TURNkey - Towards more Earthquake-resilient Urban Societies through a Multi-sensor-based Information System enabling Earthquake Forecasting, Early Warning and Rapid Response actions

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Towards more Earthquake-resilient Urban Societies through a Multi-sensor-based Information System enabling Earthquake Forecasting, Early Warning and Rapid Response actions

TURNkey

Deliverable D 7.7

A model Business Continuity and Resilience Plan and Disaster Management Plan Framework

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GLOSSARY

Acronym	Description
AHP	Analytical Hierarchy Process
AR	Action research
BCRP	Business continuity and resiliency plan
CBA	Cost Benefit Analysis

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DMP	Disaster management plan
DSS	Decision Support System
EEW	Earthquake early-warning
FWCR	Forecasting, early warning, consequence prediction, response
OEF	Operational earthquake forecasting
PAR	Participatory action research
RRE	Rapid response to earthquakes
TB	Test bed
TRL	Technology readiness level
UC	Use case
WP	Work package

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1 Introduction

A large part of Europe is at risk from earthquakes. To address this, the TURNkey research project aimed to foster urban resilience to earthquakes in Europe. The project covered 1) Operational Earthquake Forecasting (OEF) and simulations for seismic risk assessments during the period before an earthquake event; 2) Earthquake Early Warning (EEW) for near real-time seismic information during an earthquake event; and coordination and information management to support a Rapid Response to Earthquakes (RRE). TURNkey has worked towards the development of a Forecasting, early Warning, Consequence prediction and Response (FWCR) platform, which effectively integrates OEF, EEW and RRE. The project's goal was to close the gap between theoretical systems and their practical application in Europe. To this end, TURNkey researchers have worked with potential end-users to co-design an FWCR platform for strategic and operational decision making in the face of seismic risk and earthquake-related disasters. The approach used is called Participatory Action Research (PAR). With PAR, potential end-users take an active part in the research process as do those responsible for product/project design and development (i.e., the TURNkey scientists and engineers). The end-users included in PAR for TURNkey were civil protection, first responders, business organisations and critical infrastructure providers. TURNkey worked with potential end-users in its 6 geographical testbeds: Romania (TB-1); France (TB-2); Iceland (TB-3); Greece (TB-4); Italy (TB-5) and the Netherlands (TB-6). The TURNkey concept model was developed over three PAR cycles. This report describes the process and findings of the 3nd and final PAR cycle in the TURNkey project.

It is divided into 4 sections:

- the development of a business continuity and disaster management framework that can be used to integrate the TURNkey FWCR Platform into earthquake business continuity and disaster management plans;
- the development of a model business continuity for business or critical infrastructure organisations;
- reporting the final stage in the participatory action research (PAR) cycle that tested the final version of the TURNkey FWCR platform against the end-user use cases developed and refined throughout the TURNkey project;
- validated, from an application perspective, the analytic hierarchy process (AHP) models linking the TURNkey FWCR platform to a range of resilience metrics and overall organisation/community resilience that were developed and presented as theoretical models in D5.3;
- a consideration of the cost and benefits associated with applying the TURNkey FWCR platform to a business or critical infrastructure organisation.

Business continuity, resilience and disaster management plans provide the management basis by which organisations can prepare for, respond to and recover from disaster. This report critically reviews the literature and standards underpinning business continuity and disaster management planning apply to generic disaster events and, more specifically, to earthquakes. The report outlines the overarching structure of business continuity and disaster management plans and, through a desktop study, maps the final version of the TURNkey FWCR Platform against each stage in the disaster planning, management and recovery process. The result of the mapping exercise is a 5 steps framework that can be used by business organisations and critical infrastructure providers to help them integrate the TURNkey FWCR platform into their existing or newly developed earthquake business continuity and disaster management plans.

A model business continuity plan for business and infrastructure is outline in section 11 following the indications of the current international standards. The plan needs to be further customized according to the organisation to which it is applied.

As outlined, the TURNkey project has used a 3 cycle PAR methodology to involve end-user stakeholders in the design and development of the TURNkey FWCR platform. The first 2 PAR cycles developed end-user strategic use cases which were used by the research and development teams to inform them of the end-user expectations of the TURNkey FWCR platform against their business continuity and disaster management processes. The results from the first 2 PAR cycles have been reported in D2.6 (Jones & Mulder, 2021) and D2.8. (Jones et al., 2021). The 3rd and final cycle is reported in this deliverable. Section 5 of this report provides a detailed description of the fieldwork undertaken with end-user stakeholders part of the 3rd PAR cycle and presents the results from a series of interviews to test the degree to which the final version of the TURNkey FWCR platform addresses the expectations of the end-users. The results of the fieldwork confirm that the strategic use cases developed throughout the TURNkey project remain valid and that, generally, the TURNkey FWCR platform addresses the business organisation and critical infrastructure providers' business continuity and disaster management needs. The results further validated the use cases developed for civic protection and first responder end-users, which were also published in D2.8 (Jones et al., 2021).

TURNkey Deliverable 5.2 (D'Ayala et al., 2020) developed a theoretical model that use the analytic hierarchy process to map the potential impact that using the TURNkey FWCR Platform could have on an organisation's or community agency resilience to an earthquake. At the time of writing D5.2 (D'Ayala et al., 2020) it was not possible to apply the AHP models to real stakeholder organisations (due to limitations of the early TURNkey FWCR Platform prototype). As such, the final testing of the AHP modelling approach was moved to Task 7.3, with the results being presented in this Deliverable. As part of the 3rd PAR cycle interviews, end-user stakeholders were asked to develop a series of pairwise comparisons that rated the relative importance of a range of resilience metrics grouped as a 3 level hierarchy (the top level representing resilience, the 2nd level representing primary metrics and the 3rd level representing secondary metrics) and then to score the impact that they thought the final version of the TURNkey FWCR platform could have on the 3 level metrics. In this way, an assessment could be made of the potential impact that the turnkey FWCR platform could have on overall resilience in a way that reflected organisational circumstances and context. The results of the AHP analysis show that for all organisations surveyed TURNkey FWCR platform would be expected to have a positive impact on the organisation's overall resilience.

Finally, this deliverable considers the costs and benefits associated with a business organisation and critical infrastructure provider (and wider region) implementing the TURNkey FWCR platform. Section 12 explores the concept of Cost Benefit Analysis (CBA) and its application across a range of disaster scenarios, including earthquakes, to identify the factors that organisations need to consider when evaluating the potential that the TURNkey FWCR Platform could add to their organisation. Because of the early-stage development of the TURNkey FWCR Platform (it is currently at Technology Readiness Level 5) and the lack of a detailed business exploitation plan, only indicative costs and benefits have been identified, mainly based on similar systems that exist around the world.

Summarizing this deliverable illustrates the role an FWCR platform such as TURNkey could play in business continuity, resilience and disaster management planning, provides a framework for developing such business continuity, resilience and disaster management plans and proposes a model business continuity plan for organisations that would implement the platform.

2 Business Continuity and Resilience Plan and Disaster Management Plan in Literature and Standards

Disasters have a huge impact on the society by producing extreme damage to infrastructures, businesses and communities. Businesses and infrastructures need to quickly recover from the impact of any damage caused by the disaster, as their functional and economic performance supports the recovery of the wider society in which they are embedded. The actions taken by organisations during their recovery phase after a major disaster are planned and described in the organisation's Disaster Management Plan (DMP), Business Continuity Plan (BCP) and Resilience Plan (RP), collectively known as their Disaster Recovery Plan (DRP).

2.1 Planning for organisation resilience

Organisational recovery from a disaster is divided into four main phases: pre-disaster planning, disaster management during the disaster, shot-term recovery or business continuity, and long-term recovery. While the first two phases are clearly identifiable in the disaster occurrence timeline, the last two phases are separated by the Maximum Tolerable Period of Disruption which is defined during the pre-disaster planning phase. The BCP provides the action plan for the continuity phase, while the RP defines the action to undertake for the long-term recovery (Sahebjamniaa et al., 2014). The RP aims to support the full recovery of the organisation by detailing the actions needed to restore all the organisation's operations that were disrupted by the disaster. The BCP includes the action plan to restore the critical operations of the organisation (Sahebjamniaa et al., 2014). As described in the following sections the preparation of the BCP starts with the identification of the organisation's critical/key operations, products, and services. The operations, products and services are generally divided in two categories: 1) critical/key products and services; and 2) all the other products and services. When developing the DMP, it is worth noting the study reported by Ren at al., 2016, where they analyzed the plan at city, regional and national level and provided suggestions for their improvement, including the need to consider different geographical scales when seeking to understand the role of national/regional government, as well as local government, in tackling the emergency phase of a disaster.

In past three decades society has had to overcome several different disasters. As a consequence, a few countries started developing standards to define the underlying principle and strategies for Business Continuity Management. In 2005 Japan published Business Continuity Guideline and in 2006/2007 the UK published BS25999-1 2006 and BS25999-2. Later the International Standardization Organisation published ISO 22301 and ISO 22316 (Charoenthammachoke et al., 2020), which is examined in detail in the following section. The UK and USA were also amongst the first countries to publish BCM and BCP guidelines and tools on their institutional website to support businesses to prepare their BCP (Business continuity guide launched - GOV.UK (www.gov.uk) and Business Continuity Planning Suite | Ready.gov). Similar policies, guidelines and tools are also used by critical infrastructure organisations to prepare their BCP and DMP. However, as noted by Shimizu and Clark (2015), because of infrastructure interdependencies BCPs and DMPs have not always been actionable or practical. Amongst the factors contributing to the ineffectiveness of the BCPs and DMPs is the lack of 'command and control' strategies that provides collaboration between government, organisations (infrastructures and businesses) and communities and detailed consideration of interdependencies within the supply chain (Hatton et al., 2018; Shimizu and Clark, 2015). This said, their importance in analysing the potential effects of disaster events on business, critical infrastructure and community resilience is well recognised (Charoenthammachoke et al., 2020) and the subject of continued development of international standards (ISO 22361).

2.2 Business Continuity and Disaster Management Planning: ISO 22316

ISO 22316 (2017) defines organisational resilience as "…the ability of an organisation to absorb and adapt in a changing environment to enable it to deliver its objectives and to survive and prosper...". In seeking to enhance resilience organisations (in the context of this deliverable business and critical infrastructure) need to take action to prepare for, respond to and recover from an unforeseen disaster event (in the context of this deliverable an earthquake) as part of a system-of-systems approach that integrates resilience of organisations infrastructures and communities. Businesses and infrastructure organisations resilience integrate their physical assets with its operational processes and wider relationships with their suppliers and customers/users. The theoretical models underpinning organisational and infrastructure resilience were reviewed in TURNkey Deliverable 5.1 (Jones et al. 2020) and hierarchical models of the potential impact that the TURNkey FWCR Platform could have on business and critical infrastructure and community resilience were presented in TURNkey Deliverable 5.2 (D'Ayala et al., 2020) . This section of TURNkey Deliverable 7.7 extends the thinking presented in the previous two deliverables by exploring the relationship between the TURNkey FWCR Platform and business continuity and disaster management planning.

Business continuity and disaster management plans are the practical tools used by organisations to help them better understand their vulnerability, exposure and risks to a disaster event and to prepare practical plans to help them manage their risks and respond to and recover from a disaster event should one occur. As Dormady et al. (2019) highlighted the main difference between resilience of engineering system and business is in the object of resilience appraisal. Whilst the engineering systems resilience appraisal is oriented on the estimation of physical damage, businesses are more interested in assessing the disruption and recovery to the "flow of goods and services": extending resilience appraisal beyond physical damage appraisal and repair options. This said, Dormady et al. (2019) defined only the actions undertaken after the disrupting event as actions affecting resilience, with mitigation and preparedness actions not considered as part of the resilience process, even though preparedness is widely acknowledged as having an impact on organisational resilience (ISO 22316, 2017; Alderson et al, 2015).

This wider view of resilience is also reflected in the USA Presidential Policy Directive 21 which presents a definition of resilience similar to the definition provided by UNDRR (2020). While this definition is proposed for critical infrastructure, no study or policy document had been found by the authors that indicates that critical infrastructures are not also business organisations, especially if end users pay for their service, either directly or indirectly. For this reason, we consider critical infrastructure providers as a subset of general business organisations from a BCP and DMP perspective.

