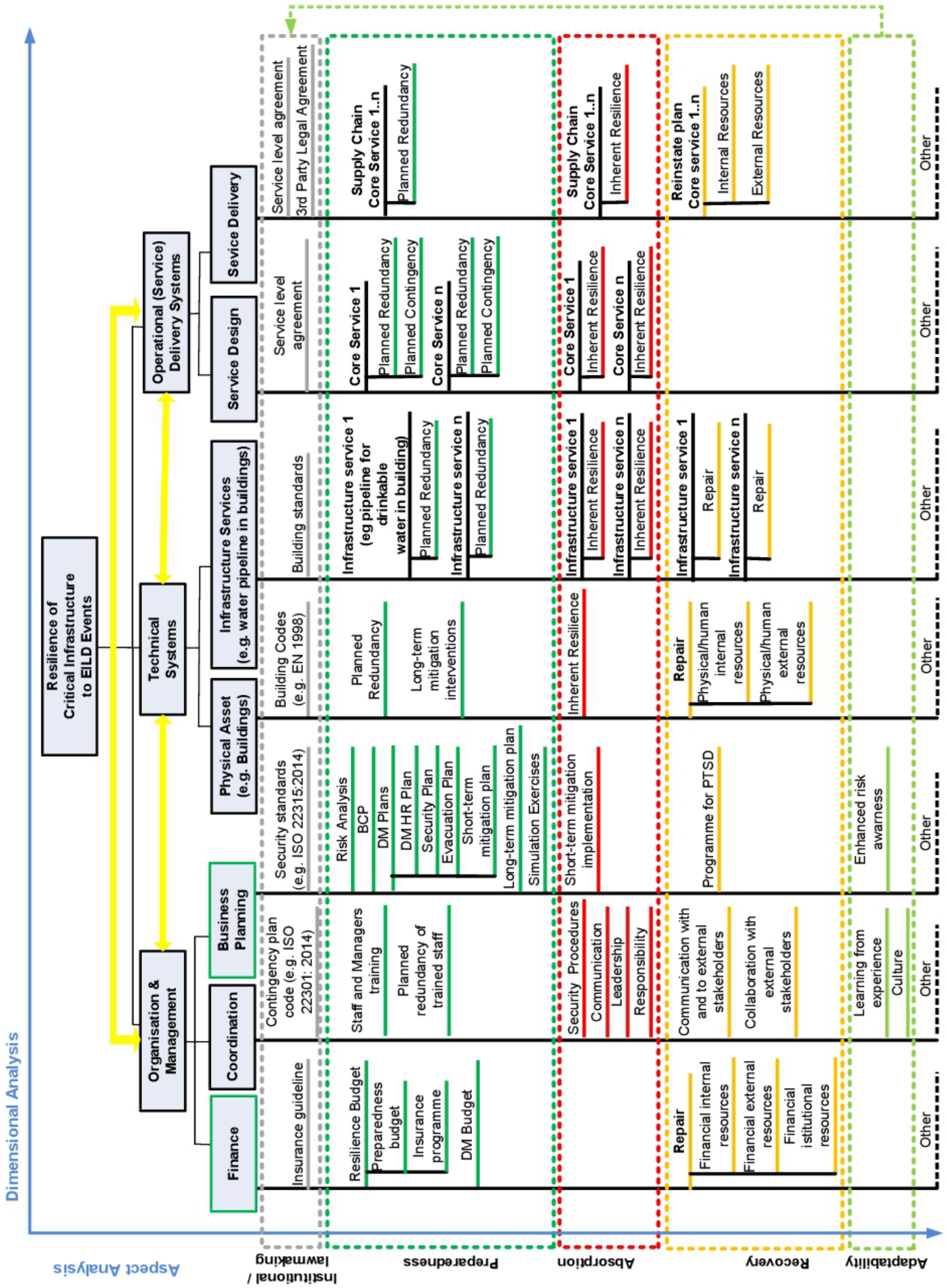

Figure 4.8 Final version of LIQUEFACT CI resilience tool

Therefore, the indicators included in the preparedness aspect of the second version of LIQUEFACT CI resilience tool are classified respect to those plans and a few as related to the implementation actions of those plans (Figure 4.5).

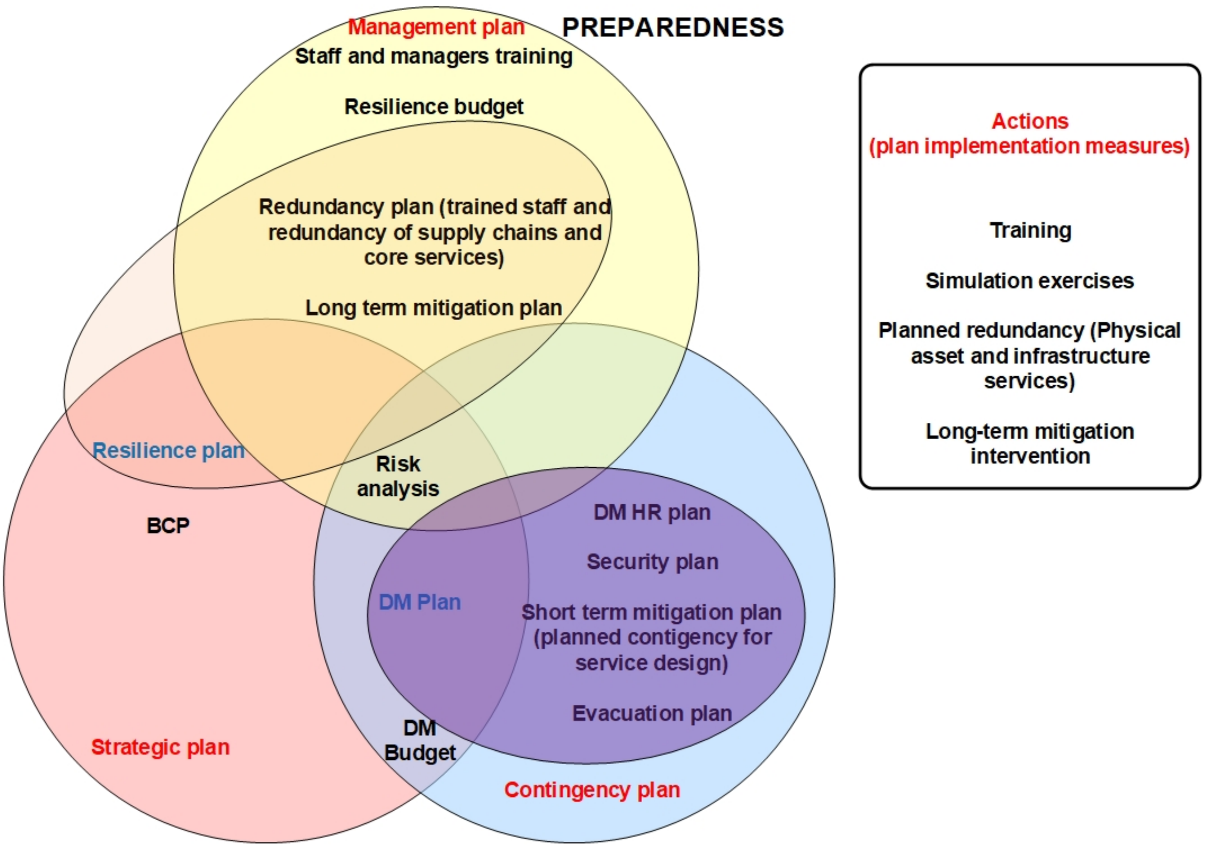

Figure 4.5: Preparedness indicators of LIQUEFACT CI resilience tool classified in plans (according to ISO 22301:2014)and implementation actions

The diagram of CI preparedness (Figure 4.5) shows that the "Disaster Management (DM) plan" includes few elements, i.e. "DM HR plan", "Security plan", "Short-term mitigations plan" and "Evacuation plan", and it is also called "Contingency plan". The "short-term mitigation plan" is an element/indicator added in the final version of CI resilience tool and it is related to the "planned contingency" included in the "Service design". The "DM plan" is part of the strategic plan as well, together with the "DM budget". The "Business Continuity Plan" (BCP) and the "Resilience plan" are also numbered among the "Strategic plan" elements. Moreover, the "Resilience plan" includes "Redundancy of supply chains", "Redundancy of trained staff", and

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”Long-term mitigation plan”. The “Redundancy of trained staff” is also a new indicator introduced in the final version of the CI resilience tool, as well as the “Long term mitigation plan”. Whereas the first indicator resulted from the literature review of the Canterbury earthquakes, the second is extracted from ISO 22301:2014. The “Resilience plan” is part also of the “Management plan”, which includes additionally “Staff and managers training” and ”Resilience budget”. The indicator “Risk analysis” is an element/indicator included in all three plans defined by the ISO 22301:2014. Few indicators, such as “Training”, ”Simulation exercises”, “Implementation of planned redundancy” of both the physical asset and infrastructure services and ”Long-term mitigation interventions”, are implementation actions of the plans. Although some indicators are embedded in others, the separation of implementation action from the plan highlights the CI capacity to self-organize and prepare ex-ante to a disaster. Therefore, all the elements included both in plans and actions and their corresponding indicators included in Liquefact tool estimate the a-priori CI resilience. It is worth to remind that the preparedness is recognised as the easiest resilience aspect to manipulate and enhance in order to meet the goal of improved community resilience (Bruneau et al., 2003) ex-ante disasters. Thus, LIQUEFACT proposed a clear scheme of the correlation amongst the preparedness indicators.

The experience defined in terms of “Learning”, developed risk “Culture” and ”Increased risk awareness” in staff, senior managers and institutional leaders form the basis for the preparation to the next disaster and allows the a-posteriori assessment of CI resilience. The experience provides input to institutional/lawmaking ability of the CI resilience together with community’s expectations established through processes of participatory democracy (Figure 4.6).

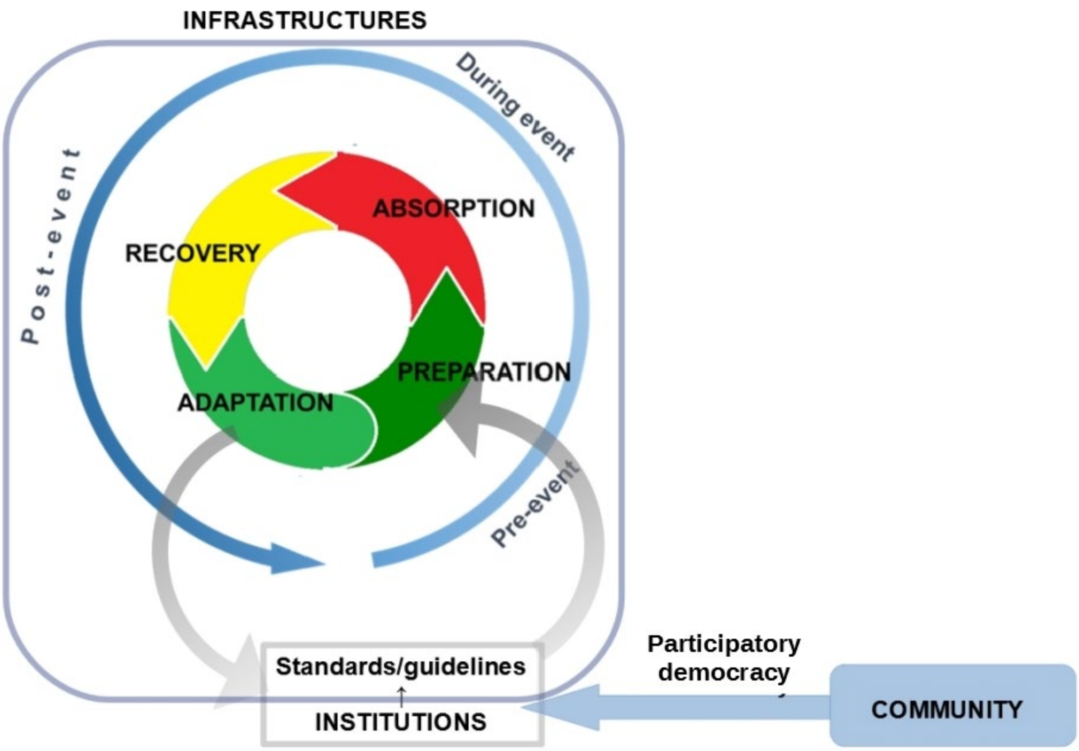

Figure 4.6: CI resilience and disaster phases and link between CIs and community

4.5 Description and analysis of the indicators selected for the final version of LIQUEFACT CI resilience tool

The third and final version of LIQUEFACT CI resilience tool presents few indicators missing in the previous two versions of the tool. For this reason, a description of all indicators of the final version of the tool follows.

Sub-dimension: *Finance*

Insurance guidelines. In Europe insurance of commercial and private line is not compulsory, as it would limit the free market (Insurance Europe, 2013). However, in few MS insurance are compulsory for some threats. In particular, in France, in Belgium (for commercial low values elements and for private line), in Norway (for commercial line only) insurance for earthquakes is compulsory (Insurance Europe, NatCat). However, in any of those countries insurance is not explicitly compulsory for earthquake cascade hazards, such as soil liquefaction events. In all other MS, insurance covering earthquake damages is optional. As consequence, the value of this indicator depends on the geographical location of the CI. Finally it is important to remind that the Insurance Union can be a soft infrastructure of a State.

Resilience Budget. This is the budget that CIs must estimate and use to plan and operate actions to reduce their vulnerability to EILDs and speed up their recover after them. This includes all CI costs of its preparedness to the disaster and the internal financial resources allocated for the repair in case of disruption. This budget should include the cost of an insurance plan as well. The need of such kind of resources is identified in ERMP (Gaitanidou et al., 2018).

- **Preparedness budget**. This is the amount that CIs must estimate and use for all actions needed to increase their preparedness to EILDs (e.g. long-term mitigation actions, redundancy of core services and supply chains, staff and managers training).
- **Insurance programme**. The European Resilience Management Guidelines (ERMG) highlights that CIs must evaluate their financial need in case of emergency and recovery from a disruption, plan to cover those needs and estimate their capacity to involve stakeholders and obtain their financial support (Gaitanidou et al., 2018). ERMG suggests that CIs need to arrange an insurance and have a re-insurance plan. According the ERMG, a good estimation and plan of needed financial resources affects the infrastructure resilience (Gaitanidou et al., 2018).

DM budget. This are the amount of financial resources allocated by a CI to deal with an emergency. For example, it pays short-term mitigation implementation, and actions to ensure the supply chain to the core services.

Repair. Repair costs can be covered with different resources: internal, external and institutional.

- **Financial internal resources**. These are the capital expenditure budget and the operation expenditure budget of the CI. Whilst the first budget can be used to cover the repair costs of heavy damages of the built asset after EILDs; the second one can be used to cover the cost of minimal damages, such as equipment damages.
- **Financial external resources**. These are the insurance payout and amount provided by stakeholders.
- **Financial institutional resources.** These are the financial aid that the State of some European Countries pays after a disaster (Maccaferri et al., 2012).

Sub-dimension: *Coordination*

Contingency plan code. National and international standards define plan and actions to apply in case of contingency. ISO 22301:2014 indicates the elements to be included in a generic contingency plan. However, standards or guidelines for specific CIs can provide indications about security measures in case of emergency.

Staff and managers' training. The ERMG identifies also the need of cooperation skills and training for the staff and managers (Gaitanidou et al., 2018) in case of emergency.

Planned redundancy for staff. According to the study carried out in New Zealand after Christchurch earthquake and soil liquefaction events in 2011 by Resilient Organizations Ltd, the staff ability to deal with different tasks in case of disaster increases the resilience of an organization (Resilient Organizations LTd, 2014). Infrastructures are major organizations; therefore, this element is included in Liquefact CI toolkit. The ERMG identifies also the need of redundancy of all staff, as affecting the resilience of the whole infrastructure (Gaitanidou et al., 2018).

Security procedures. CIs must have a plan of the security procedures in case of disaster, in order to contain cascade effects to people, environment and other infrastructures. This plan must be tailored respect to the kind of CI and the environment in which it operates.

Communication. Communication is a critical element during the absorption of a disaster in order to reduce unnecessary cascade effects. However, it plays an important role also before the disaster. In fact, the Business Contingency Management System policy shall be communicated within the organization (ISO 22301:2014). Moreover, communication is identified as an element interconnecting several systems at urban or regional scale (Chang et al., 2014). Extending this concept communication is the link between the physical system and human one (Chang et al., 2014). In LIQUEFACT CI resilience tool, this indicator refers to the staff members' ability to communicate during the crisis to each other and with the senior staff.

Leadership. The ability of senior managers to coordinate the operations during crises (i.e. the disaster absorption phase) by taking timely decisions, defining priorities and leading the staff is critical for the organizations' resilience, as pointed out by some studies (Resilient Organizations Ltd, 2014; Hatton et al., 2018) and advised by the ERMG (Gaitanidou et al., 2018). A hierarchic internal organizational system of the organization with a leadership in charge of defining and knowing the business contingency management system policy is a requirement for all organizations (ISO 22301:2014).

Responsibility. This factor indicates the staff's ability to be proactive during the crisis. This factor had been analysed in previous studies, such as those investigating the factors that played a major role in the organizations' resilience during 2011 Christchurch earthquakes (Resilient Organizations Ltd, 2014).

Collaboration with external stakeholder. External stakeholders might have an impact on the CI resilience recovery speed, although it is weak according to Hatton et al.'s analysis (Hatton et al., 2018). Among external stakeholders, national, regional and local governments are included.

Communication with and to external stakeholders. The collaboration with external stakeholders is possible only through a good communication between the CI and stakeholder management teams. Policies to establish the commutation should be defined in the DM plan and such communication must be hold during the recovery phase.

Learn from others/Learning from experience/Culture.: Those indicators are not influential in the infrastructure resilience assessment to earthquakes, as those events are strongly related to site hazard (Chang et al., 2014). Therefore, they even less influential in the infrastructure resilience assessment to EILD events because such disasters are localized phenomena. However, they are included in LIQUEFACT CI resilience tool because they can drive an enhanced preparedness of infrastructures to EILD events through processes of participatory democracy and lawmaking.

Sub-dimension: *Business planning*

Security standards. Standards provides indications about security measures to implement within specific CIs to withstand an emergency. For instance, ISO 22315:2018 presents guidelines to draft the mass evacuation plan.

Risk analysis. The risk analysis is at the base of all preparation plans (strategic, management and contingency plans) and actions that the CI, respectively, must develop and initiate to reduce the damages in case of IELD. The risk analysis begins with the hazard intensity assessment for the CI, to which the evaluation of the CI vulnerability and exposure follow. LIQUEFACT project delivered a software for the risk analysis of elements of the built environment.

Business Continuity Plan. The BCP defines the minimum resources that ensure the organization reaches the minimum level of products and services acceptable for it also soon after disrupting events (ISO 22301: 2014).

Disaster Management Plans. These plans form the contingency plan indicated in ISO 22301:2014. They include a set of specific contingency plans for both soft and hard components of the CI.

- **Disaster Management Human Resource plan**. The DM HR plan describes the role that each manager and staff member has during the crisis phase and indicates the staff redundancy.
- **Security plan.** This plan indicates the security procedures to apply in case of disaster.

- **Evacuation plan**: This plan describes the procedures to evacuate the CI in case of disaster and it is drafted according international and national standards, such as ISO 22315:2018.
- **Short-term mitigation plan**: This plan indicates all mitigation actions to reduce the consequences of a disaster, such as cascade effects.

Simulation exercises. The BCP procedures shall be tested against appropriate scenarios. Moreover, security plan and evacuation plan (ISO 22315:2018) must be tested to train managers and staff to operate during the emergency.

Short-term mitigation implementation. In case of disaster, short-term mitigation interventions must be implemented to reduce the consequences of the crisis and minimize the overall damage of the CI.

Programme for staff to cope with and recover from Post-Traumatic Stress Disorders. Large organizations, such as CIs, have the capacity to organize post-traumatic programmes for staff's mental recovery. The recovery of all staff after a major disaster depends on the individual strength (social resilience) and the intensity of the CI damages and personal losses. For instance, some studies, such as Seville et al. (2014), indicated that the staff was afraid to be in buildings after a major earthquake.

Enhanced risk awareness The people working in the organization shall be aware of the business contingency management system requirements and policy to deal with the disruptive incidents. Risk analysis and preparing for crises increases the staff's risk awareness (Hatton et al., 2018) which is critical to enhance the infrastructure resilience and is embedded in several factors included in the organization and management dimension of LIQUEFACT CI resilience tool.

Sub-dimension: *Physical asset*

Building codes. Codes and standards for design of robust buildings and lifelines withstanding to hazard events with a given intensity are necessary to protect the physical asset of CIs.

Planned redundancy. The physical asset, either it is a network or a localized structure, should be planned with an "optimal" redundancy to overcome disruption. The optimal redundancy should be planned according to service level agreement and the admissible design vulnerability of the physical asset to a given hazard intensity.

Long-term mitigation interventions. In case the vulnerability of the CI physical asset to soil liquefaction events characterized by a given intensity is too high to guarantee a minimum service level soon after the disaster, mitigation interventions must be planned, designed and implemented.

Inherent resilience of the physical asset. In LIQUEFACT CI resilience tool the Inherent resilience of the physical asset indicates the complement of losses after a disaster. Therefore, it measures the physical asset performance (i.e. robustness) after an EILD.

Repair of physical asset. Resources are necessary to carry out the repair works of the CI physical asset. Besides the financial resources indicated in the "Finance" sub-dimension, others must be available.

- **Physical/human internal resources for repair**. The indicator measures the availability of all physical resources that the infrastructure stores to rebuild partially the infrastructure in case of damage and the availability of staff able to repair the infrastructure. The importance of this indicator in the resilience matrix of a CI depends on the kind of physical assets it has. Indeed, it might have low impact in case the physical assets are only buildings, but a large impact in case of pipelines.
- **Physical/human external resources for repair**. The indicator measures the availability of all physical resources that the infrastructure could gather to rebuild partially the infrastructure in case of damage and the availability of specialized labour suitable to repair the infrastructure. Some studies pointed out that the lack of construction workers in New Zealand after Christchurch earthquake in 2010 delayed the repair of structures and infrastructures (Stevenson et al., 2014).

Sub-dimension: *Infrastructure services*

Building standards. Codes and standards for design of robust CI services withstanding to hazard events with a given intensity are necessary to protect the physical asset of CIs.

Redundancy of i-th infrastructure service. The infrastructure service should be planned with an "optimal" redundancy to guarantee a minimum service during the crisis (absorption) phase of an IELD. The optimal redundancy should be planned according to the design service defined for each core service line of the CI.

Inherent resilience of the physical asset. This indicator measures the performance (i.e. robustness) of the i-th infrastructure service in a physical asset after an EILD.

Repair of i-th infrastructure service. As the physical asset, infrastructure services must be repaired after EILD. Therefore, internal and external resources should be available to plan and carry out repair works. The infrastructure service should be restored as soon as possible after an IELD, especially in case of minor damage to the CI physical asset.

Sub-dimension: ***Service design***

Service Level Agreement. CIs provide services that must be guaranteed also in case of earthquakes and soil liquefaction events. Service Level Agreements (SLAs) could be worked out at the institutional level, or among a group of infrastructure owners and service providers. The SLA provides also indications about the maximum time of outage acceptable. For instance, a document signed by the rail infrastructure managers in Europe indicates as duration to assess the impact an outage time of a section longer than three calendar days (Rail Net Europe, 2018). This time length is defined in relation to disruption caused by accidents, but it can be considered as measure to assess the length of the disruption caused by earthquake and soil liquefaction as acceptable or not and define a contingency plan in case it is not. In the service design sub-dimension, the SLA is related to the plan of the infrastructure resources.

Planned redundancy in i-th core service. The service design must include a redundancy for each core service in order to guarantee the minimum service level also in case of disaster. Planned redundancy of the technical system and trained staff must be reflected in the planned redundancy prospective of the service design.

Planned contingency in i-th core service. The service design must include a contingency plan for each core service. This means that the business contingency plan should provide a list of disaster mitigation actions for each core service.

Inherent resilience for i-th core service. This indicator measures the performance (i.e. robustness) of the i-th core service after an EILD.

Sub-dimension: ***Service Delivery***

Service Level Agreement and third party legal agreement: CIs must guarantee their service also in case of disaster. The SLA rules both the CI service design and service delivery. In the service delivery sub-dimension, the SLA rules only the external resources needed for the CI service delivery and the relation with the third party providing those resources is regulated by the third party legal agreement.

Planned redundancy of supply chain of i-th core service. This indicator measures the redundancy of the supply chain, so the service or goods is provided by more than one supplier or through different paths.

Inherent resilience of supply chain for i-th core service. This indicator measures the robustness of supply chains in case of EILD.

Reinstate plan of i-th core service: The repair of physical assets or infrastructure services exclude the reinstate of service. It is related to the external resources, such as supplied resources or internal resources needed to reinstate the service.

- **Internal resources**: stored resources, together with staff and functioning technical systems are needed to reinstate the CI services.
- **External resources**: external resources, such as material resources or services, supplying core services are needed to reinstate the CI service.

4.6 Liquefact CI resilience scorecard

The LIQUEFACT CI resilience scorecards has a specific question for each of the indicators included in the related tool. The experts have 6 different possible replies scored from 0 to 5. Each reply begins with a “yes/no” reply to the question, to which a clear explanation follows. The explanation grades the short reply by providing details about the CI resilience conditions. All questions and replies listed in the scorecard are extrapolated from a literature review presented in this document. The LIQUEFACT CI resilience scorecard is the Appendix 1 of this document.

5.0 Cost/Benefit Analysis of Mitigation Options for Improved Resilience to EILD Events

Deliverable 5.3 provided a generic overview of Cost/Benefit Analysis (CBA) and discussed how this tool could be used to evaluate disaster mitigation options. Deliverable 5.3 concluded that the approaches developed for CBA for generic disaster mitigation (risk based or impact based models) developed by previous researchers (for instance Smyth et al. 2004; Mechler et al. 2014) could be applied to the evaluation of EILD mitigation options. In addition, deliverable 5.3 outlined various costs and benefits associated with EILD damages and mitigations. This chapter extends the discussions of the previous deliverable and provides further guidance of how to conduct an EILD CBA assisted by outputs from the LRG loss assessment software developed by the LIQUEFACT project. This chapter also provides further guidance on how to source and use appropriate cost data to conduct a CBA.

Cost/benefit analysis for disaster mitigation option appraisal can be conducted at an individual site level; a regional level; and in some cases at a national level.

Previous researches contain a number of detailed examples on how to conduct a CBA for an individual asset to evaluate earthquake related mitigation options. Paxton et al. (2017) analysed a hypothetical two-storey building in downtown Victoria for three mitigation options. Martins (2018) presented details of a CBA conducted for two moment-frame reinforced concrete buildings located in Portugal for two mitigation options. Smyth et al. (2004) analysed an actual building located in Istanbul, for four mitigation options. The approach to conducting a CBA for liquefaction mitigations outlined in this chapter follows similar steps to those suggested by previous researchers (Figure 5.1). However, unlike some disaster events that affect a wide geographical area, EILD hazard impacts are much more localised. As such, evaluating the potential impacts of liquefaction mitigation options at the individual asset level needs more localised data, such as soil profile and ground water conditions of the individual site.

The application of regional level CBA as part of the options appraisal process depends largely on the type of disaster(s) being considered. Some disasters, such as floods, could be mitigated by the provision of centrally funded regional protection (e.g. flood barriers or coastal protection). Whilst for other types of disaster events providing regional level technical mitigations is not feasible. Earthquake hazards and liquefaction hazards falls into this category. As such, improving regional resilience to such disaster events relies instead on improving the resilience of individual assets or sites, particularly those assets or sites that form the critical infrastructure on which communities rely. However, this disjuncture between those who would benefit from the mitigation measures (the community) and those who have to pay for the measures (the asset owners) causes problems when trying to develop the business case for mitigation, and in particular when trying to quantify the intangible benefits

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to offset against the costs. This said however, whilst regional (and national) stakeholders find it difficult to justify spending public money to support private (or quasi private) industry they do generally recognise the benefits that improving the resilience of such assets or site would have on reducing the impact on their community should a disaster event occur. As such, one mitigation intervention that local and/or central governments may consider are strategic level mitigations such as incentivising individual asset owners to undertake strengthening options. Such an approach is consistent with the Sendai Framework for Disaster Risk Reduction and the UNISDR Disaster Resilience Scorecard for Cities.

Examples of regional level CBA analyses are limited within literature. Ramirez et al. (2012) estimated probabilistic earthquake related losses to a set of hypothetical 30 archetype reinforced concrete moment frame office buildings located at a site in the Los Angeles basin. The authors estimated annualised losses that could be used in life-cycle cost analyses, but did not consider the extent to which the avoided damages could be reduced through the application of different mitigation options. Kappos and Dimitrakopoulos (2008) explored the economic feasibility of strengthening a large heterogeneous building stock in Thessaloniki through different mitigation options. The authors (ibid) calculated cost/benefit ratios for upgrading old concrete frame buildings with no retrofit; retrofit building stock to a modern high-seismic code; (retrofit level 1) and retrofit building stock to a performance levels higher than modern seismic codes (level 2). Authors (ibid) considered four seismic intensity scenarios (very low, low, medium and intense). Kutanis et al. (2011) also applied CBA when they investigated mitigation options for 3, 5 and 8 storey frames and dual systems of several structures. Venton et al. (2009) conducted island wide cost benefit analyses of disaster risk mitigation measures for three Islands in the Maldives. This regional level analysis was conducted for three major hazards (Tsunami, Swell waves and storm surge, Rainfall flooding) four assumed scenarios related to intensity thresholds (low, medium and high); three return period intervals; and three intervals of probability of occurrence. The authors (ibid) zoned each Island using hazard based inundation curves which began at the coastline and ended at the furthest extent of flooding. Establishments, infrastructure and households that fall into each zones were surveyed and those that were vulnerable to hazards were identified and probable losses with and without mitigations were estimated.

5.1 Applying CBA to EILD events using the LIQUEFACT Reference Guide (LRG)

The LRG being developed in WP6 is an easy-to-use software toolbox that provides engineering guidance to both technical and non-technical decision makers on the potential impact that EILD events could have on built assets and on the suitability of different mitigation interventions to improve the built assets' resilience. This section of the report describes the application of the LRG to a CBA of both an individual built asset and a portfolio of built assets.

The benefits that can accrue from mitigation interventions aimed at reducing the impact of EILD damage on built assets mainly relates to the direct losses associated with avoided or reduced damage to the built asset and the indirect losses associated with the consequential expenditure needed to respond to and recover from an EILD event (see deliverable 5.3). The process for calculating such losses for an individual asset and portfolio of assets are shown in Figure 5.1.

Step 1 – Identify the client	
Individual asset level analysis (Individual buildings, campuses and the like belong to individual clients)	**Multi-assets (portfolio) analysis** - (Stock of buildings and infrastructure belong to a large client)

Step 2 – Specify the nature of the problem	
Individual asset level analysis - Site specific hazard analysis - Performance analysis (liquefaction-induced damage) of individual asset - Antecedent loss assessment (annualized) - Identify potential mitigation options	**Multi-assets (portfolio) analysis** - Regional level hazard analysis - Identify vulnerable assets (Building and infrastructure stock survey) - Performance analysis (liquefaction-induced damage) of building and infrastructure stock - Estimated loss assessment for the building and infrastructure stock - Identify potential mitigation options

Step 3 – Determine timing and direct cost of mitigations (cost analysis)	
Individual asset level analysis - Estimate timing and amount of all the costs associated with the procurement, maintenance and disposal of each option up to the end of the economic life of the individual asset	**Multi-assets (portfolio) analysis** - Sum of costs to improve individual asset belong to the client. Mitigation options decided by the client on individual assets. These may include political mitigations as well as physical (built asset) mitigations.