BCP and DMP reflect a range of strategies, policies and action plans (ISO 22316, 2017) to help organisations understand the potential impact that a disaster event could have on their organisation's ability to deliver against its key strategic objectives, and in identifying the resources (physical, human, economic and corporate) that will be available to the organisation in managing the immediate impact of the disaster and returning as quickly as possible to 'business as usual' following the disaster. To this end business continuity and disaster management plans tend to follow a plan-do-check-act cycle (Figure 1).

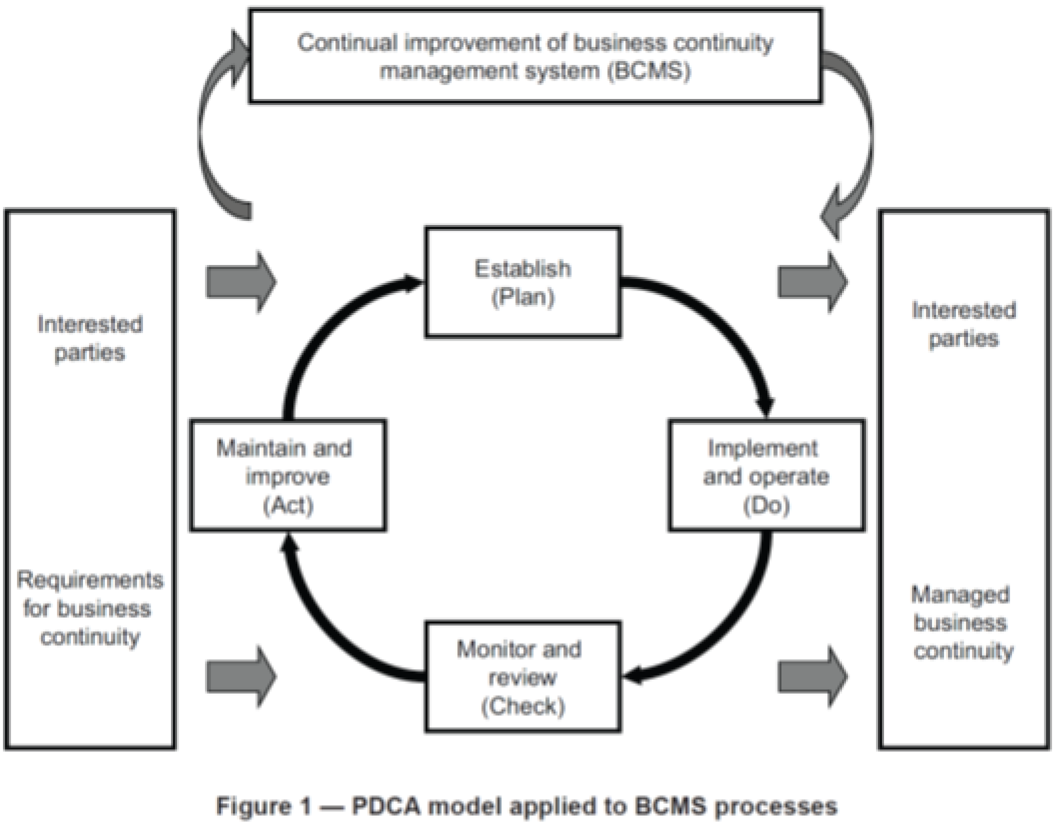

Figure 1 PDCA model applied to BCMS processes Source ISO 22316, 2017

A BCP documents the procedures that "guides an organisation to respond to a disruption and resume, recover and restore the delivery of products or services consistent with its business continuity objectives" (ISO 22316, 2017). Business continuity procedures identified in ISO 22316 (2017) include the following items:

- detailing of the scope and applicability of the business continuity management system, identifying those products and services that are covered by the plan and the wider relationship of the plan to the organisation's mission, goals, and obligations (legal and regulatory) and the needs and expectations of interested stakeholders (both internal and external to the organisation).
- demonstrating top management leadership and commitment to business continuity procedures and describing the alignment of the business continuity plan with the organisation's strategic objectives. The document also describes how the business continuity plan will be integrated into the businesses' processes and the resources that were made available for the development, implementation (including communication strategy to interested stakeholders), evaluation (including procedures for reporting back to top management), review and maintenance of the business continuity plan.
- identifying the risks (and opportunities) that need to be addressed and mitigation actions that prevents or reduces their undesired impacts on critical business objectives, including procedures to integrate the actions into the business continuity process (including effective communication) and monitor and evaluate their effectiveness. For each critical business objective, the plan should identify what action will be done, what resources are required, who will be responsible for the action, when the action will be completed and how the action will be evaluated. Where action needs to be updated the document will identify and track the development and implementation of the changes, including an assessment of the potential impact of the changes on other actions.
- committing the resources required for the development, implementation, maintenance and continual improvement of the business continuity plan. The document needs to demonstrate the competence (e.g., technical, organisational, managerial etc.) of those involved in the business continuity planning process and describe how the business continuity plan will be communicated (e.g., what will be communicated, when will it be communicated, with whom, how will it be communicated, and who will communicate it). If the organisation is seeking ISO 22316 certification, then the documents must be consistent in their presentation, be readily available (access, retrieval and use) and contain a full audit trail of their development (version control).
- procedures for systematically reviewing the risks (in line with guidance provided in ISO 31000, 2018) and evaluating their potential impact on critical business function. The procedures should include detailed assessment of the potential impact of disruption on critical business functions that directly support the provision of products and services, including an assessment of the maximum period of disruption that the business could tolerate before irreparable harm (to the business) occurs and identify recovery timeframes and priorities to minimise disruption. When evaluating potential impacts on critical business functions the document should not only consider internal interdependencies but also interdependencies with the organisation's supply chain.
- identify business continuity strategies and mitigation actions that can be applied before, during and after the disruption event to protect the organisation's critical business functions, reduce the likelihood and/or shorten the period of disruption, limit the impact of disruption on the

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organisation's products and services. The document should identify the resources required to implement each action (e.g., human, information/data, physical, and consumables, transportation and logistics, finance and partners and the supply chain and address cost benefit issues).

- plans and procedures that describe the disaster management plan for the organisation during a disruption event and the business continuity and recovery plan after the disruption event, including details on the activation (and deactivation) of the business continuity procedures. The disaster management plan should describe specific actions to be taken during a disruption, whilst being flexible enough to respond to changing internal and external conditions resulting from the disruption. The disaster management plan contains details of the teams responsible for the different aspects of the plan. These aspects include assessment of the extent of disruption and potential impact, comparison against predefined thresholds for activation of mitigation actions, prioritising specific actions assigned to each team (using life safety as the first priority but also considering the prevention of further losses and protection of the environment), monitoring the disruption and the organisations response, communicating with internal and external stakeholders. The procedures should provide details of specific communication protocols and channels with emergency responders and national/regional risk management organisations and describe a communication strategy for dealing with the media. The business continuity plan describes procedures for business recovery when the disruption event is over. The plan should provide details of specific actions to be taken to return the organisation to predefined performance levels for the delivery of products and services, including where necessary temporary workarounds (e.g., relocation to alternative premises, remote working, flexible contracts). The plan should also describe the procedure for deactivating the temporary measures and returning the business to normal operating procedures.
- detailing training and testing exercises for the BCP and DMP that include the use of scenarios to simulate disruption and procedures for enhancing teamwork competence and confidence of those with specific roles during and after a disruption event. The results from the training and testing exercises should be evaluated and any changes to procedures recorded. This is particularly so if certification is to be sought. Testing and training should also involve businesses partners from the supply chain and wider community stakeholders if appropriate.
- procedures for formal evaluation of the BCP and DMP including internal audits (carried out by impartial auditors) at planned intervals to assess the organisation's requirements of its business continuity and disaster management plans and management review of the audit results. The results of audit should be formally documented, and any corrective actions implemented. The results management review should also be formally documented and communicated to relevant interested stakeholders.

Whilst ISO 22316, 2017 (ibid.) provides the contextual overview of the business continuity management process, detailed guidance on developing and implementing such plans is generally provided by 3rd party organisations including insurance/government agencies or disaster specific disaster management organisations (e.g., American FEMA, British SAGE, European ENISA for the cybersecurity). This said, the structure of business continuity and disaster management plans do tend to follow a consistent format Figure 2.

Business Continuity and Disaster Management Plans	
Pre-earthquake Planning	Set up a team to develop the plan that is led by a senior manager with representatives from across the organisation: identify the hazard threats
Analsye Hazard Threat	Conduct an impact and risk assessment that links the hazard to the impact on built assets: risk to life -safety, property loss, functional loss
Assess Business Impact and Mitigation Options	Conduct a buisness impact analysis: Impact = Disruption to critical systems / functions and identify alternative mitigation and recovery options
Develop Plans	Develop and test business continuity and disaster management plan: reduce vulnerability, manage response (life safety) and recovery.
Implement and Maintain Plans	Approve and implement the plan, facilitate training events, maintain and revise the plan to ensure it remains in line with strategic objectives

Figure 2 Constituent parts of Business Continuity and Disaster Management Plans (FEMA (1993); FEMA (n.d.); OCIPEP (n.d.); CSO (.n.d.); LAEDC (n.d.); EPICC (n.d.)

2.3 Plan for and survive to seismic events: experience in other countries

The approach to prepare and respond to seismic events is strongly related to the culture, legislation background and learned lessons of a country. Greer (2012) proposes a comparative analysis of those factors for two specific countries: Japan and USA. The work identifies the Japanese approach on the preparedness to earthquakes as based on a top-down approach strongly related to technological advancements; these advances included Earthquake Early Warning System (EEWS) integrated into infrastructures and major business facilities automatic and manual shut-down and stand-by systems. The American approach to earthquake preparedness is described as bottom-up with a strong legislative background and rescue organisation network. A decade passed since that analysis and the Japanese preparedness to earthquake is still based on the same foundations (Jones & Morga, 2019),while the USA approach to earthquake preparedness has changed with the implementation of EEWS (ShakeAlert) initially in California (CalEOS, 2014) and later across the whole USA West coast (USGS, 2021). The USA government also developed a programme to increase the earthquake preparedness in the whole federation (FEMA P-420). The government of California (Cal EOS, 2014) indicates which infrastructures and businesses benefit from the implementation of the EEWS in California. Following the implementation of the EEWS the State of California developed a public Alert and Warning System (CalPAWS) which integrated the

EEWS features with Operational Earthquake Forecasting (OEF). Both the state and federal governments are responsible for managing the EEWS and its warnings at different levels and this partially inverts the bottom-up approach originally identified by Greer (2012).

The Japanese EEWS, managed by Japan Meteorological Agency (JMA), issues early warnings through broadcasts and through customer phone apps to large business and critical infrastructures as explained in Jones & Morga, 2019. The JMA also sells OEF data to third parties, such as companies developing and customizing alert and warning phone apps, to issue earthquake alerts Jones & Morga (2019). This strengthens the Rapid Response to Earthquake (RRE) effectiveness, as rescue teams are alerted and the DMP and BCP of business and infrastructure organisation can be triggered if OEF and EEW are identified in the DMP and BCP as instruments to activate emergency procedures., which Hatton et al., (2018) noted was a great help in responding to the Tohoku earthquake in Japan in 2011).

The Mexico EEWS, SASMEX, provided early warning for the past 30 years (Suarez, 2022). The system does not include OEF functionality. The SASMEX alert are broadcasted only through radio and television broadcasts and special receivers, which are limited in number (Suarez, 2022). As such its alert would require business organisations and critical infrastructure operators to have a receiver or stay tuned to the broadcaster that might issue the alert. As consequence, the SASMEX early warning would have little or no impact on their BCP and DMP.

In 2010-12 New Zealand was affected by seismic events which caused significant socio-economic losses, due to physical and operational damage to structures and infrastructures, including Christchurch city centre. Hatton et al. (2018) studied the effectiveness of BCP and DMP preparing for and recovering from the seismic events, and concluded that, whilst call trees and multiple communication channels were the most effective BCP factors, the "prioritization of activities" was the least effective factor, with a failure to consider the relationships with interdependent organisations (both internal supply chain and external agencies) identified as the missing key factors in the majority of BCPs of those organisations that participated in the study. This was in many cases confounded by limited or out-dated data contained within the BCPs (Hatton, ibid.). Even with these limitations however in 2019 the New Zealand Earthquake Commission (EQC) announced the willingness of the country to adopt an EEWS (ECQ, 2019; Jones & Morga, 2019)). Hatton et al. (2018) supports the SWOT analysis findings presented in D1.2 (Jones & Morga, 2019), which includes the following opportunities among others:

- better informed disaster resilience plans,
- reduced critical infrastructure/ on site facility control
- improved contingency planning.