Step 4 – Determine timing and value of loss avoided with each mitigation (benefit analysis)	
Individual asset level analysis - (Annualized) reduction of damages to individual asset(s) - Lives saved, injuries reduced or avoided - Reduction of other economic, social. heritage and environmental losses explained in Deliverable 5.3	**Multi-assets (portfolio) analysis** - Sum of reduction of economic, social. Heritage and environmental losses estimated for individual assets. - Costs avoided related to emergency services and temporary hospitality -Costs avoided related to long term housing/ shelter provision

Step 5 – Choose best alternatives by maximising net present benefits	
Individual asset level analysis - Cost-benefit ratios for various mitigation options applied to individual assets	**Multi-assets (portfolio) analysis-** Cost-benefit ratios for various mitigation options applied to a group of assets

Figure 5.1: Steps of CBA for liquefaction mitigation for individual assets and for a building stock

5.2 Step by step application of the LRG to EILD CBA

Step 1 – Identify Client Need

The first step in the CBA is to identify the client and the scope of the analysis to be undertaken; either an individual asset level analysis or a multi-asset (portfolio) level. Whilst the steps associated with each type of analysis are the same, the level of data required to support the analysis varies. An important consideration at this stage of any CBA is the client's willingness to pay all the data collection required. Client's should not underestimate the cost of this data collection and particularly the costs associated with site level investigations that will be required to support a full CBA model. As such it is essential that a full client brief is developed before any analysis is started that clearly defines:

1. the organisation's (or individual asset owners) vision, including the financial and legal context against which built asset decisions will be made.
2. a series of decision criteria (economic and social) that reflect the client's organisational and community values. These criteria will provide the framework against which EILD losses are calculated and the relative benefits of alternative mitigation interventions are evaluated.
3. the required performance levels of each individual asset and, if appropriate, the clients portfolio of assets. Indicative performance levels need to be set for each of the economic and social decision criteria (2 above) that reflect the impact that loss of built asset function would have on production levels and/or service delivery. The performance levels should be established for a range of potential damage states (e.g. slight damage, moderate damage, extensive damage and complete damage).
4. analysis of data requirements to perform analyses (identify data available within public domains (such as hazard maps) and within LRG library and define type of data that should be collected by the individual asset owner to achieve more accurate results (such as site specific soil profile data).

Although the client brief is established at the start of the CBA process it will need to be reviewed to reflect unforeseen circumstances that might arise as CBA models are developed.

Step 2 - Specify Nature of the Problem

The LRG can be used to estimate the losses (economic and social) for an individual asset or portfolio of assets subjected to a user defined earthquake scenario and local (site based) ground conditions. The selection of the earthquake scenarios (the LIQUEFACT project recommend that at least two scenarios are considered - a most severe scenario and a most probable scenario in keeping with the principles outlined in the UNISDR Disaster Resilience Scorecard for Cities) depends on local knowledge and must reflect the fact that the two scenarios relate to earthquake induced liquefaction, which may well be different to the

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scenarios that would be used for ground shaking. For this reason, the LIQUEFACT project recommends the use of sensitivity analysis as part of the CBA modelling process.

For each earthquake scenario the LRG will assess the vulnerability of the location of the asset (the user will need to provide the longitude and latitude of the asset or assets being assessed) to the earthquake hazard and, depending upon the ground profile (the user will need to provide ground characteristics - see the LRG user manual for specific details of the data required[14]) the liquefaction hazard. Once the liquefaction hazard has been calculated the LRG will evaluate the capability of the built asset(s) to withstand an earthquake induced liquefaction through the use of fragility functions (the user will need to provide fragility functions that reflect their specific building characteristics - see the LRG user manual for specific details of the data required[14]). Damage estimates are presented either as damage states (e.g. probabilities of slight damage, moderate damage, extensive damage or complete damage) or as a mean damage ratio that combines the probabilities of each damage status into a single damage measure. The EILD damage profile estimates produced by the LRG are probabilistic based and reflect an expected outcome sometime in the future, if and when an earthquake (having the characteristics modelled in the LRG analysis) occurs. As such, for the CBA the damage estimates need to be annualised. That is, the timing of benefits (avoided damages) need to be identified over the remaining economic life of the building. However, allocating the probabilistic damage estimates produced by the LRG to each year of the remaining economic life of the asset being analysed is challenging. Previous researchers (such as Leil and Deierlein, 2013; Smyth et al., 2004) have assumed a Poisson distribution model of earthquake occurrence to estimate equivalent annualised damages for ground shaking. The LRG uses a similar approach to produce an annual estimated damage profile for the remaining economic life of the asset (note: the user needs to input the remaining economic life assessment into the LRG).

The damage estimates produced by the LRG can be converted into loss estimates using economic data input by the user. Cost of damage (or resultant repair and reconstruction costs) are estimated based on the replacement cost (input by user) of the asset and the damage status. The replacement cost of an asset should be sourced locally considering the location, inflation and other aspects associated with building typology such as building height and other architectural and structural design parameters (Ramirez et al. 2012). It should be noted that the replacement cost is usually higher than the new construction cost of a similar building in a similar location due to extra external works associated with repair and refurbishment works. As such, the cost of demolition and clearing of debris should also be added to the calculation of replacement cost of a building. The possible short term increase in local construction prices

[14] Note: Due to the complexity of the analysis LIQUEFACT recommend that asset owner commission a consultant to obtain data related to soil susceptibility which can then be input to the LRG. Whilst the LRG has an in-built library of fragility functions for common building typologies across Europe if these are not suitable, asset owner needs to commission a consultant to develop fragility functions specific to their assets which can be input into the LRG and used in the assessment.

due to a surge of repair/reconstruction jobs aftermath a disaster should also be considered as part of this calculation.

In general practice it is more appropriate to rebuild rather than repair assets with more than 50% mean damage ratio or with extensive or collapse damage states. The LRG estimates repair costs associated with other damage states as a % of total replacement cost. As the default the LRG estimates repair costs associated with slight and moderate damage as 8% and 33% of replacement cost respectively. However, the LRG allows users to change these values as appropriate to their individual circumstances. Again the LIQUEFACT project recommends the use of a consultant to advise on the most appropriate values to use.

The LRG takes a similar approach to estimate the loss of contents within buildings and to losses related to business interruption. The LRG assumes coefficients for content loss and business interruptions for each damage state (these values are similar to those used by the insurance industry for assessing general earthquake losses). The total estimate of contents loss can be calculated by multiplying the coefficient of content loss by the total value of the contents within a building (input by the user). This value is most likely to be that are used by the asset owner as part of the building insurance). By default the LRG assumes that slight, moderate, extensive and complete damages states to assets will result in 20%, 50%, 85% and 100% losses to its contents and 0% 15%, 100%, and 100% interruptions to business functions within such buildings respectively. However, given the variability between building use across different business and critical infrastructure sectors the LIQUEFACT project strongly recommends that individual asset owner considers their circumstances and identify more specific coefficients which could then feed into LRG. The link between damage states and loss of business function (e.g. production or service delivery etc) should be assessed as part of the organisations general risk assessment and Business Continuity and Resilience/Disaster Management Planning[15].

At present the LRG only estimates losses associated with damages to physical assets. For a more accurate CBA users should estimate the costs associated with short or long term rental (of alternative built assets or equipment) and moving people and contents out of damaged built assets during the demolition, repair and reconstruction process. This could be estimated based on local knowledge related to hauling rates and rental rates. For short term relocations in cases of minor repair, the average daily cost of staying in a local hotel could be identified and multiplied by the number of days requires for repair and number of people that need to be moved. For long term rental related to major repair and reconstruction, the cost of short term rental (a monthly rate) in the locality should be considered. This can then be multiplied by the number of months required for repair or reconstruction. The relocation of building contents (to alternative assets or to storage) will normally only be considered in cases of complete reconstruction. Two-way hauling rates along with contents storage rates should be identified locally where appropriate.

[15] See ISO 22301 Business Continuity Management - Minimize the impact of disruptive incidents

As it is unlikely that liquefaction will cause large-scale deaths or mortal injuries (Daniell et al, 2017) the LRG does not include such estimates as part of its loss assessments. Earthquake induced liquefaction has accounted for only 21 of the 2.3 million fatalities associated with earthquake events since 1900 (Daniell et al, 2017) and as such the LIQUEFACT project recommend that such losses are excluded from the CBA unless there is compelling local evidence to suggest that it could be a significant factor. If the user does want to consider such losses in their CBA then they will need to generate the loss data outside the LRG.

Monetising the impact of death and injuries is challenging. Considering individual circumstances, users may estimate probable deaths and injuries that could occur at each damage state based on a severity scale. For example, Erdurmus (2005) and Erdik and Ayinoglue (2002) in their researches considered 4 severity levels. The least severe incidents were related to injuries requiring basic medical assistance without hospitalisation and most severe level normally include instant death at the scene or mortally injured. Cost of deaths and injuries can be estimated by placing a monetary value against each severity level. Smyths et al (2004) stated that previous researches have used a plausible range for the value of a statistical life saved in the United States (between $2.5 million and $4.0 million) in 1999 dollars. However, converting these numbers into other regions were challenging. Hence, Smyths et al (2004) used two arbitrarily chosen values for their CBA analysis. The more recent common approach to monetising the value of death and injuries is the consideration of earning levels of habitants of the asset. For example, Erdurmus (2005) in his research assumed that a person who was killed would contribute to the society for 35 years with the minimum wage cost and used this assumption to monetise death and injuries for a Turkish context. Users could use this approach to calculate the damage related to injuries based on the residents' real income levels and remaining workable age. For a large building stock, the percentage of expected incidents under each severity level should be predicted based on historic data. These percentages are then multiplied by the number of residents within the assets to estimate numbers by deaths and injuries.

The LRG will identify all possible ground mitigation interventions following a logic sequence similar to that described by Liel and Deierlein (2013), Kappos and Dimitrakopoulos (2008), or Kutanis et al. (2011). The LRG will calculate the expected losses with and without mitigation interventions and will predict the reduction in expected losses for each possible mitigation intervention. The estimated reduction in losses will be expressed in terms of a percentage reduction on the unmitigated case (e.g. mitigation option A will result in 20% reduction in losses; mitigation option B will result in 35% reduction in losses; mitigation option C will result in 60% etc. It must be noted that these estimates will be subject to significant uncertainties depending on how good the mitigation solution will be implemented in practice and the level of accuracy of the fragility curves, geotechnical profiles etc.

Step 3 – Determine timing and direct cost of mitigation options

Quantification of costs associated with each of the mitigation options identified in the LRG should be calculated using local knowledge. Similar to the replacement cost of buildings, the costs associated with the design, construction, maintenance, utilities, insurance, security (if appropriate) and disposal of each mitigation option will depend on location, inflation and other aspects associated with the building's typology (including legacy design, previous building interventions, site specific circumstances (e.g. access, proximity of other buildings, tenancy etc,), residual asset value etc.) which can only be determined on a building by building basis. These costs should be identified along with their timing until the end of economic life (appraisal period) of the asset.

Step 4 - Determine Timing and Value of Loss Avoided with each Mitigation Option (benefit analysis)

Each cost (for each mitigation from step 3) and benefit (avoided losses from step 2) that is expected to occur in the future should be discounted to its present value (annualised) to calculate a comparable cost/benefit ratio among the various mitigation options. In calculating the present value an assumed discount rate needs to be used. FEMA 227 (1992) recommends discount rates of between 3–6% for use in CBA for seismic rehabilitation. In a recent study of CBA of flood mitigation measures, Pesaro et al. (2016) used 4% as the discount rate for Italy. Paxton et al. (2017) in his CBA into earthquake mitigation measures in Victoria, Canada, used a discount rate of 5% to discount owner benefits (i.e., damage and downtime) and a discount rate of 3% to discount public benefits (i.e., reduced casualties). The user needs to determine an appropriate discount rate (or a range of rates as part of a sensitivity analysis) that reflect their specific circumstances. The LIQUEFACT project recommends the use of a consultant to advise on this issue.

Step 5 - Choose Best Alternatives by Maximising Net Present Benefits

Figure 5.2 provides a template that can be used to conduct CBA and prioritise EILD mitigations based on their predicted economic performance. This said, the final choice of which (if any) mitigation options to implement depends on more than an assessment of their predicted economic performance. Consideration needs to be given to the practicalities of implementing any given mitigation option (including possible consequences on surrounding built assets or on the integrity of underground services by be affected by the ground mitigation intervention) along with the built assets owners attitude towards risk. Consideration of the former should be undertaken as part of a full design appraisal for a preferred mitigation option; the latter needs to reflect the organisation's risk mitigation strategies including the provision of insurance to compensate for an EILD event and vulnerability of the organisations supply chain.

Cost Benefit Analysis of liquefaction mitigations

Option 1: **<description of the option>**

Date:

A sensityvity analysis should be carried out for this rate

Key Assumptions:

Social Discount Rate (r)	3.00%	
Appraisal period (years)	50	years

Input the required period of the analysis, typically the term of the required services (max 50 years)

$$discount\ factor = \frac{1}{(1+r)^{n-0.5}}$$

Year (n)	0	1	2	3	4	5	6 ~ 49	50
Discount factor (mid-year)	1.00000	0.95663	0.92877	0.90172	0.87545	0.84995		0.22476
Net Benefits (Benefits - costs)	0	0	0	0	0	0		0
Discounted Benefits	0	0	0	0	0	0		0
Present Value (PV) of benefits	0							
Discounted costs	0	0	0	0	0	0		0
Present Value (PV) of costs	0							
Net Present Value (NPV)								
Benefit cost ratio								
BENEFITS ANALYSIS								
Benefit 1 - Reduction of repair and reconstruction costs due to damages to properties	-	-	-	-	-	-	-	-
Benefit 2 - Lives saved	-	-	-	-	-	-	-	-
Benefit 3 - Injuries avoided or reduced	-							-
Benefit 4 - Loss reduction related to emergency services and temporary hospitality (if applicable)	-	-	-	-	-	-	-	-
Benefit 5 -Loss reduction related to long term housing/shelter provision								
Benefit 6 - Reduction of other economic, social and business interruption losses (eg: reduction of crimes, family violence)	-	-	-	-	-	-	-	-
Benefit 7 - Reduction in environmental losses (if applicable)	-	-	-	-	-	-	-	-
Benefit 8 - Reduction in environmental losses (if applicable)	-	-	-	-	-	-	-	-
Total Benefits (mid-year)	0	0	0	0	0	0		0
COST ANALYSIS								
Cost 1 - Planning, design and other consultations	-	-	-	-	-	-	-	-
Cost 2 - Capital Construction cost	-	-	-	-	-	-	-	-
Cost 3 - Annual service/maintenance cost (if any)	-							-
Cost 4 - Major repair and services (if any)	-	-	-	-	-	-	-	-
Cost 5 - Overhall or complete replacement (if relevent)								
Cost 6 - Utilities costs (if relevent)								
Cost 7 - Disposal cost								
Any other costs (eg: Insurance, security provision)	-	-	-	-	-	-	-	-
Total Cost (mid-year)	0	0	0	0	0	0		0

Benefits estimated to receive within each year

Costs estimated to incur within each year

Figure 5.2 CBA Template

5.3 Discussion of Issues/Uncertainties in CBA Estimates

There are a number of well documented problems associated with predicting earthquake losses.