3 Integration of TURNkey FWCR platform in business continuity and disaster management planning

The following subsections describe the different aspect of the process to formulate the BCP. They also present the related TURNkey FWCR Platform features to clarify how TURNkey FWCR Platform can be used as a tool to support the business continuity of business and infrastructure organisations.

3.1 Pre-earthquake planning

3.1.1 Planning team

The primary role of pre-earthquake planning is to assess the vulnerability and resilience of the business or infrastructure organisation to an earthquake event. Pre-earthquake planning is part of resilience according to the definition of resilience proposed by UNDRR (2020). While planning for an earthquake is an action, its effect is the preparedness of organisations and its products are BCM, DMP, and RP. Business Continuity Planning normally starts by establishing a management team to examine the range of hazards that could affect the business. The planning team is led by a member of senior management and has representation from all the functional areas of the organisation. The team identifies the strategic objectives of the organisation and sets a clear mission statement and goal for the business continuity plan, along with an operating budget and project timeline to develop and report the plan. It reviews all relevant internal plans and policies and questions employees, customers and the organisation's wider supply chain to identify the potential impact that the disaster event could have on the functional performance of the business, and on its potential recovery routes. To this end the planning team reviews the business flowchart and identifies critical operations and systems that must continue (e.g., production/service delivery, inbound and outbound logistics, facilities management, HR, finance, customer relationship management etc.) and establishes protocols for engaging a wider range of internal and external stakeholders in the business continuity planning process. The planning team also examines the wider socio-economic context within which the business operates, identifying the governance and legal framework within which the business operates, and any statutory requirements that the business may need to satisfy. The planning team also needs to consider economic risk mitigation activities that could be needed to support the business survive and recover from a disaster event. This would include the level of insurance cover (if such cover is available) and access to public or private sector emergency funds if these are available. The planning team also needs to identify effective management of communication with the wider community, including emergency responders and civil protection, the broadcast media, and members of the general public.

According to the "QuakeSmart Ready Business Toolkit" proposed by Ready programme of the Homeland Security agency of USA (DHS, 2022; Ready, 2021) for most business organisations the goal of the BCP will be to minimise human, property (space, systems, structure) and economic losses and economic losses across the whole of the earthquake sequence (during the earthquake response and recovery phase).

During and after the disaster the planning team (or a subset of the team) is normally also responsible for the day-to-day management of the response to a disaster event through an Emergency Operations Centre (EOC).

<u>The TURNkey FWCR platform</u> contains the names and contact details of the planning team; a repository of the organisation's key strategic documents including BCP, DMP and RP; contact details of the EOC. As such, it can be used during the emergency phase and by providing the members of the EOC access to the relevant documents to action as part of their BCP and DMP. In case any quick amendment is needed to BCP and DMP, the platform can also provide the contact of the planning team, which would be responsible for approving any modifications to the plans.

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3.1.2 Analyze the hazard threat, the risk for and impact on the physical asset of the organisation

The first step of the preparation of the BCP is to analyze the threats to the business or infrastructure organisation posed by the hazard. This involves identifying the level of exposure to a range of threat scenarios and assessing the risk that the hazard poses to the organisation. In assessing exposure and risk the organisation needs to appraise its inherent vulnerability and estimate its resilience to the hazardous event as well as identifying the direct (e.g., building damage, production system damage, loss of access, trapped persons etc.) and indirect (e.g., loss of power, loss of communication, etc.) impacts that the hazardous event may have on the organisation during the event and the recovery period.

In case of a seismic hazard, the organisation needs to assess the inherent vulnerability of its buildings, from a structural and non-structural perspective and the direct impact this may have on the organisation service delivery considering different earthquake scenarios. This assessment starts with an initial assessment of the buildings vulnerability classes and fragility curves based on their typology and technical documents available (TURNkey Deliverable 4.1, Schwarz et al., 2021) or through a visual survey (e.g., FEMA P-154, 2015) to estimate a range of damage states or seismic performance score that could be expected following an earthquake (FEMA P-154, 2015; Gruenthal, 1998). This assessment provides an initial estimate of the potential impact that the earthquake would have on the ability of the building to continue to support the business functions assigned to it (e.g., primary production activities, secondary support activities, back-office activities etc.).

For a building with "Grade:1 Negligible to slight damage" and "Grade 2: Moderate damage" (Gruenthal 1998) the assessment of potential non-structural element damage should follow to establish potential damage that could disrupt the operation of the building immediately following an earthquake. The assessment would look to identify poorly performing non-structural elements and services (e.g., mechanical and electrical services, distribution systems, such as ducting and pipework, suspended ceilings, non-load bearing walls, cladding systems etc.) that could be damaged during an earthquake resulting in mortality/morbidity to employees or the public, business disruption and financial loss. In particular, the assessment of non-structural elements and services should examine system connections which could rupture causing secondary damage (e.g., fire, water damage, leakage of critical logistics etc.) and identify systems that could collapse (e.g., suspended ceilings, internal partitions etc.) or fixtures and fittings that could overturn/fall and identify potential mitigation interventions that could reduce damage due to shaking (e.g., fixing storage units to a wall). The assessment of potential damage to non-structural systems for several earthquake scenarios could be used to inform seismic risk rating in terms of life safety, property loss and functional loss. The estimate of seismic intensity can be based on an assessment of regional or local seismicity. Linking seismic intensity to a risk rating for different non-structural components can be done by using existing guidance, such as FEMA E-74 (2012) or performed by the organisation's risk manager or by an external consultant.

The TURNkey FWCR Platform produces an estimate of the EMS-98 damage state for earthquake scenarios through its "simulation function" after inputting the vulnerability function or assessment

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of the structure and its typology; the platform can operate using a pre-set fragility function or using a customized fragility function tool. The platform also produces an estimate of the losses using a pre-set catalogue of the loss functions and earthquake scenarios by taking into account macro and micro scale seismic maps and it can update those scenarios using TURNkey and national network sensor data that identify seismic activity.

3.1.3 Business impact analysis

The impact on the business or infrastructure ability to continue to deliver its core functional service depends upon the impact that the damage to its physical systems has on the performance of business functions. Each critical function should be ranked on its level of criticality (e.g., high, medium, low) depending upon what business objectives the function supports; the resources required to perform this function (e.g., human, physical, logistical, information technology etc.); the frequency with which the function needs to occur; the number of units that perform the function (e.g., redundancy); inter-dependencies between this function and other critical functions; impact on financial losses; impact on statutory compliance or potential litigation; and reputational loss.

As such, in case the threat is earthquakes, the planning team needs to consider the impact that each earthquake scenario could have on each critical business functions (e.g., downtime, recovery process, etc.). To this end the planning team need to identify those business functions and processes that are critical and assess the impact that any damage to buildings or service systems would have on these functions and processes by linking the physical damage caused to structural and non-structural systems to the damage to production/operational systems the business relies on to deliver its products or services. This link requires the planning team to initiate a series of detailed assessments of the potential damage of critical items for the production or service equipment (e.g., production line equipment, IT infrastructure, non-structural component of infrastructure etc.) and business operations (e.g., upstream and downstream supply chain logistics, customer relationship management, etc.) to earthquake scenarios. For each critical function the organisation should identify the maximum level of disruption (downtime) that the organisation could accommodate before irreparable harm is done to it. The organisation also needs to identify and assess the potential impact that the earthquake would have on the availability of each resource beyond buildings, services and equipment following an earthquake.

The TURNkey FWCR Platform provides the organisation with an overview of the potential state of damage across a region which could support an analysis of resource availability. As such, the platform has the opportunity to provide data to improve the BCP of a specific organisation and integrate those data in a regional DMP, which is the responsibility of civil protection, local authorities and first responders.

3.1.4 Structural mitigation options

The overall resilience of an organisation can be improved by seismic resistant buildings. For buildings that are potentially highly vulnerable the TURNkey FWCR Platform simulation function could assess the risk and loss level for earthquake scenarios so that the organisation management team could commission a long-term structural mitigation plan. However, this in scope with the RP.

3.1.5 Non-structural mitigation options

The identification of equipment, fittings and fixtures that are vulnerable to a hazardous event could trigger non-structural mitigation options to reduce damage and losses in case the event occurs. In case of an earthquakes hazard, mitigation actions for equipment, fittings and fixtures could include relocation of large, heavy freestanding items; regular inspection of evacuation routes; the removal of items that are no longer required; ensuring secure storage of hazardous materials and supplies; anchoring equipment and storing unts; attaching tethers to suspended items (e.g., light fittings, ceilings etc.); fitting isolators or 'shut off' valves; installing more earthquake resilient fixtures and fittings (e.g., flexible connections) (e.g., FEMA E-74, 2012).

The TURNkey FWCR Platform provides a simulation function to assess the structural damage level of the structure which can be used to initiate also non-structural mitigation actions in case the expected structural damage level is grade 1 or 2 of the EMS-98 scale or equivalent for the earthquake scenarios that the organisation decides to consider. The platform offers details about the changes in shaking intensity data (OEF features). This could be used by the planning team to review the BCP and trigger non-structural mitigation actions. The same can be used by the civil protection and local authorities to review the DMP and increase the emergency alert level in the region.

From the business and CI prospective, the TURNkey FWCR Platform could also be used as a repository for non-structural mitigation action plans which would be activated on an ad-hoc basis depending on the severity of the earthquakes impact.

3.1.6 Operational mitigation options

Mitigation plans to reduce the potential damage to operational systems includes actions to minimise the damage caused by shaking and secondary impacts.

In the case of an earthquake hazard an EEW system could trigger automatic or manual operation mitigation actions to reduce the damage to operational equipment and morbidity and mortality of operators and/or users. An early warning could trigger placing critical systems into a 'fail-safe' mode in advance of strong shaking (e.g., slowing or stopping mass transit vehicles, moving elevators to the nearest floor and opening the doors, vertical transport systems in buildings at a safe location, activate active isolation systems; close valves to gas and water distributions systems to reduce secondary impacts due to pipeline rupture; activate signals to reduce vehicles speed on highway).

If the early warning system is linked to the organisation emergency alarm system the warning could trigger evacuation, if time permits; taking drop, cover and hold-on actions; or moving to an area of greater safety (e.g., away from equipment that could potentially fall); or stop some sensitive operations like surgeries, use of chemicals in labs, use of any dangerous utensil, etc.

The TURNkey FWCR Platform has the EEWS functionality and can be linked to automatic systems or used to trigger manual emergency procedures, which included manually shut-down systems following warmings (see Jones & Morga, 2019) or quickly actionable procedures such as stopping a crane and conducting it to a safe position, reducing the train speed before the automatic braking system is activated etc., This kind of actions can be linked to the organisation emergency alarm system.

3.2 Plans for actions during the earthquake

Disaster (emergency) Management Plans describe the actions that an organisation should take to manage the immediate impact of the earthquake. The primary priority of all disaster management plans is to protect life safety. Business organisations should have detailed evacuation, fire protection and health and safety plans in place that can be immediately activated when an earthquake occurs. The plans should be regularly tested within the organisation; in the case of large organisations (like critical infrastructures) they should be tested also with those wider stakeholders responsible for responding to an earthquake (e.g., first responders, civil protection, healthcare and security organisations, statutory and regulatory agencies, supply chain etc.) to ensure that each group has a detailed understanding of their responsibilities and their commitments to others.

The TUNkey FWCR Platform could provide an early warning to the business organisation via the platform operator which would enable the business organisation to give advance warning of strong ground shaking. The TURNKey FWCR Platform could act as a repository for the disaster management plans and provide the potential scenarios for either internal and/or external testing of the plans. Although the immediate response to an earthquake resides with management who are on the premises at the time of the earthquake, coordinating and managing the wider response lies with the organisations Emergency Operations Centre (EOC) team, which is notified of a rise in probability of an earthquake occurring: if a pre-set threshold is exceeded an earthquake early warning is triggered. The TURNkey FWCR Platform could also initiate automatic messaging to members of the EOC requesting their attendance at a meeting by sending them an automatic message on their phones. The EOC could then use the platform to retrieve the BCP and DMP and activate the prescribed actions.