Forward looking estimates (including that of the LRG produced by LIQUEFACT) of loss include large uncertainties (Crowley et al. 2005) which can significantly reduce the accuracy of damage estimates. Previous researchers (see Del Vecchio et al. 2017; Spence et al. 2003; Eleftheriadou et al. 2016) have highlighted differences between predicted damage and observed damage for earthquake hazards. Del Vecchio et al. (2017) studied actual versus predicted repair costs for selected case studies of reinforced concrete buildings damaged by L'Aquila earthquake, Italy. By investigating 3 RC concrete buildings, Del Vecchio et al. (2017) found that the total predicted repair costs (predicted as 7-13% replacement cost) are significantly lower than actual costs (observed as 20-35% replacement cost). Bird et al. (2004) and Spence et al. (2003) presented results of a study comparing predicted loss estimation with observed damage for the 1999 Kocaeli Earthquake in Turkey. Spence et al. (2003) reported a significant over prediction of damage levels by 60-100% for two observed zones in Kocaeli. Investigating loss prediction accuracy of shear wall vulnerability model for mid-rise RC buildings in Kocaeli, Bird et al. (2004) found that undamaged building numbers is under-predicted by 35%, moderately damaged building numbers is over-predicted by 40%, and completely damaged building numbers is under-estimated by 15%. Eleftheriadou et al. (2016) compared actual loss to structures and estimated probable structural losses for the 7/9/1999 Parnitha (Athens) earthquake.). Authors found that Post Earthquake Crisis Management Divisions has over estimated costs associated with structural losses by 7.2, 69.2 and 27.4 % for collapsed, moderately damaged and lightly damaged buildings. However, there has been a satisfactory agreement between total observed damage cost (2450.02 M€) and total estimated damage cost (2627.77 M€). Porter et al. (2002 cited in Del Vecchio et al 2018) highlighted that variability in repair cost predictions (derived based on damage estimates) due to uncertainty concerning the ground motion is about 22% of the total replacement costs.

All of these studies in one way or another drew attention to the limitations of the CBA approach in the light of such uncertainties and as such the user must be aware of the limitations that CBA has in supporting the options appraisal process for EILD mitigation interventions.

The above said, the accuracy of loss estimates depends on the selection of an appropriate ground-motion model (Crowley et al. 2005) where aleatory variability in the ground-motion prediction is an important element of the uncertainty (Bommer and Crowley, 2006). The validity of both traditional approaches to hazard assessment or embedding the variability within the vulnerability calculations at each location is ambiguous (ibid). Modelling the shaking component of the loss model by triggering large numbers of earthquake scenarios that sample the magnitude and spatial distributions of the seismicity, and also the distribution of ground motions for each event is more accurate (ibid Wesson et al. (2004) studying 1994

Northridge, California, claimed that ground motion derived from ShakeMap estimates, provides a better basis for calculations.

As the LRG uses data derived from ShakeMap and therefore can be considered a more accurate approach compared to traditional approaches.

Input from geological surveys and geophysical tests use to predict vulnerability of location to earthquake hazards and the soil susceptibility to liquefaction are reasonably accurate, thus has a less impact on of uncertainty on the final loss estimate. User can choose to use the data from existing surveys and tests conducted for nearby locations. This option is less expensive but would undermine the accuracy of the results. End users input soil profile and water content data will improve the accuracy of the estimate produce by the LRG.

Estimating the capability of an assets to withstand in event of a soil failure (fragility functions) is more challenging. LRG has a library of in-built pre-existing fragility functions. Users can either use these if they are appropriate or commission a consultant to develop specific fragility functions suitable for their own building topology. Accuracy of pre-existing fragility functions depend on many aspects related to the assets such as the age of the building, materials used, construction methodologies, etc…, Majority of these pre-existing fragility functions were developed in the US to suit the circumstances of the assets in their region. Using these to predict damages to assets with different building typologies could significantly impact resultant damage estimation. For example, Del Vecchio et al. (2018) found that using pre-existing fragility functions led to significant underestimations (83–90%) of the actual repair costs of infills and partitions for the case study buildings, due to the difference of infills and partitions use in US and European buildings.

The accuracy of the estimate also depends on the cost data used within the study. The replacement cost in particular can have a significant impact on the accuracy of the assessment. Studying repair cost aftermath L'Aquila earthquake in Italy Del Vecchio et al. (2018) found that only 14–44% of the total replacement costs are related to actual repairs to the buildings and the remaining costs involved external works or other costs associated with repairs.

6.0 Review of the LIQUEFACT Resilience Assessment and Improvement Framework (RAIF)

Deliverable 1.3 developed a Resilience Assessment and Improvement Framework (RAIF) to assist CI and community stakeholders reduce their vulnerability and improve their resilience to EILD events. The RAIF integrates a range of tools developed in the LIQUEFACT project into an overarching framework that provides the business models to assess the potential of mitigation interventions to improve community and CI resilience (Sections 3 and 4); including CBA models (Section 5) to allow option appraisals and prioritisation of mitigation interventions into built asset management plans (section 2). This section of the deliverable draws all the previous sections together into the final Beta test version of the RAIF that will be used in conjunction with the LRG to develop a series of use-cases for improved resilience to EILD events through strategic built asset management. This section will briefly review the theoretical background to the RAIF and consider the degree to which the initial assumptions identified in deliverable 1.3 have been addressed through the development of the LIQUEFACT tools (developed in WP2, WP3, WP4 and WP5) and the LRG (WP6). In particular the section reports the results of two workshops that tested the usability of the RAIF and LRG against four CI scenarios. This section also presents the final Beta test version of the RAIF which will be used alongside the LRG to develop the use-cases as part of the LIQUEFACT validation process (WP7).

6.1 Theoretical Background to the RAIF

The theoretical background to the RAIF is based on Cutter's DROP model (Cutter et al, 2008) (Figure 6.1) and Jones' risk/resilience model (Figure 2.7) developed as part of the CREW project (CREW, 2012). The LIQUEFACT project reinterpreted Cutter's DROP model (Cutter et al, 2008) and Jones' risk/resilience model (CREW, 2012) into a built asset management framework (Figure 2.3) to assess vulnerability, resilience, and mitigation options to support the development of business models to identify and prioritise mitigation actions to improve CI and community resilience to EILD events (Figure 6.2).

Alongside the development of the RAIF, other LIQUEFACT work packages have developed the range of tools needed to assess the potential of a range of mitigation interventions to improve resilience to EILD events. The community resilience tool (section 3) seeks to assess the antecedent (baseline) and post-mitigation community resilience to an EILD event. The CI tool (section 4) seeks to assess the resilience of CI system(s) to the EILD event. The CBA tool (Section 5) seeks to assess the economic feasibility of a range of mitigation interventions to improve a built assets resilience to an EILD event.

The initial version of the RAIF is shown in Figure 6.3. The RAIF draws together two main activities; a risk-based assessment of the antecedent conditions that affect built assets and community resilience pre event and a resilience improvement framework that will allow alternative mitigation options to improve built assets and community resilience to be evaluated against a range of post event scenarios.

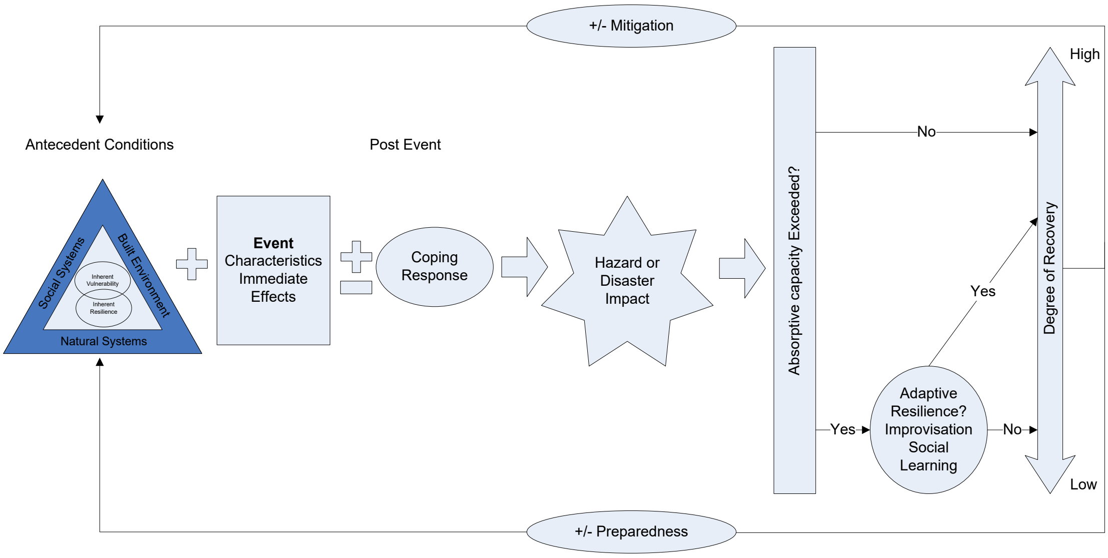

Figure 6.1: Schematic representation of the disaster resilience of place (DROP) model (Source: Cutter et al, 2008)

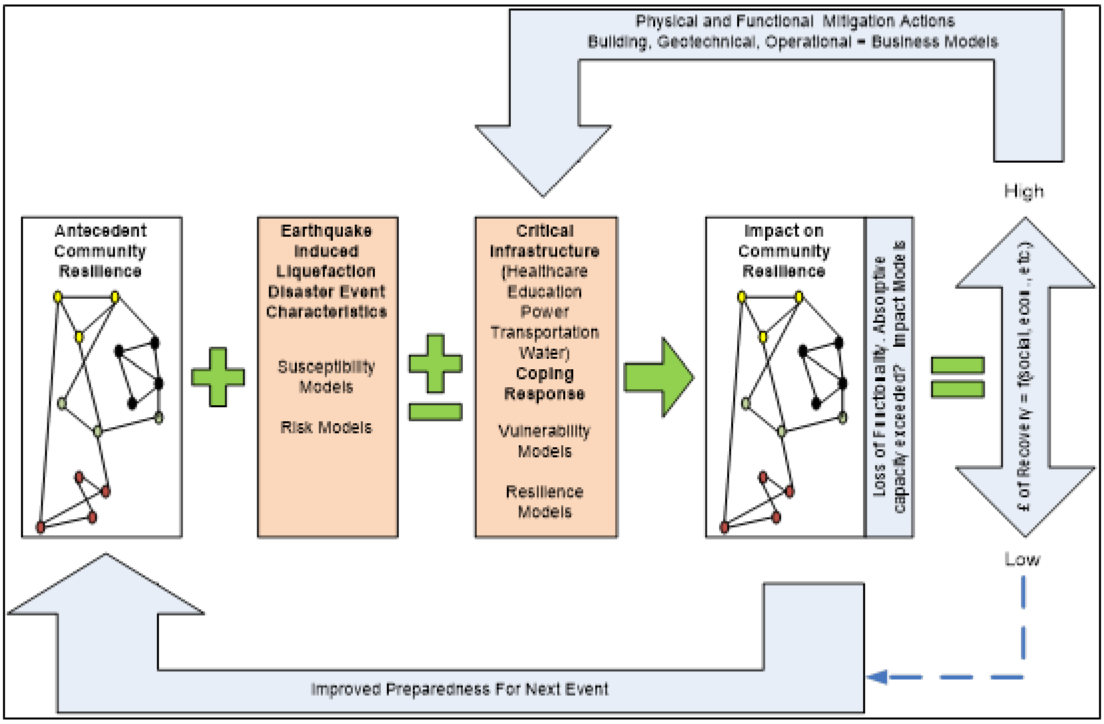

Figure 6.2: LIQUEFACT RAIF tools mapped onto Cutter's DROP Model

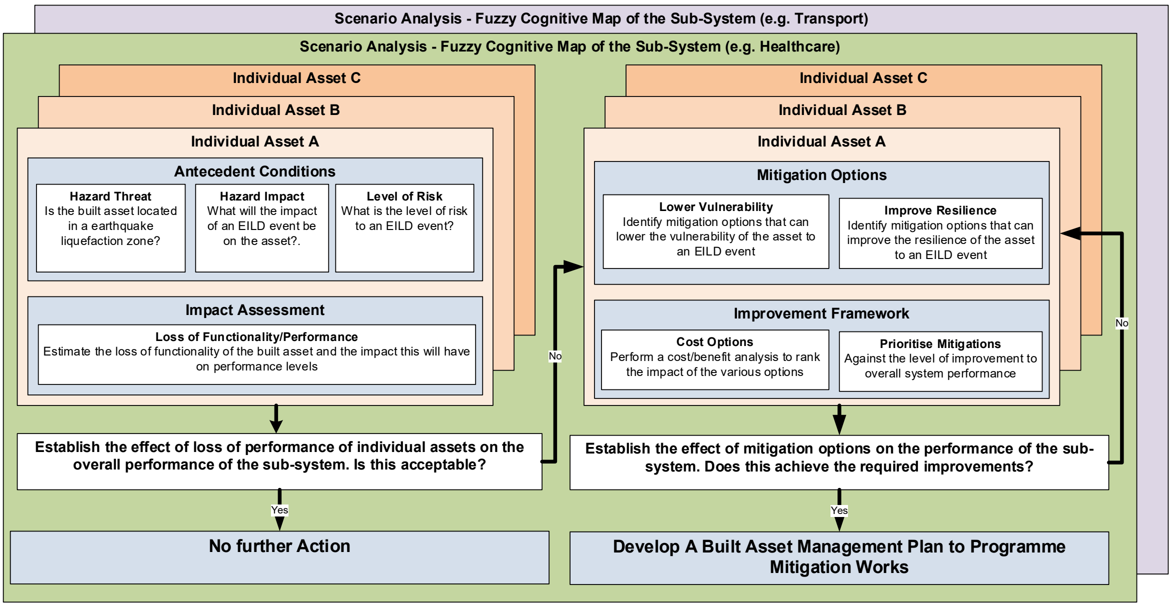

Figure 6.3: Resilience Assessment and Improvement Framework

The original version of the RAIF envisaged a six stage process.

Stage 1 - Current Condition Analysis: requires an examination of the hazard risk to built assets 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.

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.

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.

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.

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).

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.

6.2 Validation of the RAIF (Rome Sprint Test)

The ability (validity and usability) of the theoretical model outlined above was tested (at the suggestion of the LIQUEFACT International Advisory Board) using a 'sprint test' methodology that tested each stage of the RAIF against a hypothetical scenario. The aims of the sprint test were to:

- To review the ability of the RAIF and to support a facility manager/operational engineer assess:

- ➢ The antecedent vulnerability and resilience of their infrastructure assets to an EILD event; and
- ➢ Assess the relative improvement in vulnerability and resilience that could be achieved through the use of a range of mitigation interventions.

- Identify what data (performance indicators, metrics and variables) are needed by the RAIF at each stage of the assessment process.
  - ➢ Write a development specification for each of the indicators, metrics and variables; and
  - ➢ Identify which LIQUEFACT work package was responsible for their development.

The Sprint test took place at a one-day workshop held in Rome (17th November 2017). All LIQUEFACT partners and work packages were represented at the workshop.

Each stage of the RAIF was addressed in turn and its potential application to a hypothetical region was assessed using a simplified (hypothetical) primary health care scenario (Case study box 1). A summary of the results from the sprint test workshop are given below.

Case study box 1: Hypothetical 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.

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, statewide 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.

During the development of the RAIF it had been assumed that the GIS platform for localised regional assessments of EILD hazards across Europe and the European Liquefaction Hazard Mapping Framework being developed in WP2 would provide the level of detailed needed by the RAIF to allow end-users to geo-locate their built/infrastructure asset(s) onto the GIS platform and assess their Hazard Level to a localised liquefaction event. If there is no (or very low) potential exposure then the assessment would be deemed complete. If there is a potential exposure then the level of the exposure would need to be investigated further. The sprint test confirmed that this assumption was valid and that the tools being developed in WP2 would provide the level of detail needed.

It had further been assumed that for each built/infrastructure asset identified as at potential exposure to an EILD event:

- the level of hazard could be evaluated by considering the probability of an earthquake hazard and the susceptibility of the ground to liquefaction; and
- the data on liquefaction hazard mapping generated in WP2 could be used to develop a Susceptibility Matrix (Figure 6.4) that could relate Earthquake Hazard Characteristic to Ground Characterization to identify the level of hazard to the asset. The level of hazard would 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.

The sprint test confirmed that this assumption was valid in part. Whilst the principle was valid it was uncertain at the time of the test as to whether robust characteristic variables could be defined for all circumstances. It was agreed to continue with the principle of using a form of hazard level matrix but to leave the definition of metrics open until later in the LIQUEFACT project.

		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

Figure 6.4: Hazard level matrix for selected site

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 typology 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 Figure 6.5 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 Figure 6.5 is shown as two dimensional it is more likely to be three dimensional to take account the different hazard levels identified in Figure 6.4.

It had been assumed during the development of the RAIF that the tools being developed in WP3 would be able to identify different building/infrastructure typologies and assess their inherent resilience to EILD events. The data from these assessments would then be used to develop a classification systems that would allow the potential level of damage to be identified for a range of building/infrastructure assets and ground condition scenarios (Figure 6.5). The sprint test confirmed that this assumption was valid.

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. 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.

During the development of the RAIF it had been assumed that the two scores from the hazard-exposure and vulnerability/resilience matrices (Figure 6.4 and Figure 6.5) could be used to assess the level of risk (Figure 6.6) to building/infrastructure asset(s) which in turn could be used as the basis to assess the loss of functionality of the building/infrastructure asset(s) immediately following an EILD event.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

		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

Figure 6.5: Typical building vulnerability/resilience matrix

It had further been assumed that the loss of functionality would be made on a case by case basis using the expert knowledge of the facilities/building manager and building users to interpret the impact that any given level of risk will have on functionality and performance. It was assumed that the loss of functionality would 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. The sprint test confirmed that this assumption was valid.

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 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

		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

Figure 6.6: Level of risk of the single asset

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.

It had been assumed in the RAIF that the impact of the loss of performance of individual building/infrastructure assets on the resilience of a community following an EILD event would 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 described the complex relationships (physical, social, organizational, economic etc.) that constitutes a communities resilience to disaster events. Although there was some concern over the complexity involved in the developing a generic FCM the sprint test confirmed that this approach was valid, particularly the need to consider the 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.

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.

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 need to 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.

It had been assumed in the RAIF that two types of mitigation actions would 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. It had been assumed that a range technical building level interventions would be developed in WP3. However, during the sprint test it became clear that this would not be the case. Whilst WP3 would develop a range of fragility curves for different building typologies it wouldn't explicitly develop fragility curves for different types of building level mitigation. What WP3 would do was to develop a range of methodologies for generating fragility curves that could be used to examine specific buildings (i.e. detailed analysis of bespoke buildings that could be run before and after mitigation interventions).

It had further been assumed that a range of ground interventions would be developed in WP4. The sprint test confirmed the validity of this assumption.

Finally it had been assumed that a range of operational interventions would be developed in WP5. The sprint test confirmed the validity of this assumption in part. WP5 would consider a range of operational interventions that could be used to mitigate the impact of EILD damage on the built asset performance this would be done as part of an organisations business continuity and resilience/disaster management planning and as such would need to be bespoke to each organisation to reflect that organisation's local operating conditions. As such generic operational mitigations would not be developed but guidance for developing such plans would be provided.

Once the mitigation options have been identified the RAIF assumed that a cost/benefit analysis would be calculated for each specific sub-system component. The cost/benefit analysis would 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). The sprint test confirmed the validity of this assumption.

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 RAIF assumed that an options appraisal approach would be used by built asset owners to manage the retrofitting of mitigation interventions. The sprint test confirmed the validity of this assumption.

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.

Once priorities have been set, it had been assumed that detailed built asset management plans could 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. The sprint test confirmed the validity of this assumption.

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.

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.

Whilst the concepts underpinning the RAIF did not change as a consequence of the Sprint test and ongoing discussions between LIQUEFACT researchers, the operational assumptions did. As a consequence the following operational considerations were incorporated into the RAIF:

- **Antecedent Conditions**: during discussions with WP2 it became clear that the level of resolution that would be available through the macro-zonation and micro-zonation maps would not be at a scale to allow the level of risk of an individual built assets or small sites to be established with any degree of certainty. As such a third level of assessment, individual (local) site level ground investigations would be required to determine the susceptibility of a particular site (and the built assets located on the site) to earthquake induced liquefaction. Detailed guidance on how such site level ground investigations would be undertaken would be developed in WP4.

- **Impact Assessment**: during discussions with WP3 it became clear that the level of work required to produce fragility curves for a comprehensive range of building typologies and ground conditions was beyond the scope of the work package and as such it was agreed that WP3 would produce fragility curves for typical building typologies and ground conditions as well as developing outline methodologies (rapid risk assessment and detailed fragility models) that could be applied by built asset owners (through their consultants) to develop bespoke fragility curves that would reflect their specific building construction and ground conditions. It also became clear during discussions with WP3 and WP5 that linking loss of performance of a specific built assets to reduced functionality as a consequence of the potential damage caused by an EILD event would need to reflect the specific functional requirements of the built assets from a business perspective, which would be independent of the physical design of the built asset (e.g. a concrete frame hospital building would have different performance requirements than a concrete framed office building) and as such a decision was made to develop a range of damage states for different building typologies as part of the work of WP3 but to leave the linking of specific damage states to loss of performance of the built asset to the owners/operators of the built asset. For most organisations the linking of damage state to loss of performance as a consequence of a disaster event forms part of their business resilience and continuity/disaster management planning process. As such the original version of the RAIF was divided into two sections a hazard and risk assessment section and a business continuity and resilience planning section.
- Mitigation Options: during discussions with WP3 and WP4 it became clear that the range of technical interventions being developed were primarily focused on developing new ground improvement to reduce the risk of earthquake induced liquefaction occurring rather than developing building level interventions as such the focus of the RAIF was narrowed to reflect this reality (although it is possible that the final version of the LRG will include more mitigations options than are currently being developed by LIQUEFACT). During discussions with WP5 it also became clear that, as with linking damage states to operational performance, operational level mitigation interventions would need to reflect the specific functional requirements of the built asset from a business perspective and as such a range of generic business level mitigations (e.g. insurance, alternative supply chains etc.) would need to be considered on an organisation by organisation basis as part of the organisation's business continuity and resilience planning (BCRP) and disaster management planning (DMP).
- **Improvement Framework**: during discussions with WP5 and WP6 it became clear that whilst the principles of CBA could be applied to EILD events the scope of any

CBA would be limited by the lack of historic data, particularly around the effect of EILD events on intangible losses, and as such it was decided to develop a CBA model that would focus on direct losses but that would allow a range of indirect losses to be modelled depending on the specific business requirements of the organisation. This approach is consistent with that used in the options appraisal process for evaluating and prioritising built asset level mitigation interventions over the building life-cycle.

- **Develop a Built Asset Management Plan**: during discussions with WP5 and WP6 it became clear that the generic approach to built asset management planning envisaged in the RAIF to program EILD mitigation interventions into a built asset life-cycle was consistent with the approaches being adopted in other disaster mitigation research projects and as such no changes were made to the assumptions underpinning this aspect of the RAIF.
- **Community Resilience**: during discussions with all LIOQUEFACT partners it became clear that, whilst the original concept of developing a community level resilience model to EILD events was consistent with approaches being taken by other research projects, the level of complexity (and stakeholder time) required to develop such a model using Fuzzy Cognitive Mapping was considered disproportionate to the EILD risk for most communities. At the same time, the development by the UNISDR of a generic Disaster Resilience Scorecard for Cities, and its promotion at the global level, caused researchers working in WP5 to re-evaluate their approach to modelling community resilience to an EILD event. As the UNISDR scorecard covered all (and more) of the criteria originally identified at the Bologna workshop as important constituents of a community resilience model it was decided to adapt the generic UNISDR or card to reflect specific considerations that were relevant to an EILD event. As such WP5 decided to augment the standard UNISDR Disaster Resilience Scorecard for Cities with additional guidance (additional considerations required for an EILD event) and an scoring mechanism (comment level of resilience and relevance of the criteria to overall community resilience) that would allow resilience score to be calculated at a range of levels (individual criterion, collective criterion, and overall community levels). The one aspect of the UNISDR scorecard that was considered insufficient for the needs of the RAIF was the way it dealt with the impact that critical infrastructure could have on overall community resilience to an EILD event. As such WP5 decided to develop a bespoke CI scorecard that would allow the resilience of each critical infrastructure system to be assessed independently and the results then integrated into the customised UNISDR scorecard to provide an overall assessment of community resilience to an EILD event.

Following the Sprint test and ongoing discussions (both face-to-face and virtual) between the LIQUEFACT partners (led by WP6 and WP5) between November 2017 and March 2018 version 2 of the RAIF (Figure 6.7) and version 1 of the conceptual design and processing schematic for the LRG (Figure 6.8) was developed. These were used by all the LIQUEFACT work packages to inform their ongoing work and the development of their LIQUEFACT tools.

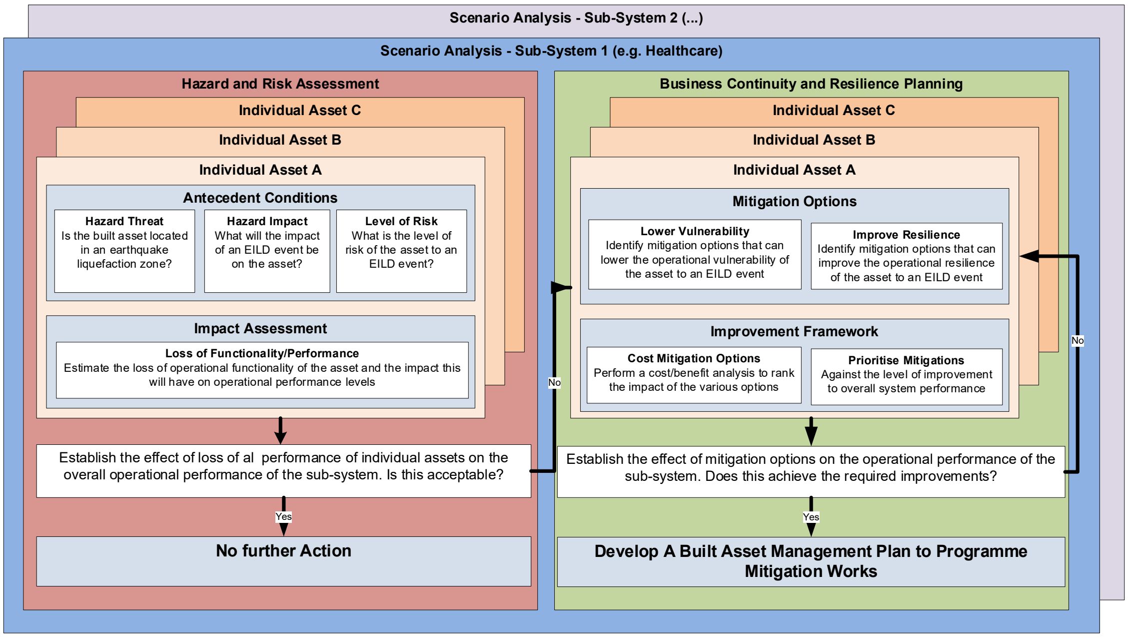

Figure 6.7: Version 2 of the LIQUEFACT RAIF

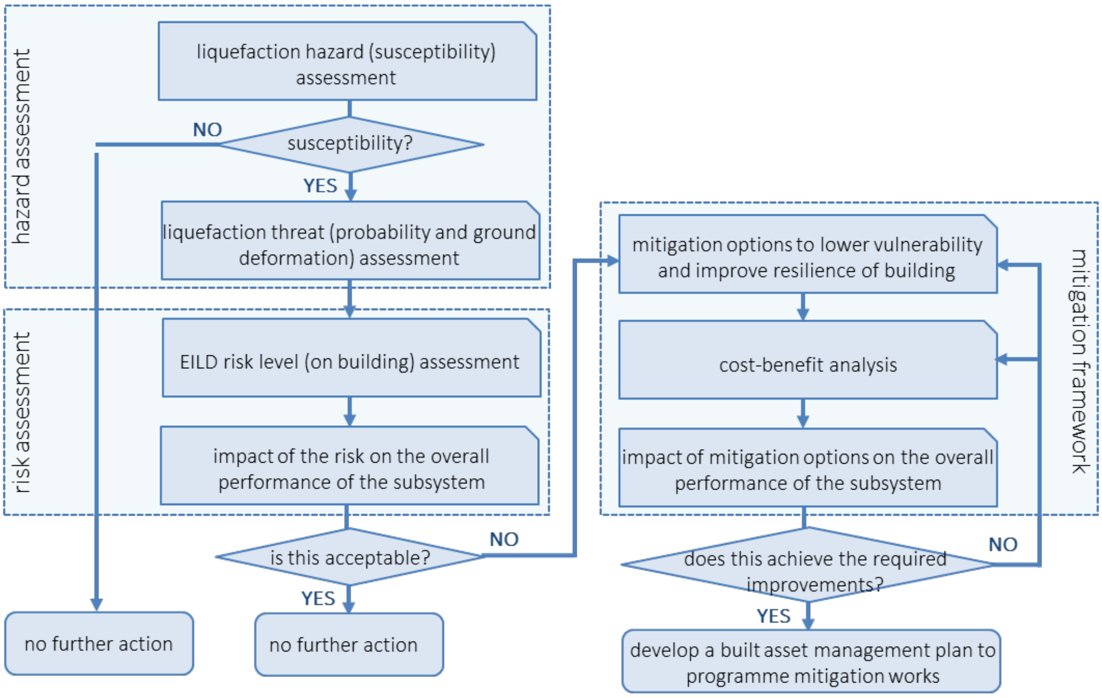

Figure 6.8: LRG software processing and analysis concept (source LIQUEFACT D6.1)

7.0 A Whole Life Built Asset Management Plan for Improving Resilience to and EILD Event

The previous sections of this deliverable presented the background theory and outline tools developed by WP5 to support the whole life built asset management framework for integrating mitigation to EILD events into strategic built asset management planning. This section of the deliverable integrates all of these tools, and the tools developed by other LIQUEFACT work packages, into a 10 step built asset management planning framework to guide facilities/built asset managers through the EILD mitigation evaluation and planning process. In essence, the 10 step built asset management planning framework operationalises the RAIF and provides practical guidance on which LIQUEFACT tools to use at each stage of the analysis. Although the built asset management plan has yet to be externally validated (this will take place as part of WP7) two internal validation events have been held and the results of these are presented in this section.

7.1 Applying built asset life cycle models and BAM models to evaluating mitigation interventions to reduce the impact of EILD events on the organisational performance

The Sprint test held in Rome (see section 6) began the process of operationalising the RAIF as the basis for developing whole life built asset management plans for improving the resilience of built assets to an EILD event. This process continued as part of WP5 where the tools from the various LIQUEFACT work packages have been combined with the built asset management life-cycle model (Figure 2.2) and the performance based built asset management process model (Figure 2.3) to develop a guidance framework that facilities/built asset managers can use to evaluate the potential for different liquefaction mitigation interventions to improve the resilience of their individual assets and business/organisational performance to an EILD event (Table 7.1).

The role of built assets is to support the primary function of an organisation (its core business) in the most effective and efficient way. Built asset management is the process by which the performance (effectiveness and efficiency) of built assets to support 'core' business are specified, measured and planned. Key to the BAM process is identifying an organisation's Critical Success Factors (CSF's) and using these as the criteria against which performance is measured. Although from a strategic perspective we consider built assets as holistic entities in reality all buildings comprise a complex arrangement of components (structural and non-structural) and sub-systems (business functions; FM services; HR services etc.) that work together to deliver the organisation's primary output (e.g. product or service). As such BAM performance has to be considered from different perspectives:

- Organisation/Management;
- Technical Systems; and
- Operational (Service).

As such key performance Indicators (KPI's) and benchmarks need to be established that describe how performance will be measured and set the tolerable range (or more commonly ranges that reflect desired, acceptable and unacceptable levels of performance) within which the KPI needs to sit to ensure that the organisation's built assets are not having a negative effect on the organisations ability to deliver its product/service in an efficient and cost effective way.

Once the KPI's and benchmarks have been set the current level of performance of each of the organisation's built assets to support its primary business is measured and the root cause of any underperformance is identified through a process of inquiry (empirical analysis of system performance), design evaluation (systemic analysis/modelling of product/service design), statistical models (comparative analysis system performance) and experiential studies (case study analysis of system performance).