3.3 Plans for rapid response to earthquake

Following an earthquake, the buildings should be evacuated in case any damage to non-structural or structural elements occurs following a clear evacuation plan.
The TURNkey FWCR Platform could contain immediate action protocols which are sent to security teams as soon as an earthquake is detected. The TURNkey FWCR Platform could also provide a list of individuals authorized to check the resources.

Following an earthquake, organisations need to make an early assessment of the potential damage to the organisations buildings and the potential impact that the damage could have on the organisations critical systems and processes to assess the need to activate the business continuity plan.

TURNkey FWCR Platform can be used to store the results of earthquake scenarios simulations and retrieve them to compare against the early estimate of earthquake intensity (provided by the TURNkey FWCR Platform) of a real earthquake intensity (when one occurs) to obtain an early estimate of the potential (modelled) damage state of the business or infrastructure. If the earthquake intensity and damage levels exceed a predefined threshold, then the BCP and DMP are activated, and the first responders are contacted. If the platform does not have a stored simulation with an earthquake scenario comparable with the early estimate of the earthquake intensity, the platform can be used to run a simulation using the early estimate intensity measures (magnitude, epicentre location and hypocentre depth) to generate an early estimate of potential damage states of business or infrastructure.

An early actual damage grade of the building would be estimated by the inspection team. A further assessment is carried out by trained teams of engineers coordinated by the civil protection. Any observed damage can be communicated to the EOC.

TURNkey FWCR Platform could provide details of site and building layout and technical drawings and other data, through its app; which also provides a process for reporting first-hand level of damage, impact on performance and expected recovery time. It can store the report of actual damage to make them accessible to EOC or other authorized individuals. The data are also communicated to the first responders. The platform also provides a facility through its app to photograph and describe any damage.

After the structural and non-structural damage of buildings and their immediate environs have been checked, the organisation needs to ensure security of its critical resources, including its physical assets (e.g., equipment, logistics, consumables etc.) and its information and data. The data provided by real-time observation from inspection teams can be used by the EOC to establish priorities for action and coordinate the immediate recovery response. Priorities would be informed by the estimated downtime compared to the maximum tolerable downtime identified in the business impact assessments.

TURNkey FWCR Platform could store the BCP and action protocols for the EOC to identify the action to undertake in the first phase of the recovery (e.g., activation of off-site backup facilities, initiating virtual working protocols, transferring critical business functions to different parts of the organisation not as badly affected by the earthquake etc.). If could also provide coordination and control of immediate actions, including monitoring the progress of the actions. The platform also provides a facility through its app to photograph and describe damage to the businesses critical systems. This function supports the preparation of insurance claims or access to disaster recovery funds.

3.3.1 Plans for aftershock event.

Less intense seismic events can occur after a main shock when the business or service has already suffered damage. Business and infrastructure organisations need to consider carefully how to manage life safety and further business or service disruption resulting from a major after-shock. In fact, after-shocks can result in further damage and losses because of damage to structural and non-structural element sustained because of the main shock.

TURNkey FWCR Platform could play a major role in helping organisations manage after-shocks through the after-shock OEF facility that can provide an estimate of the probability gain of an after-shock occurring and provide a new early warning when an after-shock is detected. Moreover, knowing the state of damage of the organisation assets, the platform can be used to run further simulations with earthquake scenarios in which the structural and non-structural elements are already damaged.

TURNkey FWCR Platform could also manage communication with customers and supply chain, as it can contain supplier and customer contact details and any pre-set massages defined in the BCP and DMP and stored in the platform.

The integration of the TURNkey FWRC Platform into a business and critical infrastructure organisations BCP, DMP and RP outlined above was demonstrated to Spanish stakeholders during the final stakeholder workshop held in Orihuela, Spain on Monday 25th – Thursday 28th April 2022. The demonstration used a hypothetical hospital scenario to show how the TURNkey FWCR Platform could be applied before, during and after an earthquake to help the hospital prepare for, manage and recover from a simulated earthquake. Full details of the demonstration can be found in Deliverable 7.6 (Molina-Palacios, 2022). The process of integrating the TURNkey FWCR Platform more generally into BCP, DMP and RP was presented to members of the Institution of Engineering and Technology (virtual presentation to IET members on 9th March 2022) and to facilities managers at the EUROFM symposium in Breda, The Netherlands (on 15th June 2022) and at the CIB World Congress in Melbourne (on 29th June 2022). Copies of all these presentations are available from the authors on request.

4 Participatory Action Research in TURNkey

4.1 Introduction and summary of PAR cycle 1 and 2

TURNkey uses participatory action research (PAR) to connect the needs and expectations of potential end-users of the TURNkey FWCR Platform with those who lead on its design and development. PAR is a research methodology that approaches end-users as active participants in the research process, as opposed to objects to be studied. PAR is iterative in nature. It relies on constructive discussions to develop solutions, together with end-users and those responsible for delivering the desired change (or product). It loops through four phases (plan, act, evaluate, review) until an acceptable solution has been achieved. TURNkey is based on three PAR cycles. This report covers the findings of the 3rd and final round of PAR. The first PAR cycle commenced with a literature review; interviews with experts from Japan and New Zealand; and an analysis of the current state of the art. This was followed by in-person and online discussions with potential end-users of the platform as well as the researchers and developers working on TURNkey. ARU led PAR with business and critical infrastructure end-users in Iceland, France and the Netherlands, whereas NTC led PAR with civil protection and first responder organisations in Italy, Greece and Romania. On the basis of this research, initial versions of end-user use cases for the TURNkey FWCR Platform were published in Deliverable 1.3 (Callus, 2020) and Deliverable 1.4 (Jones et al. 2020). At the end of PAR Cycle 1, these use cases were revised based on discussions with TURNkey researchers and developers, which explored what was possible from an engineering and scientific point of view. This was published in Deliverable 2.6 (Jones & Mulder, 2021). The insights from PAR Cycle 1 informed the research tools used during PAR Cycle 2. Due to the COVID pandemic, PAR had to be conducted online as opposed to in person. A virtual demonstrator of the TURNkey project was developed to support both technical and operational discussions. The demonstrator comprised five short videos, which showed the TURNkey FWCR Platform

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conceptually (videos 1 and 2) as well as its different features in the areas of OEF, EEW and RRE (videos 3, 4 and 5). As during PAR Cycle 1, ARU led PAR with business and critical infrastructure end-users in Iceland, France and the Netherlands again; and NTC led PAR with civil protection and first responder organisations in Italy, Greece and Romania. On the basis of this research, the end-user use cases were adapted. The findings of PAR Cycle 2 were published in Deliverable 2.8 (Jones et al., 2021) and Deliverable 2.10 (Callus, 2021). This revised set of use cases was validated during PAR Cycle 3.

4.2 TURNkey FWCR platform: PAR cycle 3

In order to complete the PAR with cycle 3 by a final set of interviews were held with selected project stakeholders to check that the operational expectations of the end user stakeholders were satisfied by the TURNkey FWCR platform, To assess the resilience of businesses, infrastructures, and community, Deliverable 5.2 (D'Ayala et al., 2020) developed a series of AHP models that linked organisational (and community) resilience metrics to overall resilience through a hierarchy that allowed individual stakeholders to contextualise the relative importance of each of the resilience metrics to their specific circumstance and rate the impact that they thought the TURNkey FWCR Platform would have on each metric. The AHP models were tested using hypothetical data in Deliverable 5.2 (D'Ayala et al., 2020) and were used with real data provided by stakeholders during the 3rd PAR cycle.

The interviews for the PAR cycle 3 occurred online due to uncertainty surrounding COVID travel restrictions. The interviews were combined with a presentation introducing TURNkey FWCR platform functions.

This section describes how the data was collected for the findings presented in the sections on AHP modelling and the end-user use cases.

At the beginning of the interview stakeholders were given a top-level overview of the TURNkey project on the basis of a simplified version of Figure 3 from the original TURNkey Grant Agreement (below).

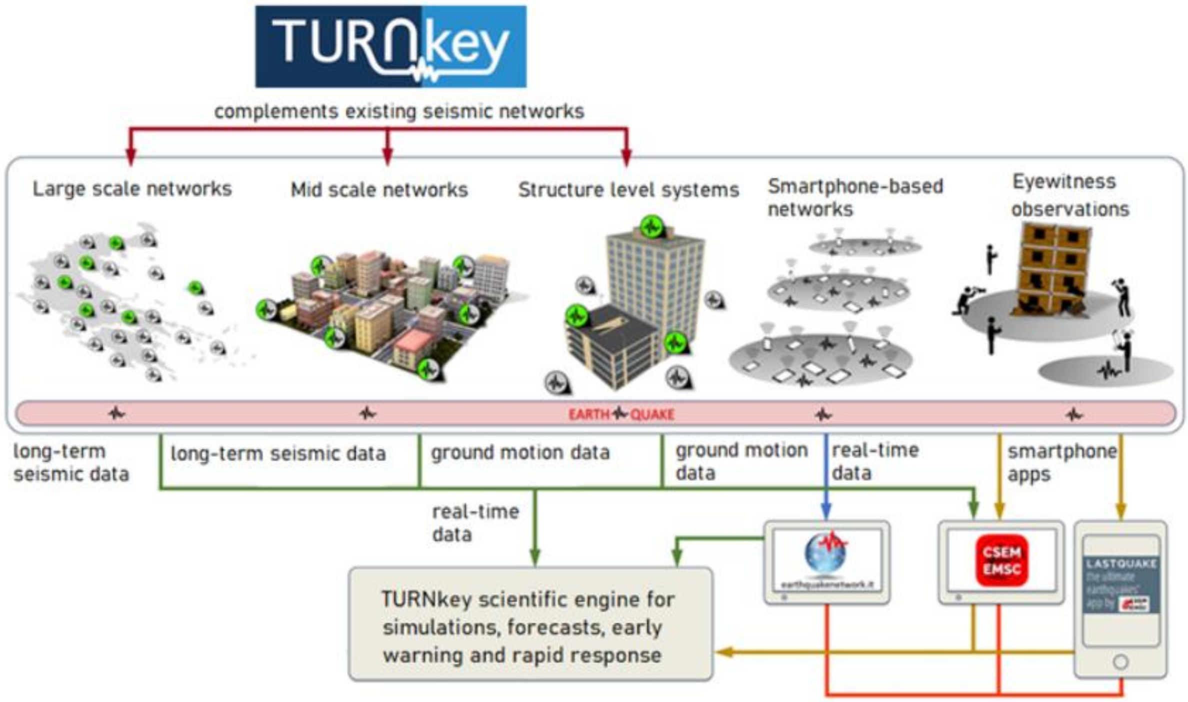

Figure 3 Overview of the TURNkey project (simplified)

They were also informed that TURNkey had developed a new multi-sensor unit that, along with existing seismic networks, continuously monitors ground motion at the national, regional and building scale. It was also explained to the stakeholders that the TURNkey FWCR Platform has the functionality to integrate this sensor data with motion data captured on smartphones and eyewitness observations – so as to provide a cloud-based earthquake simulation, forecasting, early warning and response tool. Stakeholders were also told that one of TURNkey's goals is to foster resilience to earthquakes.

After this brief introduction, stakeholders were asked to give their views on the resilience of their organisation at the current point in time. The findings of this part of the research are presented in the sections *'AHP model to measure community resilience and TURNkey with civil protection', 'AHP model to measure organisational resilience of businesses' and 'AHP model to measure organisational resilience of CI'.*

After this, stakeholders were provided with a more detailed explanation of TURNkey's features on the basis of screenshots showing the platform's latest rendition. The screenshots were provided by BETA80. The explanations of the platform functions were provided by BETA80 and NORSAR during four training sessions delivered for ARU and Nutcracker Research.

In turn, they were asked their opinion about TURNkey FWCR Platform functions for:

1) Operational Earthquake Forecasting (OEF) and related simulations;
2) Manual simulations;
3) Earthquake Early Warning (EEW); and
4) The dashboard to support a Rapid Response to Earthquakes (RRE).

For each set of functions, stakeholders were asked to give feedback and input on the use cases that had been developed during PAR cycles 1 and 2. They were also asked if there were additional use cases that had not yet been considered. *The findings of this part of the research are presented in the sections 'Use Cases Civil Protection and First Responders' and 'Use Cases Business and Critical Infrastructure.'*

The next subsections describe how the topics of OEF, simulations, EEW and RRE were discussed with stakeholders during PAR Cycle 3.

4.3 Operational Earthquake Forecasting (OEF) before an earthquake / aftershock

This part of the research started with a brief overview of OEF. Participants were told that the purpose of OEF is to provide reliable and timely hazard information that can be used by government agencies, business organisations and critical infrastructure providers to help them prepare for a potential earthquake/ aftershock. It was made clear to them that OEF is not an earthquake prediction, but like an extreme weather forecast, it is a probabilistic assessment of the likelihood of an earthquake of a given magnitude, occurring at a given location, within a given time period: from a few hours to a few days. Participants were informed that, whilst TURNkey provides OEF for both mainshocks and aftershocks, the majority opinion amongst experts is that OEF is really only potentially useful for aftershocks (and not mainshocks). It was also highlighted that TURNkey combines OEF forecasts with simulations to provide information on the potential impact that the forecasted earthquake could have on human, physical and financial losses. Finally, the manual forecast earthquake function (again with the caveat that this might not be useful for mainshocks) and the automatic forecasts function for aftershocks was explained to the interviewees.

The explanations were accompanied by screenshots of related TURNkey's OEF features.
For example, Figure 4 shows that the TURNkey FWCR Platform gives users the option to manually perform OEF by selecting the desired forecast date.

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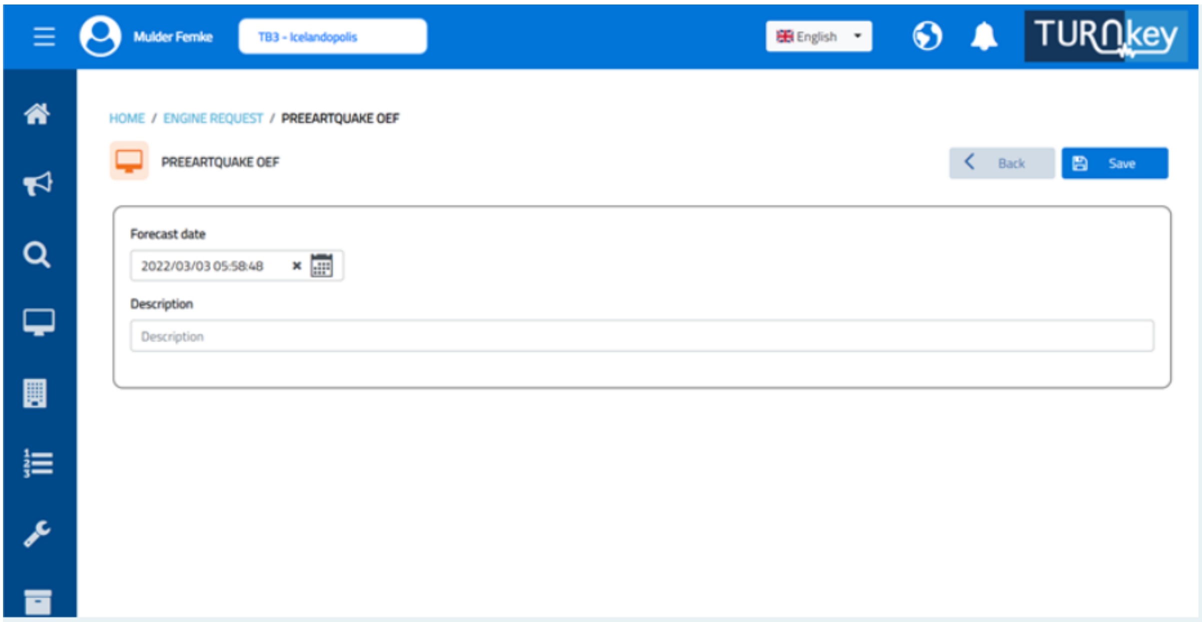


Figure 4 Manual OEF - screenshot TURNkey platform

The OEF TURNkey function that compares long-term and short-term statistical data about the daily risk of a strong earthquake event (the 'probability gain') to assess if there is an increased daily risk of a strong earthquake was also explained to the interview participants. They were shown how TURNkey displayed this information on the basis of screenshot in Figure 5, below.

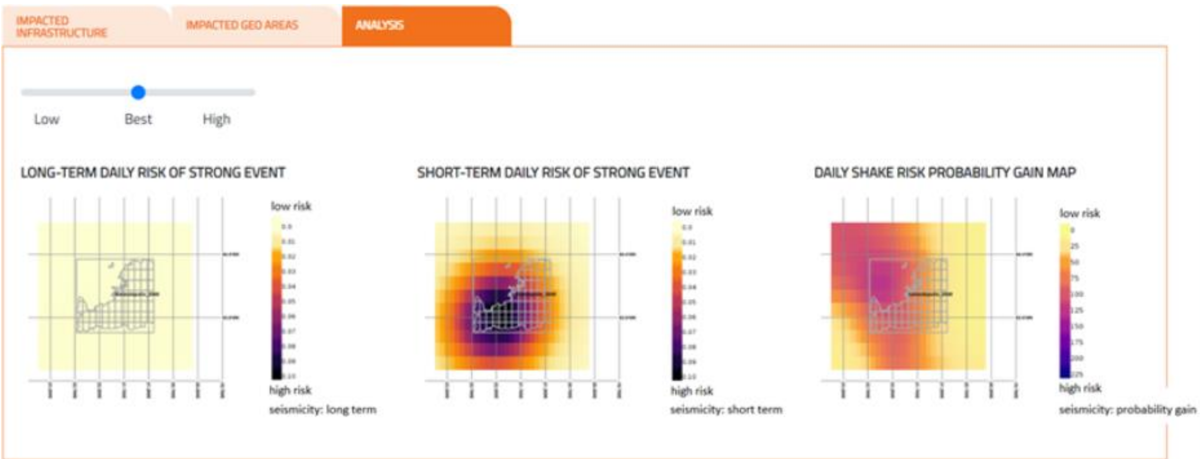


Figure 5 The OEF probability gain – medium level of uncertainty ('best forecast')

It was explained to participants that users can change the uncertainty levels of the forecasts. To this end, the same forecast shown in Figure 5 (above) was presented again to them with a low level of uncertainty (Figure 6, below) and a high level of uncertainty (Figure 7, below). It was clarified to them that the higher the level of uncertainty, the less conservative the forecast.

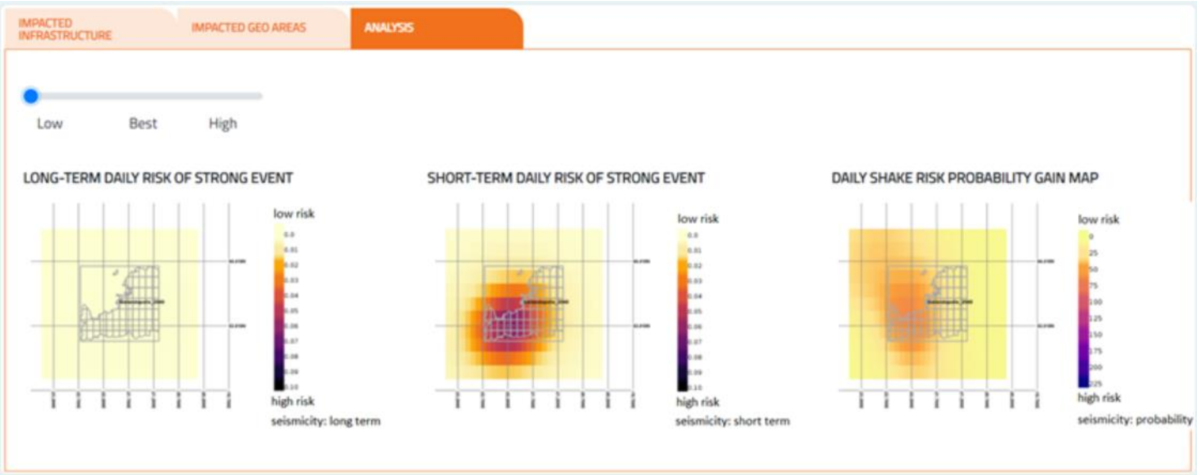


Figure 6 OEF with a low level of uncertainty - conservative forecast

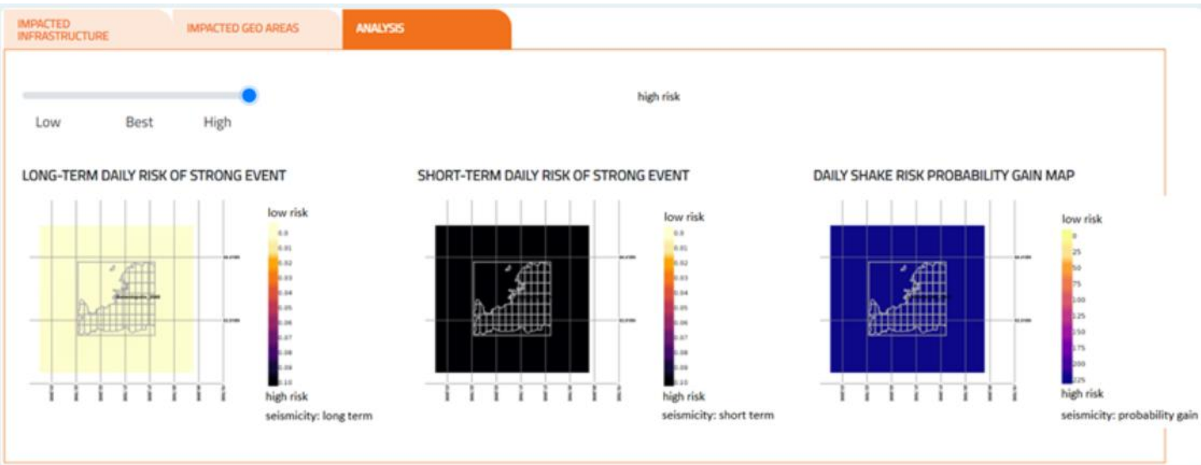
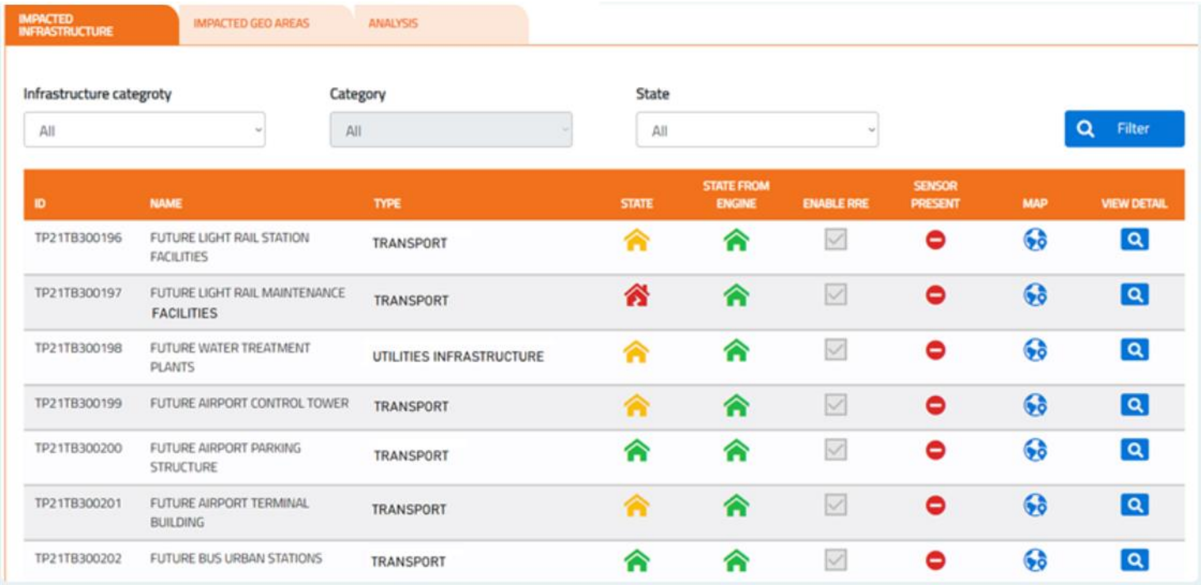


Figure 7 OEF with a high level of uncertainty - worst case scenario

After this brief overview of how end-users can run OEF in the TURNkey FWCR Platform, the discussion moved on to the simulations (informed by OEF) that provide information on the potential impact that the forecasted earthquake could have on human, physical and financial losses. At this point, participants were shown how TURNkey displays the potential impact on infrastructure and assets (Figure 8, below). They were told that TURNkey FWCR Platform will generate vulnerability assessments for individual buildings or assets, showing their status in red, amber, or green.