Once the root cause of underperformance has been established desired improvements in performance (in terms of improved KPI scores) and a range of possible interventions (both the built asset business process levels) are identified and an options appraisal process instigated to evaluate the potential impact that each intervention has on business performance. The options appraisal process includes CBA and impact analysis models (implications of delay in instigating an intervention on core business risk - although the above process has been described at a single point in time; in reality all built assets have a 'life-cycle'.) That allow interventions to be ranked and prioritised (based on both their cost benefit ratio and risk profile).

Once implemented the performance of each intervention to deliver the desired improvements in KPI's scores is assessed through the direct measurement (where the intervention is intended to have an immediate effect) or against future scenarios (where the intervention is intended to reduce future risks).

Although the above model has been developed primarily to support businesses / organisations manage their planned interventions against current performance levels it has been applied (either implicitly or explicitly) by researchers (Palliyaguru and Amaratunga, 2008; Kempton, 2014; Ngwira et al, 2012; Higgins, 2014; Jones et al, 2017) to identify and manage the implementation of mitigation and adaptation interventions to reduce vulnerability, or improve resilience of built assets to disaster events.

7.2 10 Step Built Asset Management Plan for Improving Resilience to an EILD Event

Figure 7.1 shows the 10 step built asset management framework to guide facilities/built asset managers through the application of the RAIF and LRG to the evaluation of mitigation to improve built asset resilience to EILD events.

Built Asset Management Framework for Improved Resilience to an EILD Event (v1.0)		
Step	**Task**	**Data Source / tools**
1	Define the geographical area under investigation. This could be a site, town, city or region depending upon the scope of the study (site level for an individual built asset: town, city or regional level for horizontal critical infrastructure). Define the key objectives (in terms of resilience improvements) required from the study. This could be at the organisational or community level and could involve specific operational improvements or more general community resilience improvements. Identify the range of built assets (longitude and latitude for each building) to be included in the study.	A workshop should be held with the key stakeholder commissioning the study. The workshop should explore the resilience improvements required and define the critical success factors against which effectiveness of different EILD mitigation interventions will be measured and identify availability of existing building level data.
2	Identify whether any of the built assets identified as part of the study are potentially susceptible to EILD events. The user will have to set tolerance thresholds based upon their attitudes towards risk and identify which, if any, of the critical infrastructure elements or built assets should be investigated in more detail.	The LRG should be used to assess the antecedent resilience of individual built assets. The LRG will provide European wide macrozonation maps and specific regional microzonation maps that will identify the potential susceptibility (very low, low, medium, high, very high) of each built asset to an EILD event for any given earthquake scenario. Where micro-zonation data isn't available in the LRG the user will have to provide site/region specific data generated from a detailed geotechnical investigation. The LRG library will provide guidance on how to conduct such investigations.

3	A detailed geotechnical investigation should be commissioned for the sites on which each element of critical infrastructure or each built asset identified for detailed investigation is located. The user will have to set tolerance thresholds based upon their attitude to risk to identify which if any of the critical infrastructure elements or built asset should be investigated in more detail.	The LRG will provide guidelines for commissioning a detailed geotechnical investigation at the site level. The detailed site-specific geotechnical data should be entered into the LRG to confirm the potential susceptibility (very low, low, medium, high, very high) of the particular site to an EILD event for the given earthquake scenario being considered.
4	Identify the potential damage profile for those elements of critical infrastructure or individual built assets identified in (3) above that exceed the user's tolerance thresholds.	The LRG contains generic fragility curves for a range of typical critical infrastructure and building typologies that are used to generate probability profiles of four damage states (slight, moderate, severe and complete damage) along with the mean damage ratios (for the built asset, for built asset contents and for disruption to business). Where a generic fragility curve matches the user's need the user will need to provide technical details of the specific critical infrastructure or built asset being analysed. This data could come from the users existing built asset database or could be generated through critical infrastructure or building surveys. Where a generic fragility curve does not match the user's needs the user will need to commission the development of bespoke fragility curves for each of their critical infrastructure elements or built assets being evaluated. The LRG library will provide technical guidance on how to develop fragility curves.

5	Identify the financial loss for each critical infrastructure element or built asset including an assessment of the impact that each damage state would have on the performance of the critical infrastructure or built asset (in terms of the impact that reduced functionality would have on). The loss of functionality (performance) should be made on a case by case basis using the expert knowledge of the facilities manager/building users or critical infrastructure asset managers to interpret the impact that any given damage state will have on production (e.g. for commercial organisations) or service delivery (e.g. for critical infrastructure). For critical infrastructure these assessments should be based upon the collective loss of performance across all the infrastructure's assets.	The LRG will provide an estimate of the economic loss associated with the mean damage ratio for each critical infrastructure element or built asset. The user is required to provide an assessment of the asset value, contents value and business interruption costs. Wherever possible these should be in line with the organisation's insurance policies. The LRG uses a series of weighting factors to calculate the economic losses. The user can input their own weighting factors if required. The loss of functionality should be assessed by reference to the organisation's / infrastructure managers Business Continuity and Resilience Plans/Disaster Management Plans.
6	Identify the impact that the loss of performance of critical infrastructure elements or built assets would have on the resilience of the organisation or community. Apply the criteria identified in step (1) to identify those critical infrastructure elements or built assets where potential mitigation actions are needed to reduce the adverse effects that a future EILD event would have on resilience (from either an individual business perspective or community perspective.)	Use an organisation's BCRP / DMP and business risk framework to assess the impact that loss of performance would have on the organisation. Use the customised UNISDR Disaster Resilience Scorecard to assess the impact that a loss of performance would have on the community. USE the LIQUEFACT CI scorecard to assess the impact that a loss of performance would have on the critical infrastructure system.

7	Identify a range of technical and operational mitigation actions for each critical infrastructure element or built asset whose impact has been identified as having a significant (using critical success factors identified in step 1) on either an individual organisation's resilience, critical infrastructure system resilience or community resilience.	The LRG will identify a range of technical (ground improvement) mitigation options that are suitable for the critical infrastructure element or built assets typology being modelled. For each of these mitigation options the LRG will identify a potential improvement score (expressed as a percentage improvement above baseline - no mitigation) along with an indicative assessment of costs (very high, high, medium, low, very low). Operational mitigations should be identified on a case by case basis as part of the organisations BCRP and DMP.
8	Perform a CBA for the mitigation options identified in step 7. The CBA should consider both direct and indirect costs and benefits at the individual built asset and critical infrastructure system level. Identify those mitigation options that have the most favourable return on investment and investigate any preferred options in more detail. The CBA at the community level needs also to consider the direct and indirect community costs and benefits.	The LRG will provide a CBA analysis at the individual built assets and critical infrastructure element level. The CBA will provide an assessment of the return on investment for each mitigation option. The individual built asset and critical infrastructure element data can be aggregated to provide an indicative assessment of the return on investment at the community level. Note: such macroeconomic analysis beyond the scope of the LRG.

9	Commission a detailed options appraisal for those preferred mitigation options identified in step 8. This will include detailed design considerations of each mitigation option for each critical infrastructure element or built asset as well as detailed assessments of the costs associated with each preferred mitigation option. Identify which, if any, mitigation options should be implemented and prioritise these using the critical success factors identified in step 1.	Commission a local geotechnical engineering company to develop detailed designs for the preferred mitigation options. The cost (capital and operating) of implementing each mitigation option will be dependent upon local circumstances and as such will need to be derived from local cost databases (where these exist); historic accounts (if available) and contractor's estimates. The cost of operational mitigations should be derived through discussions with the building/asset owners/FM.
10	Programme those mitigation options identified for implementation into a built asset management plan. When developing the plan each mitigation intervention should be programmed to occur at some future point in the remaining critical infrastructure element or built assets life cycle.	The timing of future mitigation interventions will depend on the remaining residual value of the critical infrastructure element or built asset and on where the asset currently sits in terms of the organisation's maintenance and refurbishment cycle and on the organisation's attitudes towards risk. These evaluations will need to be made on organisation by organisation basis.

Table 7.1: Built Asset Management Framework for Improved Resilience to an EILD Event (v1.0)

Note: full details on how to carry out each stage of the analysis using the LRG will be provided in the software user guide.

7.3 Validation of Built Asset management Framework for Improved Resilience to EILD Events

In April 2019 the built asset management framework and the latest versions of the LIQUEFACT tools (including the LRG) were tested against a range of scenarios with a view to identifying any changes required to the tools before the final prototype versions were released. The validation took place during the LIQUEFACT project management workshop held in Istanbul (where all WPs were represented) and during a two-day workshop held in Chelmsford between WP5 and WP6.

A 1.5 hour workshop was held as part of the Istanbul project management meetings to test the ability of the built asset management framework to integrate the LIQUEFACT tools to support the development of business cases to support (or reject) mitigation interventions to improve resilience to EILD events. During the workshop three teams of researchers from the LIQUEFACT project were asked to apply the built asset management framework to three hypothetical scenarios (primary health care scenario, public building scenario, and a road scenario). Each team was asked to consider each step in the built asset management framework in turn and decide amongst themselves whether that step could be supported by the LIQUEFACT tools or whether modifications were required to the tools in order to deliver the expectations of the built asset management framework? Each team considered one of the hypothetical frameworks. Each team comprised members drawn from all the LIQUEFACT work packages that had been responsible for the development of the LIQUEFACT tools. As such, each team could be considered to contain 'experts' in all aspects of the built asset management framework. All the teams concluded that the steps of the built asset management framework were appropriate for the evaluation of alternative mitigation options to improve resilience to an EILD event. In addition, all the teams provided practical suggestions, or identified current limitations, with the built asset management framework that will be investigated further during the external validation of the built asset management framework in WP7 and development of the typical use cases use-cases that will be developed as part of WP8.

Following the Istanbul workshop, a two-day workshop between researchers from WP5 and WP6 was held at Chelmsford to validate the technical aspects of the built asset management framework against the latest version of the LRG software tool. Again, a hypothetical health care scenario was used to evaluate the ability of the LRG to support each step of the built asset management framework. The health care scenario was an extension of that used in the Rome 'Sprint Test' where multiple sites were included as part of the scenario.

The scenario used in the Chelmsford workshop considered a hypothetical primary health care system comprised of nine built assets located on four different sites across the city. Each step of the built asset management plan was evaluated, against two earthquake scenarios chosen to represent the most severe and most likely scenarios required by the customised UNISDR disaster resilience Scorecard. At each step data was entered into the LRG (or data already contained with the LRG was used) to provide the technical output required for the built asset management plan. The key technical findings from the hypothetical scenario are summarised in Table 7.2.

Table 7.2: Results from the Chelmsford validation workshop

Step	LRG Process/Comments
1	The LRG was able to define the hypothetical city under consideration and geo-locate each built asset with the hypothetical city.
2	The macro-zonation output from the LRG identified that all the hypothetical buildings were potentially susceptible to an EILD event. Micro-zonation further refined the level of potential susceptibility for each building (very-low, low, medium, high, very-high) for each earthquake scenario.
3	Site-specific ground profile data, including the equivalent soil profile, were input into the LRG where the micro-zonation data was deemed insufficient to identify potential susceptibility of a building to an EILD event. Output from the LRG identified 3 of the 9 buildings as having a very low susceptibility and these were removed from further investigation.
4	Hypothetical physical details of the remaining (6) buildings (structural characteristics, material characteristics, storey height, and foundation system) were entered into the LRG and fragility analyses were performed using fragility functions contained within the LRG. A range of damage profiles in the form of profitability profiles (slight damage, moderate damage, severe damage, complete damage) were generated for each building along with an assessment of each buildings mean damage ratio.
5	Economic loss was calculated for the building structure, its contents and building interruption using pre-existing weighting factors within the LRG.
6	The societal loss as a consequence of reduced functionality of the built asset cannot be calculated within the LRG as this requires business specific data on a case by case basis. Societal losses will need to be calculated using the customised UNISDR scorecard and CI scorecard.
7	Although not yet implemented, the LRG software is designed to provide suggestions of soil mitigation interventions that should result in a change to the soil profile. The LRG will repeat steps 3 to 6 for each mitigation intervention, identifying an improvement potential score (in terms of a percentage improvement above the non-mitigated case) and an indicative mitigation cost, probably in the form of a qualitative scale (very low, low, medium, high, very high).
8	A detailed CBA is outside the scope of the LRG software and the CBA tool developed by WP5 will be used as part of an options appraisal process. The LRG will provide an indicative return on investment for each mitigation option based upon the expected in mean damage ratio change (with and without mitigation) divided by the indicative cost. This indicative return on investment will allow and initial ranking of mitigation options.
9	The detailed options appraisal, including detailed design considerations and an assessment of construction costs is outside the scope of the LR.G software

10	The planning of mitigation interventions is outside the scope of the LRT software.

The results from both the Istanbul workshop and Chelmsford workshop have been included in the built asset management framework given in Figure 7.1.

The built asset management framework described in Figure 7.1 will be further validated against five hypothetical use cases as part of WP7 (once the final beta versions of the LRG and LIQUEFACT tools are available). Once these use cases have been completed the final version of the built asset management framework will be developed to reflect the final versions of the LIQUEFACT tools and the LRG. As such, the built asset management framework described in Figure 7.2 should be considered a work in progress until the validation has been completed.

7.4 Business Continuity Management: Business Continuity Plans and Disaster Management Plans for an EILD Event

Business continuity management (BCM) is a holistic approach for ensuring that business operations can be maintained and/or recovered in a timely fashion in the event of a disaster event. To this end BCM focuses on minimising the operational, financial, legal, reputational (and other business critical) consequences that can arise from the impact caused by a disaster event. Business continuity management typically incorporates: pre-disaster event planning; disaster event management; and post-disaster event recovery..

Pre-disaster event planning includes business impact analyses to identify critical operations and services, including internal and external linkages and dependencies (e.g. supply chain logistics, communication channels etc.), and establishes tolerance levels to assess the risks and potential impact of a range of disaster event scenarios on the organisation's ability to continue to deliver its primary function and manage it stakeholder relationships (including customer relationships).

Disaster event management includes establishing disaster management plans that identify business recovery objectives and priorities to ensure that agreed levels of service (with internal and external stakeholders) are maintained during the disaster events and support a rapid return to normal business operations once the disaster events is over.

Post-disaster event recovery includes establishing business continuity plans that provide detailed guidance for implementing the disaster management plans including, establishing clear roles and responsibilities for managing operational disruptions in the case of disruptions to normal decision-making hierarchies.

7.4.1 ISO 22301:2014 - societal security-business continuity management systems-requirements.

The European standard EN ISO 22301 (2014) provides detailed guidance on the development of business continuity management systems (BCMS). EN ISO 22301 emphasises the importance of:

- understanding the organisation's needs;
- implementing and operating controls on measures for managing an organisation's overall capability to manage disruptive incidents;
- monitoring and reviewing the performance and effectiveness of BCMS; and
- continually improving the BCMS in light of objective feedback.

EN ISO 22301 identifies five key components of a BCMS relating to:

1. policy;
2. human resources;
3. management processes (e.g. policy, planning, implementation and operation, performance assessment, management review, and improvement)
4. documentation; and
5. any business continuity management processes relevant to the organisation.

EN ISO 22301 also stresses the contribution the business continuity planning contributes to a more resilient society and the need to engage the wider community in the recovery process.

EN ISO 22301 applies a "Plan-Do-Check-Act" model to planning, establishing, implementing, operating, monitoring, reviewing, maintaining and continually improving the effectiveness of an organisations BCMS (Figure 7.1). In this context, Plan involves establishing the business continuity policy, objectives, targets, controls, processes and procedures relevant to improving business continuity in order to deliver results that align with the organisation's overall policies and objectives. Do involves implementing and operating the business continuity policy, controls, processes and procedures. Check involves monitoring and reviewing performance against business continuity policy and objectives and reporting the results to management for review, remediation and improvement. Acts involves maintaining and improving the BCMS by taking corrective action, based on the results of management review and reappraising the scope of the BCMS and business continuity policy and objectives.

7.4.2 Developing a BCMS for EILD events

Whilst EN ISO 22301 provides detailed guidance for the development of BCMS, this guidance is independent of the other type of business disruption. As such EN ISO 22301 should be used as a checklist by organisations as they develop their BCMS for specific disaster events.