IMPACTED INFRASTRUCTURE | IMPACTED GEO AREAS | ANALYSIS

Infrastructure categroty: All | Category: All | State: All | Filter

ID	NAME	TYPE	STATE	STATE FROM ENGINE	ENABLE RRE	SENSOR PRESENT	MAP	VIEW DETAIL
TP21TB300196	FUTURE LIGHT RAIL STATION FACILITIES	TRANSPORT						
TP21TB300197	FUTURE LIGHT RAIL MAINTENANCE FACILITIES	TRANSPORT						
TP21TB300198	FUTURE WATER TREATMENT PLANTS	UTILITIES INFRASTRUCTURE						
TP21TB300199	FUTURE AIRPORT CONTROL TOWER	TRANSPORT						
TP21TB300200	FUTURE AIRPORT PARKING STRUCTURE	TRANSPORT						
TP21TB300201	FUTURE AIRPORT TERMINAL BUILDING	TRANSPORT						
TP21TB300202	FUTURE BUS URBAN STATIONS	TRANSPORT						

Figure 8 Simulations informed by OEF: impact on infrastructure and assets

They were shown what TURNkey displays when you select 'view detail' for an individual asset: the forecasted damage grade of the asset, its functionality level, its vulnerability level and the number of expected casualties, see Figure 9 (below).

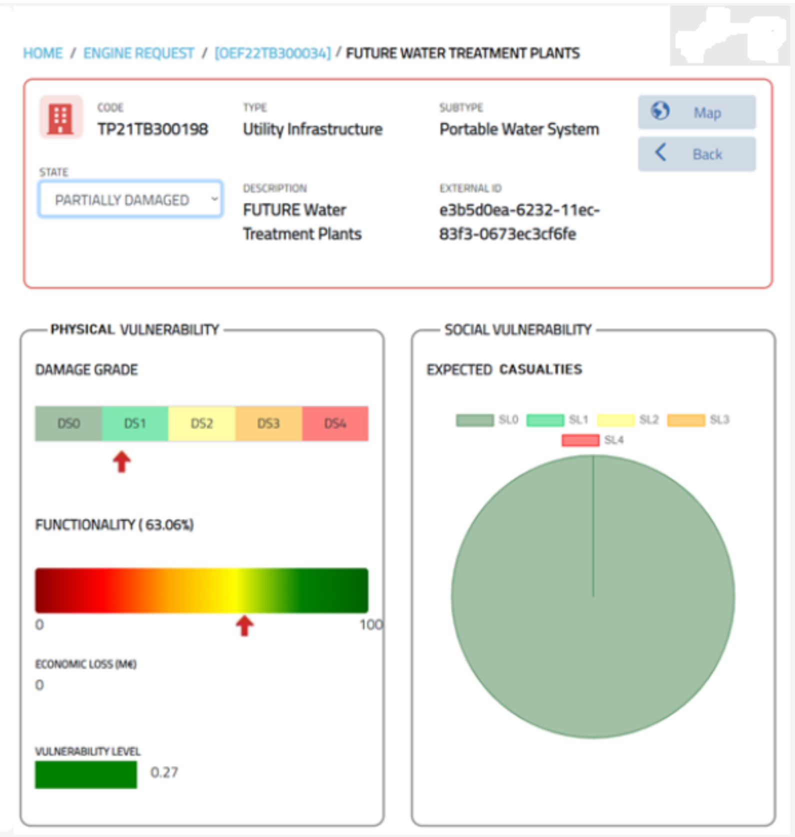


Figure 9 Simulations informed by OEF: impact on infrastructure and assets (detail)

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They were also shown what TURNkey displays when you select the 'view map' option for an individual asset: the asset on the map and its proximity to the epicentre (see Figure 10, below)

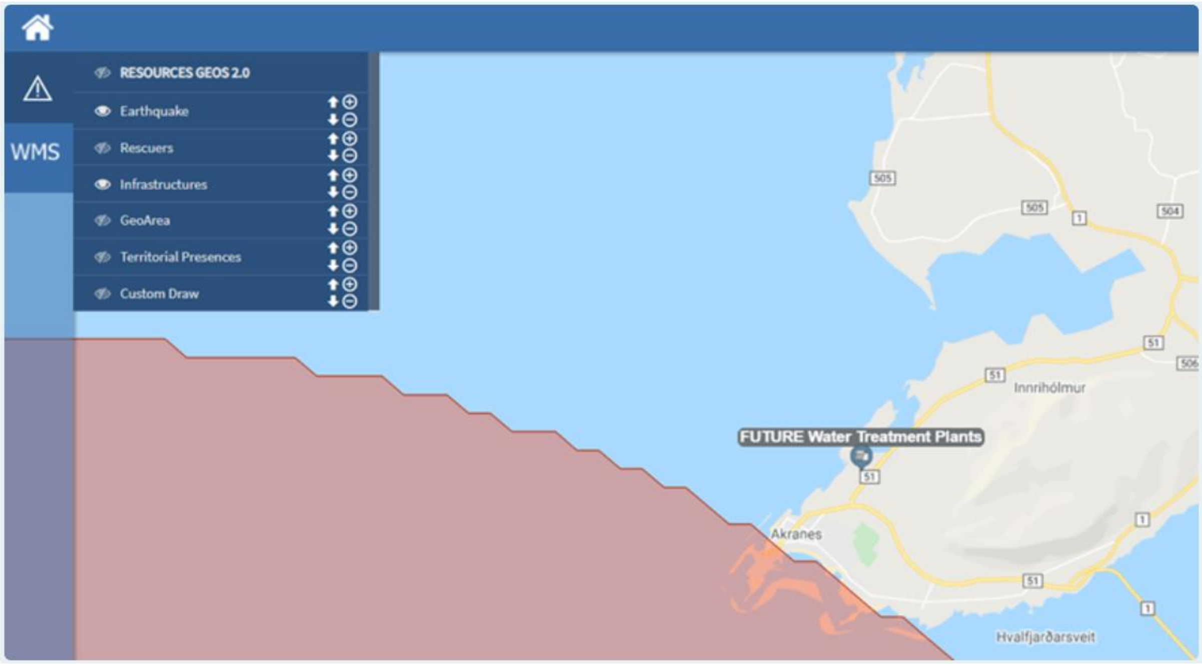
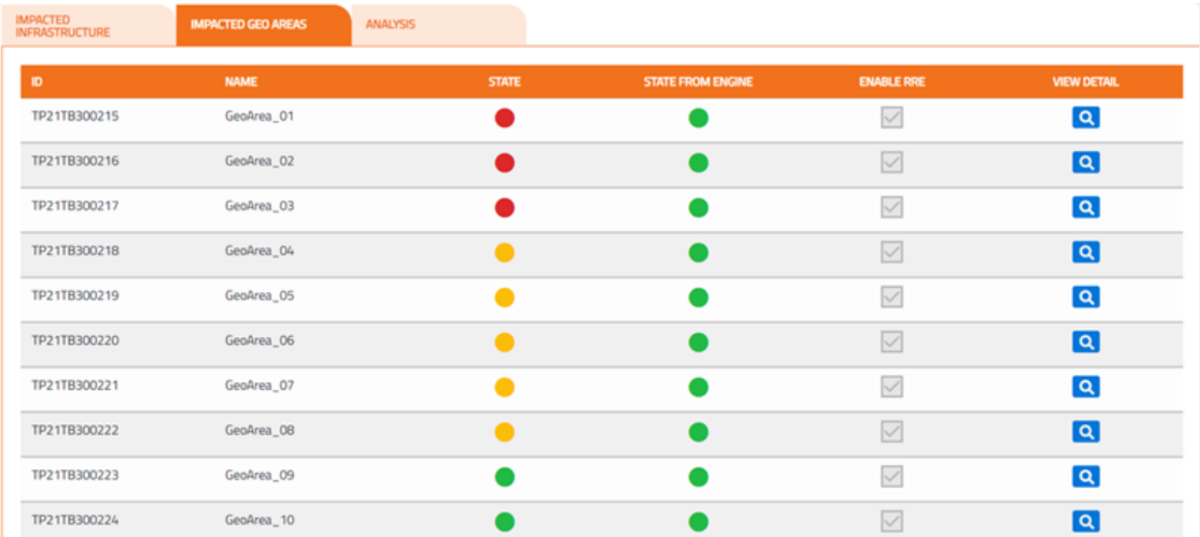


Figure 10 Simulations informed by OEF: impact on infrastructure and assets (map)

After covering simulations for individual assets and infrastructure based on OEF, participants were shown how TURNkey displays the forecasted impact on predefined areas (Figure 11, below). They were told that TURNkey FWCR Platform will generate vulnerability assessments for these areas, showing their status in red, amber, or green.



IMPACTED INFRASTRUCTURE | IMPACTED GEO AREAS | ANALYSIS

ID	NAME	STATE	STATE FROM ENGINE	ENABLE RRE	VIEW DETAIL
TP21TB300215	GeoArea_01	●	●	☑	🔍
TP21TB300216	GeoArea_02	●	●	☑	🔍
TP21TB300217	GeoArea_03	●	●	☑	🔍
TP21TB300218	GeoArea_04	●	●	☑	🔍
TP21TB300219	GeoArea_05	●	●	☑	🔍
TP21TB300220	GeoArea_06	●	●	☑	🔍
TP21TB300221	GeoArea_07	●	●	☑	🔍
TP21TB300222	GeoArea_08	●	●	☑	🔍
TP21TB300223	GeoArea_09	●	●	☑	🔍
TP21TB300224	GeoArea_10	●	●	☑	🔍

Figure 11 Simulations informed by OEF: impact on areas

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They were shown what TURNkey displays when you select 'view detail' for a predefined area: the forecasted amount of damage, the number of expected casualties – and shelters needed to house them (see Figure 12, below)

Figure 12 Simulations informed by OEF: impact on areas (detail) – medium level of uncertainty ('best forecast').

Next, it was shown to participants how the ability to change the uncertainty levels of the OEF forecast affected the simulations informed by this information. To this end, they were shown the same forecast based simulation as shown in Figure 12 (above) but with a low level of uncertainty (Figure 13, below) and a high level of uncertainty (Figure 14, below).

Figure 13 Simulations informed by OEF: impact on areas (detail) – low level of uncertainty (conservative forecast).

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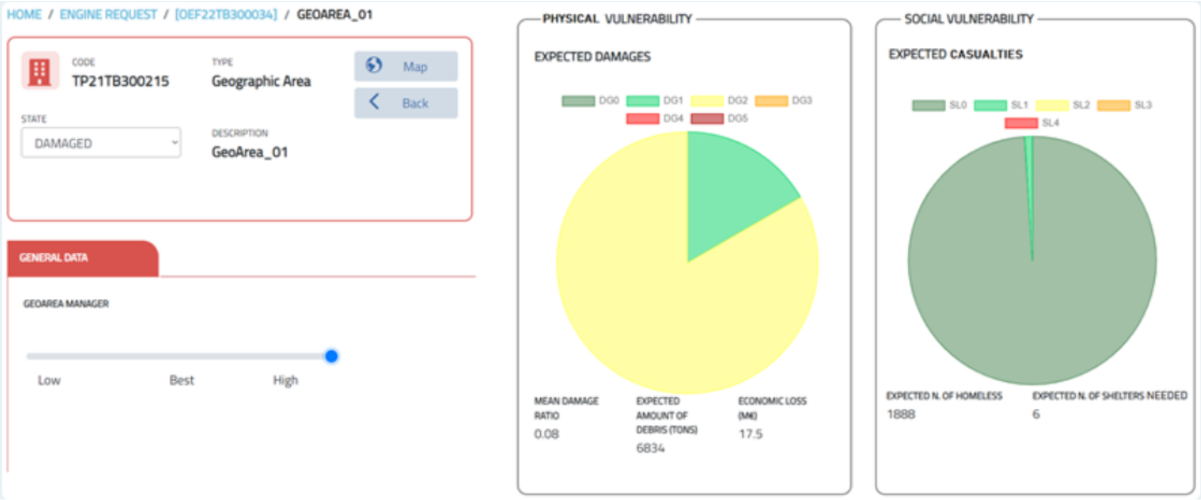

Figure 14 Simulations informed by OEF: impact on areas (detail) – high level of uncertainty ('worst case scenario').

4.4 Earthquake Simulations (before and earthquake / aftershock)

After covering TURNkey's OEF features (including simulations informed by OEF), participants were shown the platform's other simulation features. They were told that the platform also provided end-users with the option to set the earthquake magnitude, epicentre location and hypocentre depth manually. By doing so, they would get information on how the simulated earthquake would affect individual assets and regions (similar to the information provided by the simulations based on OEF). They were shown a screenshot of TURNkey (Figure 15, below) to show how end-users can enter seismic information manually.

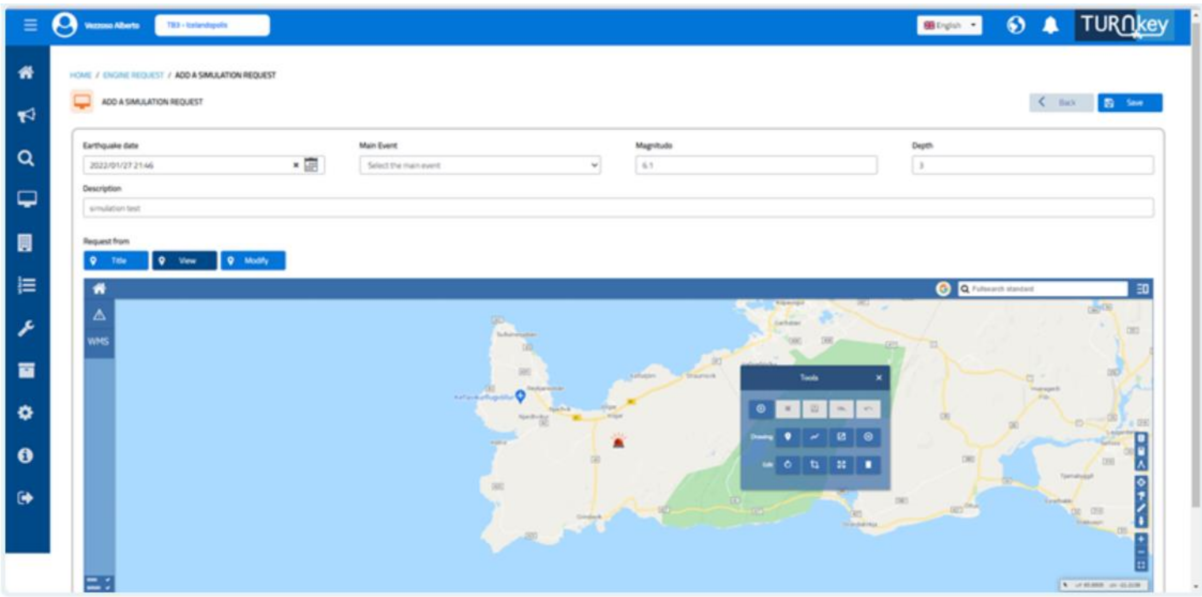

Figure 15 - Manual Earthquake Simulations (pre-earthquake / pre-aftershock)

4.5 Earthquake Early Warning (EEW) for mainshocks and aftershocks

After the discussion on OEF and earthquake simulations, the discussion turned to EEW. Participants were told that EEW systems provide advance notice of ground shaking following an earthquake. They were told that, once an earthquake has occurred, ground motion sensors are used to detect and locate the earthquake's epicentre and to estimate the earthquake's magnitude. It was explained to them that EEW systems use the difference in speed between p waves (faster) and s waves (slower but more dangerous for structures and infrastructures) to predict the time it will take for ground shaking to arrive at a given location. They were told that, if the predicted level of ground shaking exceeds a pre-set threshold, the EEW system issues an alert. Participants were told that, when an earthquake is detected, TURNkey will issue an alert, providing information on how close the epicentre is and the earthquake's magnitude. They were shown a screenshot of the TURNkey FWCR Platform issuing an EEW alert (Figure 16, below).

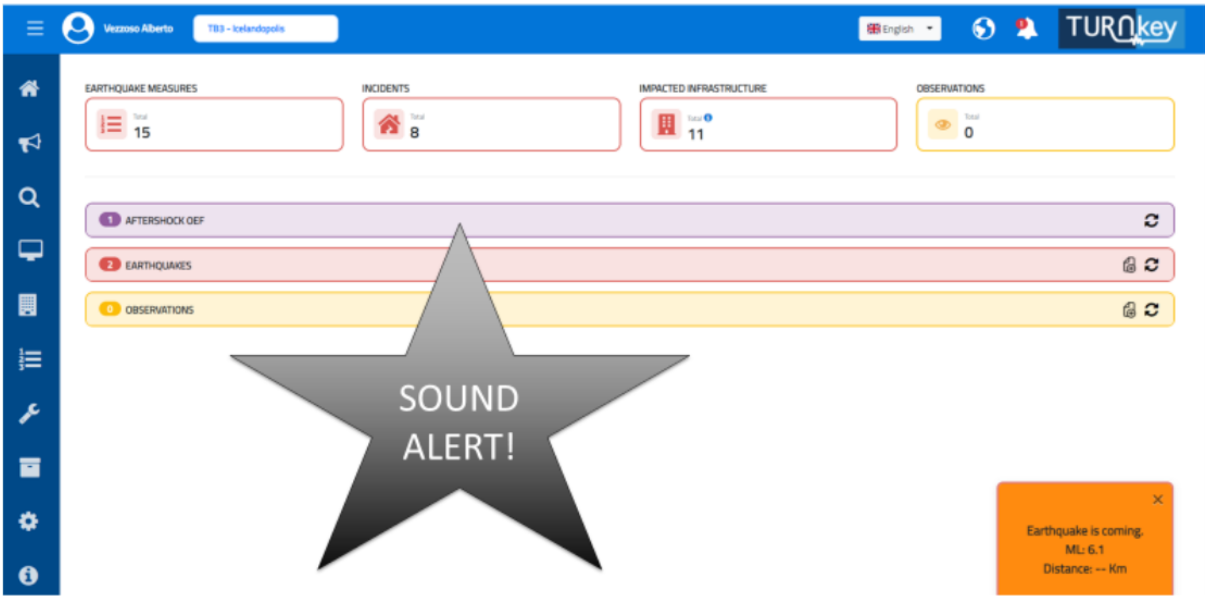

Figure 16 Early Warning for Earthquakes - screenshot TURNkey dashboard

Participants were told that TURNkey also sends EEW alerts for aftershocks via a smartphone app. This app has a 'I'm safe' button, which enables the recipient to notify their team that they are safe. Participants were shown screenshots of this (see Figure 17, below).

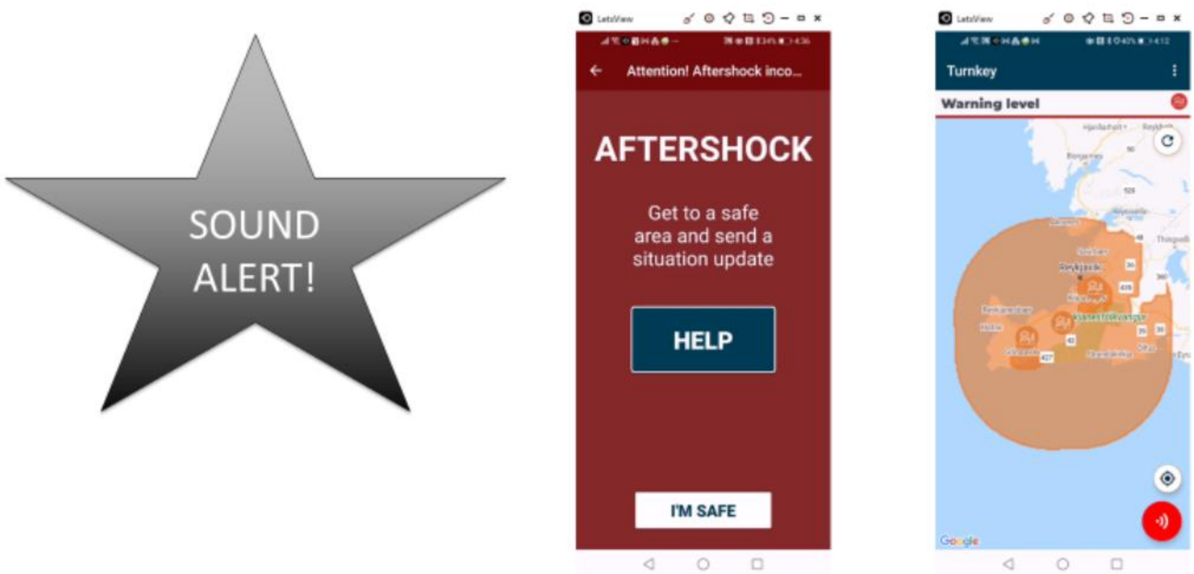

Figure 17 Early Warning for Earthquakes - screenshots TURNkey applications on mobile device

Participants were shown how EEWs for aftershocks are depicted on the TURNkey dashboard, showing their epicentre, whether an alert has been sent – and the status of security checks.

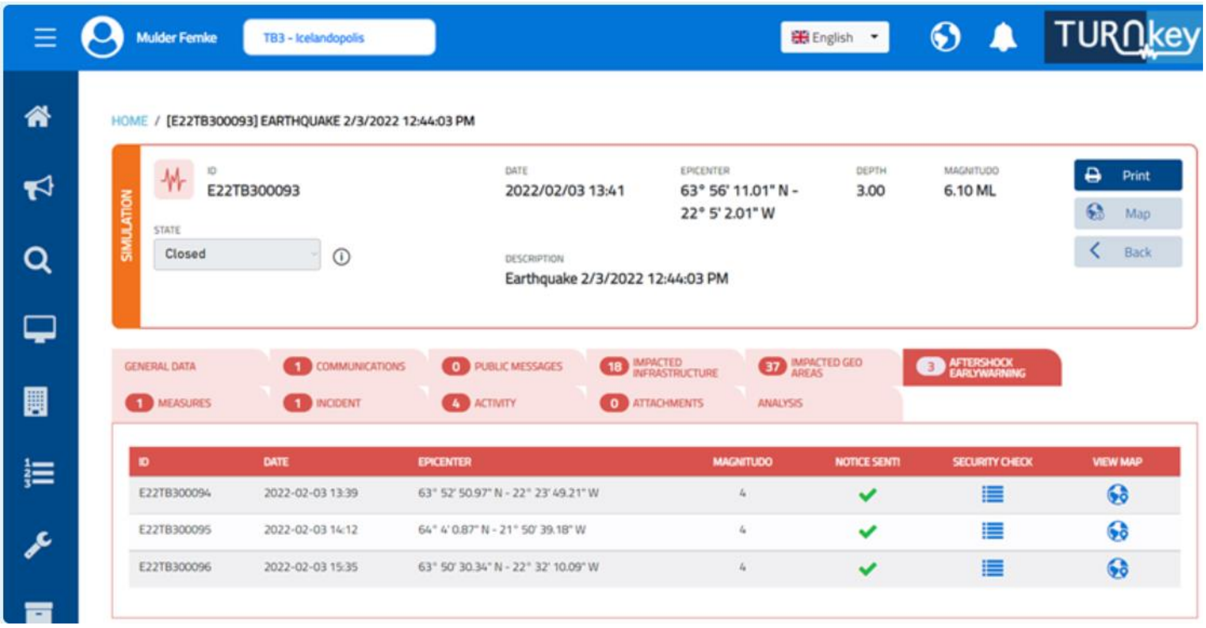

Figure 18 Early warning for aftershocks - screenshot TURNkey dashboard

4.6 Rapid Response to Earthquakes (RRE)

After TURNkey's OEF, simulation and EEW features for main and aftershocks had been covered, the discussion turned to TURNkey's dashboard for information and coordination management during the RRE phase. They were told that the dashboard shows how infrastructure and geographical areas have been affected and the state of the response: what communications have been sent, what measures have been taken and if there were any incidents. They were told that it also shows information on early warning alerts for aftershocks.

They were shown a screenshot of the dashboard (Figure 19 below), which provides general data, communications, public messages, impacted infrastructure, impacted geo areas, aftershock early warning, measures, incidents, activity, attachments, and analysis.