There are numerous guidance notes available on the World Wide Web for preparing BCMS for earthquake events[16,17,18,19,20]. The Los Angeles guidance 'Planning for Business Operations after Earthquakes[20] is typical of the advice provided to organisations and includes advice on:

- How to identify and prioritise critical business operations (e.g. financial systems, Information and Communication Technology systems, customer relationship management systems, reputation etc.) and which employees are responsible for their operation; including alternate employees who can take over should the primary responsible employee be unavailable;
- Identifying and recording details of all suppliers (and if really business critical, their suppliers) and examining how prepared they are for an earthquake event. This should include alternate suppliers if necessary;
- Developing crisis management procedures including alternate decision making hierarchies should key management employees be unavailable;
- Establishing a disaster communications plan that utilises a range of communications channels to provide redundancy in case of communication system damage;
- Testing the plans using simulations.

However, whilst most advice guides provide advice for ground shaking the authors haven't found any that provide specific guidance for earthquake induced liquefaction.

[16] https://storage.googleapis.com/laedc/Preparing%20for%20Business%20After%20Earthquakes%20by%20LAEDC%20-WEB%20%20FINAL.pdf
[17] https://www.earthquakecountry.org/library/7StepsBusiness2008.pdf
[18] https://www.fema.gov/media-library-data/1409865580490-e83e2d1b906d35cc766477cb9459ca0e/prepareathon_playbook_earthquakes_final_090414_508a.pdf
[19] https://smallbusiness.chron.com/business-recovery-case-earthquakes-69479.html
[20] https://laedc.org/eq/

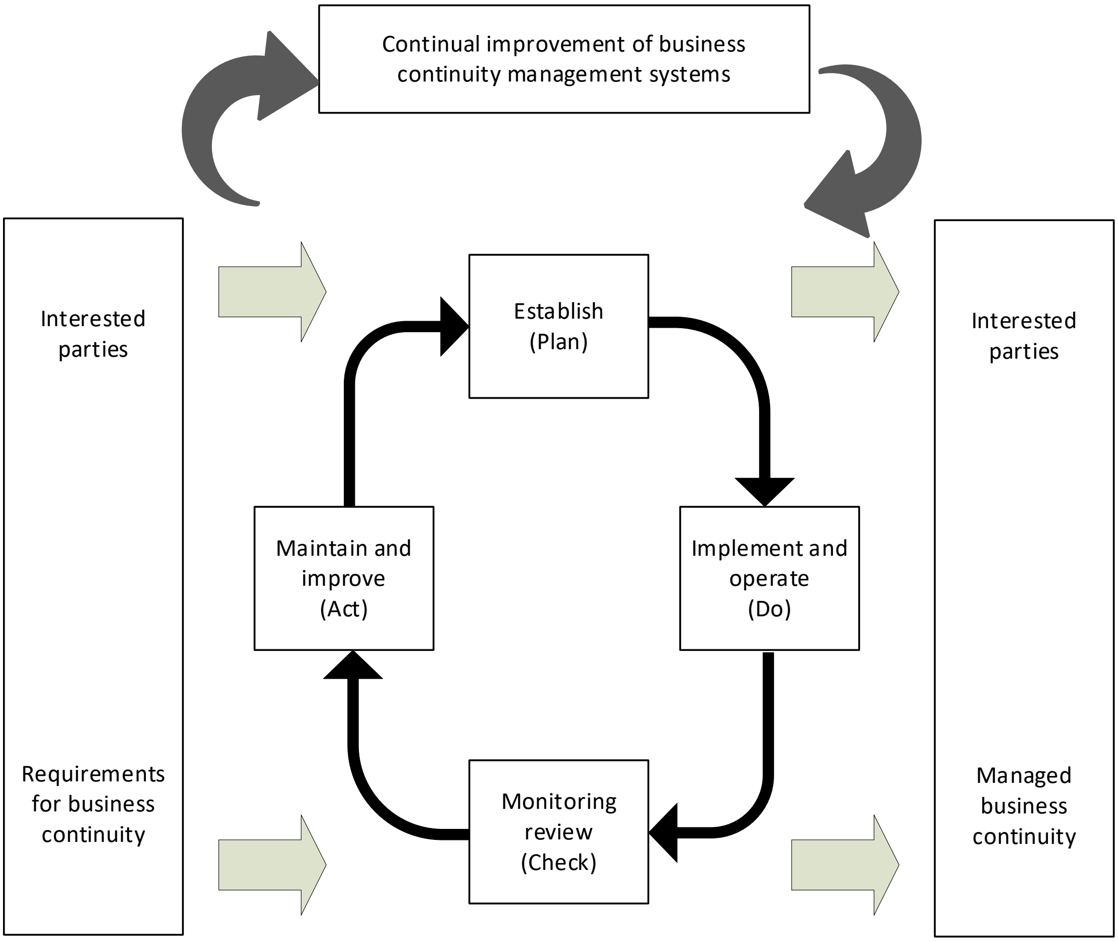

Figure 7.1: PDCA model applied to BCMS process (source EN ISO 22301)

The LIQUEFACT RAIF and LRG have been developed to help organisations (and communities) preparing a BCMS for an EILD event. Although every organisation's BCMS will be different (to reflect local business needs and circumstances) the general principles underpinning a BCMS for an EILD. Event will be the same.

The RAIF and LRG will provide organisations with an assessment of the risks that an EILD event poses to their organisation. This assessment will be in the form of a series of damage state profiles (slight damage, moderate damage, severe damage, complete damage) for each of their built assets along with an estimate of each of their built assets mean damage ratio. Each organisation will need to interpret the effect that the damage state profiles and mean damage ratio will have on the ability of their built assets to support their primary business function. This activity will need to reflect the contribution that each built asset makes to business function. Guidance on the typical types of damage (both structural and non-structural) associated with earthquake induced liquefaction is currently be compiled in WP7. Figure 7.2 gives an early overview of the type of damage that is associated with EILD events. The use-cases being developed in WP7 and WP8 will provide more detailed examples of both typical damage states and the impact that such damage states have on primary business function for a range of public and private organisation types.

Dwelling Foundation Damage Categories			
Type of Damage	Minor	Moderate	Major
Stretching	0 to 5mm	5 to 30mm	>30mm
Hogging	0 to 20mm	20 to 50mm	>50mm
Dishing	0 to 20mm	20 to 50mm	>50mm
Racking/Twisting	0 to 10mm	10 to 30mm	>30mm
Tilting	0 to 20mm	20 to 50mm	>50mm
Abrupt Differential Movement	0 to 10mm	10 to 20mm	>20mm
Global Settlement	0 to 50mm	50 to 100mm	>100mm

Figure 7.2: Indicative building damage caused by an EILD event

8.0 Next Steps

The built asset management plan, RAIF and LRG will be validated against a range of typical use cases in work package 7 and work package 8. These use cases will include examples of a:

- single domestic dwelling
- small business premises
- cultural heritage built asset
- horizontal infrastructure
- healthcare infrastructure

One the use-cases have been developed, final versions of the built asset management plan, RAIF and LRG will be developed (along with the supporting tools that have been developed by all LIQUEFACT work packages) and these will collectively form the LIQUEFACT Toolbox for improving built asset and community resilience to EILD events. However, until the final version of the tools are released the work described in this deliverable should be considered a work in progress that will be amended and added to as the LIQUEFACT project progresses.

The primary audience for the report are the LIQUEFACT partners and researchers.

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Appendix 1 – LIQUEFACT CI Resilience Scorecard

Dimension	Sub-dimension	Indicator	Sub-indicator	Specific metric / question	Measurement scale	Comment
Organization & Management	Finance	Insurance guidelines		Does a national standard or a guideline for infrastructure insurance exist?	**5-** Yes. A standard with a minimum premium exist and additionally there is state control and cover in case of insurance fails **4-** Yes. A standard with indication of the minimum premium exists **3-** Yes. A standard without indication about the premium exists **2-** Yes. A guideline with indication about the premium exists **1-** Yes. A guideline without indication of a premium exists **0-** No	
		Resilience budget	Preparedness budget	Does your organization have a budget allocated for preparedness actions?	**5-** Yes. This budget is different from the capital expenditure budget but its amount is topped up periodically **4-** Yes. This budget is different from the capital expenditure budget but its amount is not topped up periodically	

					3- Yes. It is part of the capital expenditure budget because the organization is moderately vulnerable to soil liquefaction phenomena and has planned major changes to reduce the vulnerability **2-** Yes. It is part of the operational expenditure budget because the organization is only slightly vulnerable to soil liquefaction phenomena **1-** No. But the risk analysis results showed the organization is not prone to soil liquefaction phenomena **0-** No	
			Insurance budget	Does your organization have an insurance cover for natural disasters?	**5-** Yes. It covers specifically also damages due to EILD **4-** Yes. It covers damages for earthquake and all earthquake cascade hazards **3-** Yes. It covers also earthquakes damages **2-** Yes. But it is for all natural disasters and it is not specific for earthquakes **1-** No. But it has a general insurance cover for outages or damage to third parties **0-** No	
		Disaster Management budget		Does your organization have a DM budget?	**5-** Yes. It covers the cost of emergency operation and external supply for 4 weeks after the disaster	

					4- Yes. It covers the cost of emergency operation and external supply for 1 week after the disaster **3-** Yes. It covers the cost of emergency operation and external supply for 72 hours after the disaster **2-** Yes. But it can cover only the cost of emergency security operations **1**- No. But the organization has an insurance plan that covers also DM operation and the bank will offer credit in case of emergency **0-** No	
		Repair	Financial internal resources	Does the organization have a budget to cover the repair costs after a disaster?	**5-** Yes. It has a special budget allocated to repair all equipment and physical assets **4-** Yes. It has a special budget allocated for the repair equipment and infrastructure services in case of disaster and the rest comes from the capital expenditure budget **3-** Yes. It is part of the DM budget **2-** No. But the capital expenditure budget includes also an amount to cover damage repair in case of disasters **1-** No. It has only the capital expenditure budget **0-** No. It has only the operational expenditure budget	

			Financial external resources	Does your organizations have the opportunity to get external financial resources to cover the cost of repairs in case of disasters?	**5-** Yes. It can get resources from the external stakeholders and get also the insurance payout **4-** Yes. It can ask credit to stakeholders and cover the debit with the insurance payout **3-** Yes. It can ask credit to the bank and cover the debit with the insurance payout **2-** Yes. It can ask credit to the bank and cover it increasing the price of the services it provides **1-** Yes. It can ask credit to the bank, but has no mechanism in place to cover the debit **0-** No	
			Financial institutional resource	Will public institutions cover the repair costs of your organization in case of disaster?	**5-** Yes. By paying all repair costs, substitutions of equipment and lost stored physical resources suppling the core services **4-** Yes. By paying part of the repair costs of the physical assets and the equipment and lost physical stored resources suppling the core services. **3-** Yes. By paying part of the repair costs of the physical assets **2-** Yes. By landing money to advantageous interest **1-** Yes. By landing money to 0% interest	

					0- No	
	Coordination	Contingency plan code		Do standards for emergency plans exist?	**5-** Yes. The country where the organization is located has also national codes to draft emergency plans and a control body to check the implementation of the codes **4-** Yes. The country where the organization is located has also national specific codes to draft emergency plans **3-** Yes. The country where the organization is located has also national specific guidelines to draft emergency plans **2-** Yes. The implementation of international standards, such as ISO 22301, is compulsory in the country where the organization is located **1-** Yes. The implementation of international standards, such as ISO 22301, is optional in the country where the organization is located **0-** No. International standard are not implemented in the country where the organization is located	
		Staff and managers training		Does your organization provide continuous	**5-** Yes. Periodical training and exercises about evacuation plans and others security procedure and short-term	

				training also to deal with emergencies?	mitigation actions. A clear explanation of the consequences in case of no implementation of the plans is provided **4-** Yes. Periodical training without exercises about evacuation plans and others security procedure and short-term mitigation actions. A clear explanation of the consequences in case of no implementation of the plans is provided **3-** Yes. Periodical training without exercises about evacuation plans and others security procedure and short-term mitigation actions. **2-** Yes. Training without exercises about evacuation plans and others security procedure and short-term mitigation actions is provided at the beginning of the employment **1-** Yes. Training without exercises only about evacuation plan **0-** No	
		Planed redundancy of trained staff		Does your organization plan have redundant trained staff?	**5-** Yes. For all positions. The key role in case of emergency is given according to results of attitudinal tests about the ability to deal with risk and emergency **4-** Yes. For all positions	

					3- Yes. For all positions dealing with technical operations and security procedures **2-** Yes. For all positions dealing with technical operations **1-** Yes. Only for few key positions dealing with technical operations **0-** No	
		Security procedures		Does your organizations have a plan of security procedures in case of emergency?	**5-** Yes. Also in case of natural disasters to reduce their cascade effects and provide a minimum service. The plan is explained to the staff, which is trained to implement it **4-** Yes. Also in case of natural disasters to reduce their cascade effects and provide a minimum service. The plan is explained to the staff, which is not trained to implement it **3-** Yes. Also in case of natural disasters to reduce their cascade effects, but not to provide a minimum service. The plan is not explained to the staff, which is not trained to implement it **2-** Yes. Also in case of natural disasters to reduce their cascade effects, but not to provide a minimum service. The plan is not explained to the staff, which is not even trained to implement it	

					1- Yes. But not in case of natural disasters **0-** No	
		Communication		Does your organizations have policies and procedures in place to communicate risks and actions in case of emergency?	**5-** Yes. To implement all security procedures. Communication is top-down, horizontal and bottom-up. The bottom-up communication influences the follow-up decisions and actions **4-** Yes. To implement all security procedures. Communication is top-down, horizontal and bottom-up **3-** Yes. To implement all security procedures. Communication is only top-down and horizontal **2-** Yes. To implement all security procedures. Communication is only top-down **1-** Yes. Only to implement the evacuation. Communication is only top-down **0-** No	
		Leadership		Does your organizations have managers able to lead in case of emergency?	**5-** Yes. In the organization, the communication is top-down and bottom-up to help managers to update emergency plan. Managers have expertise to modify the emergency procedure. **4-** Yes. In the organization the communication is top-down and managers expect feedback as control	

					measure of the implementation of the procedures. Managers have no expertise to modify the emergency procedure **3-** Yes. In the organization the communication is top-down and managers expect feedback as control measure of the implementation of the procedures **2-** Yes. In the organization the communication is only top-down **1-** No. The duties of who must lead emergency procedures are not clear **0-** No. Who must lead emergency procedures is not well defined	
		Responsibility		Does the staff have any responsibility during the emergency?	**5-** Yes. The staff must execute the managers' indications, provide feedback to them, and eventually take decisions in extreme conditions not according to the contingency plans, and take part in the decision loop together with the managers **4-** Yes. The staff must execute the managers' indications, provide feedback to them, and eventually take decisions in extreme conditions not according to the contingency plans **3-** Yes. The staff must execute the managers' indications, provide feedback to them and eventually take decisions in	

					extreme conditions according to the contingency plans. **2-** Yes. The staff must execute the managers' indications and provide feedback to them **1-** Yes. The staff must execute the managers' indications **0-** No	
		Communication with and to external stakeholders		Are the external stakeholders informed about the decisions taken for repair and service reinstate?	**5-** Yes. They are involved in the decisional process. **4-** Yes. During the decisional process and soon after the final decisions are taken. **3-** Yes. Before the final decisions are taken because they provide feedback. **2-** Yes. Before the decisions become public. **1-** Yes. When the decisions become public. **0-** No	
		Collaboration with external stakeholders		During the recovery phase, is there a plan to involve the external stakeholders in the decisional process?	**5-** Yes. The external stakeholders take part to the process to take decisions regarding the repair and service reinstate actions **4-** Yes. Their feedback might change the decisions taken **3-** Yes. Their feedback on the decisions is asked, but this does not change it	

					2- Yes. If they are institutional actors, their feedback is asked **1-** No. But the external stakeholders are informed of the decisions taken for the repair and service reinstate. **0-** No	
		Learning from experience/ Learning from others/ Culture		Is your organizations reviewing other organizations' experience affected by EILDs?	**5-** Yes. It is the base of a participatory democracy process involving your organization, other organizations and the institutions **4-** Yes. Review is based on shared data among organizations **3-** Yes. Review is only based public data **2-** No. It is institutions' duty to draft guidelines, standards and codes based on those experiences. **1-** No. The other organizations have nothing in common with your organization **0-** No	
	Business planning	Security standards		Do security standards exist in the country where your organization is?	**5-** Yes. The country where the organization is located has also national codes to define security measures and a control body to check the implementation of the codes	

					4- Yes. The country where the organization is located has also national specific codes to draft emergency plans **3-** Yes. The country where the organization is located has also national specific guidelines to define security measures **2-** Yes. The implementation of international standards, such as ISO 22315, is compulsory in the country where the organization is located **1-** Yes. The implementation of international standards, such as ISO 22315, is optional in the country where the organization is located **0-** No. Not even international standard are implemented in the country where the organization is located	
		Risk analysis		Is your organization aware of its level of risk to soil liquefaction phenomena?	**5-** Yes. A risk assessment is carried out periodically **4-** Yes. A risk assessment is carried out every time a large maintenance work is scheduled **3-** Yes. A risk assessment is carried out every time a major refurbishment is scheduled **2-** Yes. A risk assessment is carried out only when required by law	

					1- Yes. A risk assessment was carried out after the last occurrence **0-** No	
		Business contingency plan		Does your organization have a BCP?	**5-** Yes. It is updated periodically. The staff is constantly trained to implement it **4-** Yes. It is updated periodically. The staff is aware of the procedures to implement it **3-** Yes. It is updated only after major refurbishments. The staff is aware of the procedures to implement it **2-** Yes. It is updated only after major refurbishments. The staff is not aware of it **1-** Yes. Only with minimum requirements imposed by law. The staff is not aware of it **0-** No	
		Disaster Management plans	DM HR plan	Does your organization have a DM HR plan?	**5-** Yes. It defines all roles for the crisis management, their redundancy and defines the periodicity of the staff training **4-** Yes. It defines all roles for the crisis management and their redundancy **3-** Yes. It defines all roles for the crisis management **2-** Yes. It defines the only key roles for the crisis management	

					1- No. But the person in charge of taking decision is defined. **0-** No	
			Security plan	Does your organization have a security plan?	**5-** Yes. It is updated according to the periodical maintenance and the staff is aware of it and its changes and it is trained to implement it **4-** Yes. It is updated according to periodical maintenance and the staff is aware of it and its changes **3-** Yes. It is updated according to periodical maintenance **2-** Yes. It is updated according to the according to the standards updates **1-** Yes. With minimum requirements imposed by the standards **0-** No	
			Evacuation plan	Does your organization have an evacuation plan?	**5-** Yes. It is periodically updated following changes of the physical asset. The staff is periodically trained to implement it. **4-** Yes. It is periodically updated following changes of the physical asset. The staff is occasionally trained to implement it. **3-** Yes. It is periodically updated following changes of the physical asset **2-** Yes. It is periodically updated as the law it updated **1-** Yes. As it is required by law	

					0- No	
			Short-term mitigation plan	Does your organization have a short-term mitigation plan?	**5-** Yes. It includes the security measures to preserve the core services from further damages and minimize the cascade effect damages and the actions to repair provisionally the physical assets and guarantee alternative supply chains for the core services **4-** Yes. It includes security measures to preserve the core services from further damages and minimize the cascade effect damages actions to repair provisionally the physical assets **3-** Yes. It includes security measures to preserve the core services from further damages and minimize the cascade effect damages **2-** Yes. It includes security measures to minimize the cascade effect damages **1-** Yes. It is the security plan **0-** No	
		Long term mitigation plan		Does your organization have a long-term mitigation plan?	**5-** Yes. It is updated periodically together with a risk analysis and financial resources are planned accordingly **4-** Yes. It is updated periodically together with a risk analysis **3-** Yes. It follows the updated risk analysis	

					2- Yes. As those mitigations are required by new codes or standards **1-** No. It coincides with the refurbishment **0-** No	
		Simulation exercises		Does your organization plan exercises of BCP and security plan implementation?	**5-** Yes. It has those plans. Exercises are planned and carry out periodically and the results of exercises are used to improve those plans **4-** Yes. It has those plans. Exercises are planned and carry out periodically **3-** Yes. It has those plans. Exercises are planned and carry out occasionally **2-** Yes. It has those plans. Exercises are planned and carry out only when those are updated **1-** Yes. It has those plans, but no exercise is planned and carry out **0-** No. It does not have those plans.	
		Short-term mitigation implementation		Does your organization have a short-term mitigation implementation policy?	**5-** Yes. It has a short-term mitigation plan and it has policy to implement it which are updated as soon as the plan is updated and it follows the updated indications of external stakeholders **4-** Yes. It has a short-term mitigation plan and it has policy to implement it which are updated as soon as the plan is updated	

					3- Yes. It has a short-term mitigation plan and it has policy to implement it which are updated as soon as the plan is updated **2-** Yes. It has a short-term mitigation plan and it has an implementation policy **1-** No. It has a short-term mitigation plan, but it has no implementation policy **0-** No. It does not have any short-term mitigation plan	
		Program for PTSD		Does your organization have a PSTD program for IELD disasters?	**5-** Yes. Collective sessions are planned to explain how to reduce the post-traumatic stress. Individual sessions are also planned for everybody **4-** Yes. Collective sessions are planned to explain how to reduce the post-traumatic stress. Individual sessions are planned after a psychological test is taken **3-** Yes. Collective sessions are planned to explain how to reduce the post-traumatic stress. Individual sessions are planned only on request **2-** Yes. Collective sessions are planned to share traumatic experience **1-** Yes. Collective sessions are planned to explain how to reduce the post-traumatic stress **0-** No	

		Enhanced risk awareness		Does your organizations give the opportunity to staff to provide feedback about the BCP and DM plan?	**5-** Yes. It has both plans. The staff can give suggestions how to improve them. An iterative process with exercises are used to improve them based on the enhanced staff's risk awareness **4-** Yes. It has both plans. The staff can give suggestions how to improve them **3-** Yes. It has both plans. The staff can tell which part is not effective **2-** Yes. It has only one of them **1-** No. It does not have any of the plans **0-** No. It does not have those plans	
Technical system	Physical asset	Building codes		Does the building code indicate measures to design robust physical assets against IELD?	**5-** Yes. The building code defines those measures, which are compulsory. It gives indications about both Serviceability and Ultimate Limit State **4-** Yes. The building code defines those measures, which are compulsory. It gives indications only about the Ultimate Limit State **3-** Yes. Indications are given for all elements: for the primary ones they are compulsory, while for the secondary ones they are optional **2-** Yes. Compulsory indications are given only for the primary elements **1-** Yes. The indications are optional	

					0- No	
		Planned redundancy		Does your organization have a planned redundancy for the physical asset?	**5-** Yes. The physical asset redundancy is optimally planned to guarantee the continuity of all services **4-** Yes. The physical asset redundancy is planned only to guarantee the main service and allow a disruption 72 hours long for the secondary services **3-** Yes. The physical asset redundancy is planned only to guarantee the main service and allow a disruption 1 week long for the secondary services **2-** Yes. The physical asset redundancy is planned only to guarantee the main service and undefined duration of disruption of the secondary service. **1-** No. However, the physical asset is designed for an higher intensity of soil liquefaction respect to the one expected in the area where the physical asset is located **0-** No	
		Long-term mitigation interventions		Are there any planned long-term mitigation interventions for the physical assets of your	**5-** Yes. Long-term interventions are planned, designed and executed to protect all organization physical assets **4-** Yes. Long-term interventions are planned, designed and executed to	

				organization to protect it from IELD?	protect the organization principal physical assets **3-** Yes. Long-term interventions are planned, designed and executed only to protect the organization physical assets to ensure the implementation of DM plans **2-** No. Although the risk analysis indicates IELD as possible threats, the organization takes the risk of not planning long-term mitigation interventions for the physical assets **1-** No. However, the risk analysis does not include IELD among the threats **0-** No. No risk analysis is carried out	
		Inherent resilience		Is the physical asset of your organizations robust enough to withstand an IELD and be totally functional after a given time?	**5-** Yes. No disruption will occur **4-** Yes. After 24 hours from IELD **3-** Yes. After 72 hours from IELD **2-** Yes. After 1 week from IELD **1-** Yes. After 4 weeks from IELD **0-** No	
		Repair	Physical/huma n internal resources	Does your organization have material and human resources to repair the	**5-** Yes. The organization has internal material and human resources to restore the main service within 24 hours after IELD	

				physical asset in case of damages due to IELD?	**4-** Yes. The organization has internal material and human resources to restore the main service within 72 hours after IELD **3-** Yes. The organization has internal material and human resources to restore the main service within 1 week after IELD **2-** Yes. The organization has internal material and human resources to restore the main service within 4 weeks after IELD **1-** No. The repair can be done only with material resources external to the organization **0-** No	
			Physical/huma n external resources	Can your organization find material and human resources to repair the physical asset in case of damages due to IELD?	**5-** Yes. The organization can find external material and human resources to restore the main service within 24 hours after IELD **4-** Yes. The organization can find external material and human resources to restore the main service within 72 hours after IELD **3-** Yes. The organization can find external material and human resources to restore the main service within 1 week after IELD **2-** Yes. The organization can find external material and human resources to restore	

					the main service within 4 weeks after IELD **1-** Yes. Hardly to be certain about it **0-** No	
	Infrastructure services	Building standards		Does the building code indicate measures to design robust of infrastructure services against IELD?	**5-** Yes. The building code defines those measures, which are compulsory. It gives indications about both Serviceability and Ultimate Limit State **4-** Yes. The building code defines those measures, which are compulsory. It gives indications only about the Ultimate Limit State Only Ultimate Limit State is defined and the indications are compulsory. **3-** Yes. Indications are given for all elements: for the primary ones they are compulsory, while for the secondary ones they are optional **2-** Yes. Compulsory indications are given only for the primary elements **1-** Yes. The indications are optional	
		Infrastructure service i-th	Planned redundancy	Does your organization have a planned redundancy for the infrastructure services?	**5-** Yes. The infrastructure services redundancy is optimally planned to guarantee the continuity of all services **4-** Yes. The infrastructure services redundancy is planned only to guarantee	

					the main service and allow a disruption 72 hours long for the secondary services **3-** Yes. The infrastructure services redundancy is planned only to guarantee the main service and allow a disruption 1 week long for the secondary services **2-** Yes. The infrastructure services redundancy is planned only to guarantee the main service and undefined duration of disruption of the secondary service. **1-** No. However, the infrastructure services are designed for an higher intensity of soil liquefaction respect to the one expected in the area where the physical asset is located **0-** No	
			Inherent resilience	Are the physical infrastructure services of your organizations robust to withstand an IELD and be totally functional after a given time?	**5-** Yes. No disruption will occur **4-** Yes. After 24 hours from IELD **3-** Yes. After 72 hours from IELD **2-** Yes. After 1 week from IELD **1-** Yes. After 4 weeks from IELD **0-** No	
			Repair	Does your organization have or can it find material and	**5-** Yes. The organization has internal material and human resources and can find external ones to restore the main service within 24 hours after IELD	

				human resources to repair the physical asset in case of damages due to IELD?	**4-** Yes. The organization has internal material and human resources and can find external ones to restore the main service within 72 hours after IELD **3-** Yes. The organization has internal material and human resources and can find external ones to restore the main service within 1 week after IELD **2-** Yes. The organization has internal material and human resources and can find external ones to restore the main service within 4 weeks after IELD **1-** Yes. But the repair can done only with material resources external to the organization **0-** No	
Operational delivery systems	Service design	Service Level Agreement		Does a Service Level Agreement for the kind of service provided by your organization exist? How long is the outage it define?	**5-** Yes. Maximum outage length of the service is less than 24 hours **4-** Yes. Maximum outage length of the service is 24 hours **3-** Yes. Maximum outage length of the service is 72 hours **2-** Yes. Maximum outage length of the service is 1 week **1-** Yes. Maximum outage length of the service is 4 weeks **0-** No	

		Core service i-th	Planned redundancy	Does your organization have a planned redundancy for the i-th core service?	**5-** Yes. The core services redundancy is optimally planned to guarantee the continuity **4-** Yes. The core services redundancy is planned only to guarantee the continuity of the main services and allow a disruption 72 hours long for the secondary services **3-** Yes. The core services redundancy is planned only to guarantee the continuity of the main services and allow a disruption 1 week long for the secondary services **2-** Yes. The core services redundancy is planned only to guarantee the continuity of the main services and an undefined duration of the secondary service disruption. **1-** No. However, the core services are designed for an higher intensity of soil liquefaction respect to the one expected in the area where the physical asset is located **0-** No	
			Planned contingency	Do the contingency plans of your organization include measures	**5-** Yes. Contingency plans include measures for the i-th core service to protect staff, avoid cascade effects and guarantee the whole service	

				for the i-th core service?	**4-** Yes. Contingency plans include measures for the i-th core service to protect staff, avoid cascade effects and guarantee half or less of the service **3-** Yes. Contingency plans include measures for the i-th core service to protect staff and avoid cascade effects **2-** Yes. Contingency plans include measures for the i-th core service to protect staff only **1-** No. Contingency plans do not include measures for the i-th core service **0-** No. No contingency plan exist	
			Inherent resilience	Is the i-th core service of your organizations robust to withstand a IELD and be totally functional after a given time?	**5-** Yes. No disruption will occur **4-** Yes. After 24 hours from IELD **3-** Yes. After 72 hours from IELD **2-** Yes. After 1 week from IELD **1-** Yes. After 4 weeks from IELD **0-** No	
	Service delivery	Service level agreement/ third party legal agreement		Do a Service Level Agreement and third party legal agreement for the kind of service provided by your organization exist?	**5-** Yes. Maximum outage length of the service is less than 24 hours **4-** Yes. Maximum outage length of the service is 24 hours **3-** Yes. Maximum outage length of the service is 72 hours	

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				How long could the lack of resources provided to your organization last?	**2-** Yes. Maximum outage length of the service is 1 week **1-** Yes. Maximum outage length of the service is 4 weeks **0-** No	
		Supply chain core service i-th	Planned redundancy	Does your organization have a planned redundancy for the supply chain of the i-th core service?	**5-** Yes. The redundancy of the supply chain of the i-th core service is optimally planned to guarantee the continuity **4-** Yes. The redundancy of the supply chain of the i-th core service is planned only to guarantee the main service and allow a disruption 72 hours long for the secondary services **3-** Yes. The redundancy of the supply chain of the i-th core service is planned only to guarantee the main service and allow a disruption 1 week long for the secondary services **2-** Yes. The redundancy of the supply chain of the i-th core service is planned only to guarantee the main service and undefined duration of the disruption of the secondary service. **1-** No. However, the supply chain of the i-th core service are planned/designed for an higher intensity of soil liquefaction respect to the one expected in the area where the physical asset is located	

					0- No	
			Inherent resilience	Is the supply chain of the i-th core service of your organizations robust enough to withstand a IELD and provide the resources to your organization after a given time?	**5-** Yes. No disruption will occur **4-** Yes. After 24 hours from IELD **3-** Yes. After 72 hours from IELD **2-** Yes. After 1 week from IELD **1-** Yes. After 4 weeks from IELD **0-** No	
			Internal resources	Does your organization have supplied resources to reinstate the i-th core service after aIELD?	**5-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 24 hours after IELD **4-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 72 hours after IELD **3-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 1 week after IELD **2-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 4 weeks after IELD **1-** Yes. But the i-th core service can be reinstated only with external material resources **0-** No	

			External resources	Can your organization find supplied resources to reinstate the i-th core service after IELD?	**5-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 24 hours after IELD **4-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 72 hours after IELD **3-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 1 week after IELD **2-** Yes. The organization can retrieve internal resources to reinstate the i-th core service within 4 weeks after IELD **1-** Hardly to be certain about it **0-** No	