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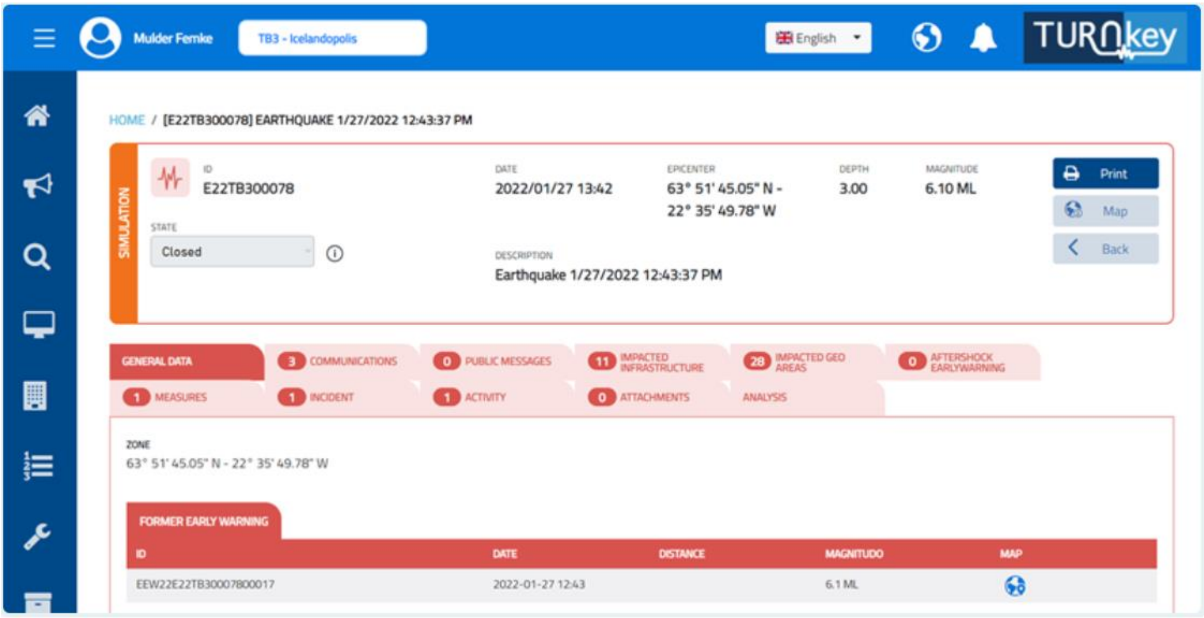

Figure 19 Dashboard for RRE - screenshot TURNkey

They were shown how the dashboard depicts the state of affected infrastructure (Figure 20, below).

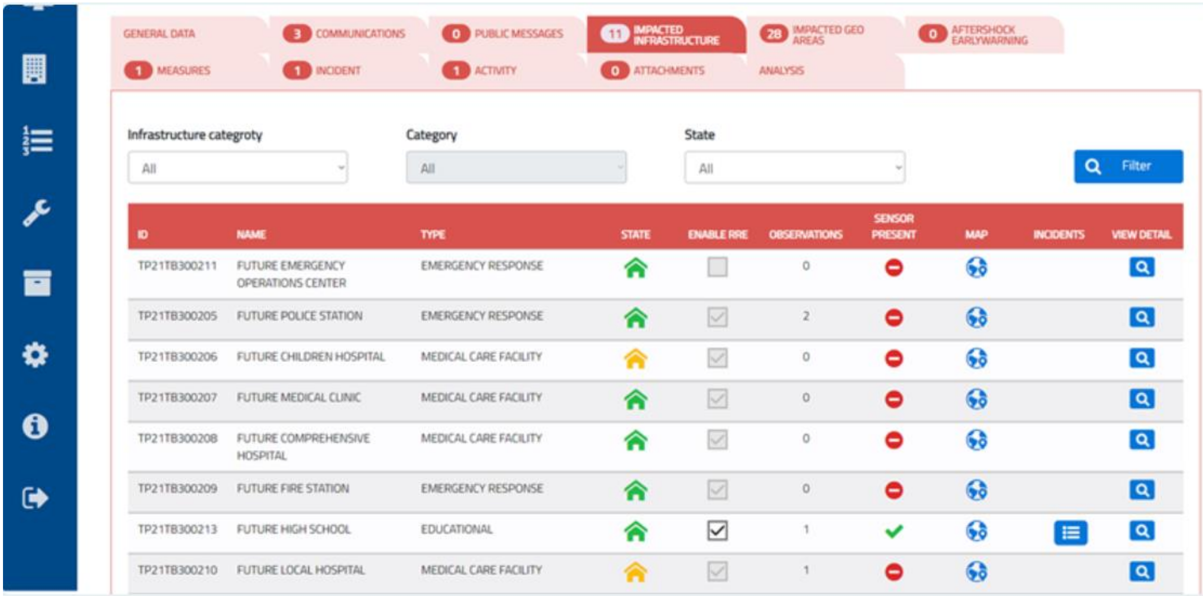

Figure 20 Dashboard for RRE - impacted infrastructure

They were shown (Figure 21, below) what TURNkey depicts when you select 'view detail' for an individual: the damage grade of the asset, its functionality level, its vulnerability level and the number of casualties.

Figure 21 Dashboard for RRE - impacted infrastructure (detail)

They were told that the TURNkey FWCR Platform will also provide vulnerability data for predefined areas, showing their status in red, amber, or green.

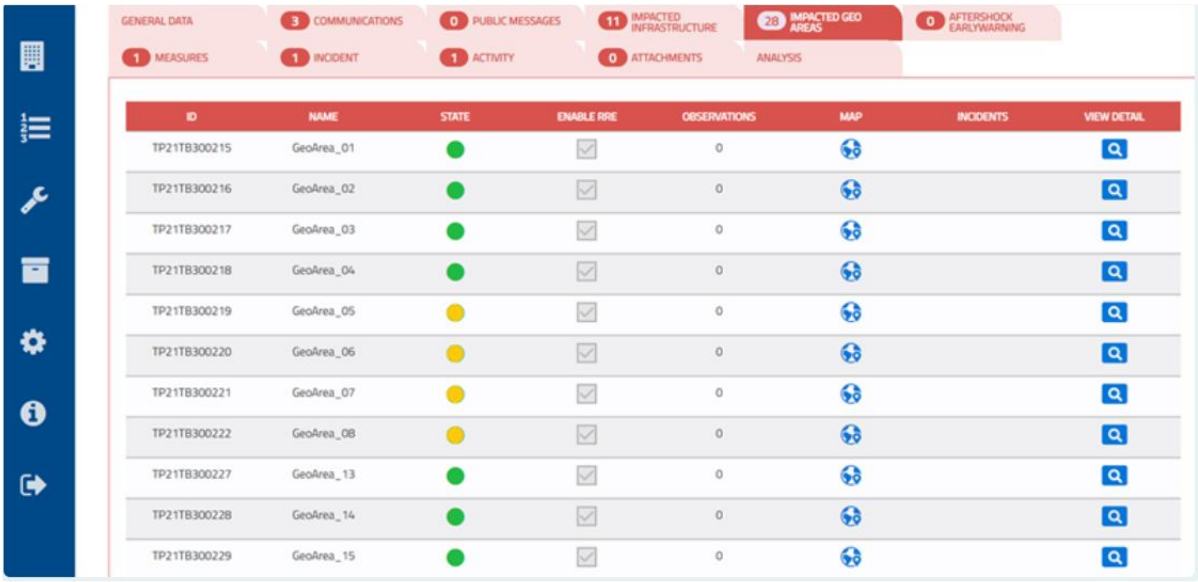

Figure 22 Dashboard for RRE - impacted areas

They were shown what TURNkey depicts when you select 'view detail' for a geographical area: the amount of damage, the number of casualties – and shelters needed to house them.

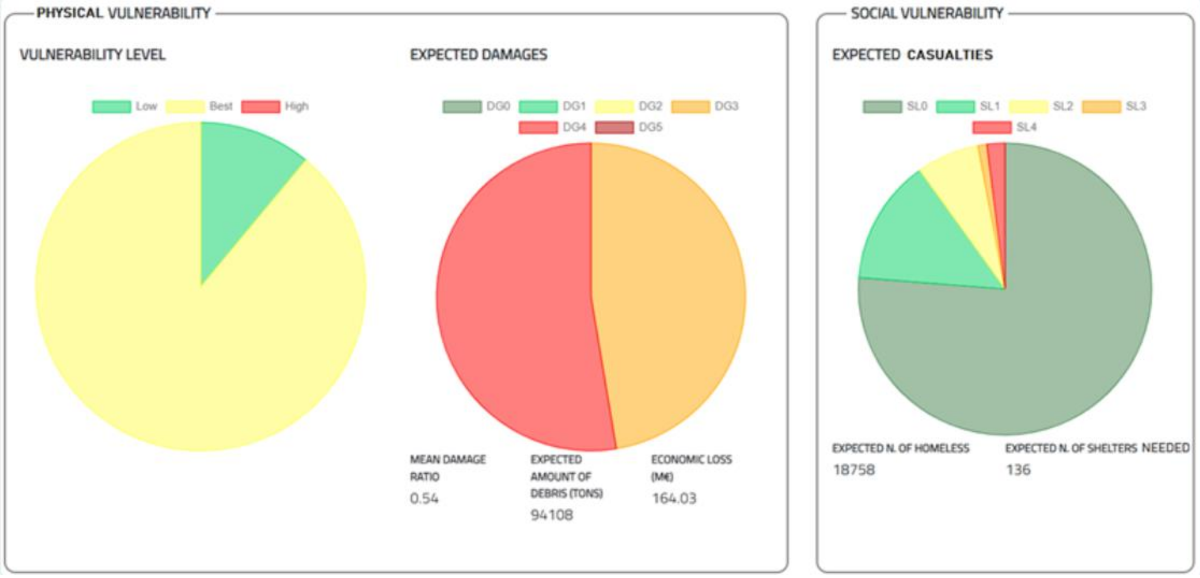

Figure 23 Dashboard for RRE - impacted areas (detail)

Participants were told that, during an earthquake response, data generated by the TURNkey FWCR Platform gets triangulated by observations from designated persons on the ground (e.g., first responders). To illustrate this, they were shown screenshots of the app (Figures 24 and 25, below).

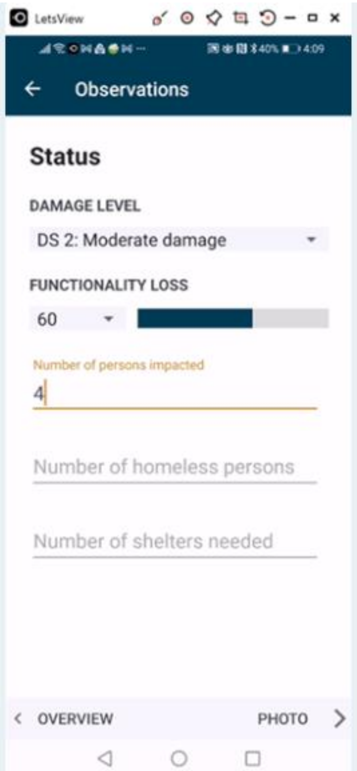

Figure 24 Response dashboard: data can be triangulated via the app (1)

They were told that observations can be uploaded via the TURNkey smartphone app – and that photos of impacted assets can also be uploaded (as depicted in Figure 25, below).

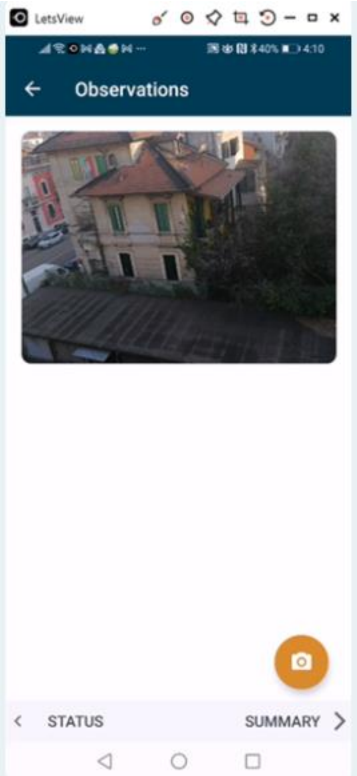

Figure 25 Response dashboard: data can be triangulated via the app (2)

They were told that observations uploaded via the app are checked by designated platform operators (e.g., based at civil protection). They were shown the interface for this on the TURNkey dashboard (see Figure 26, below).

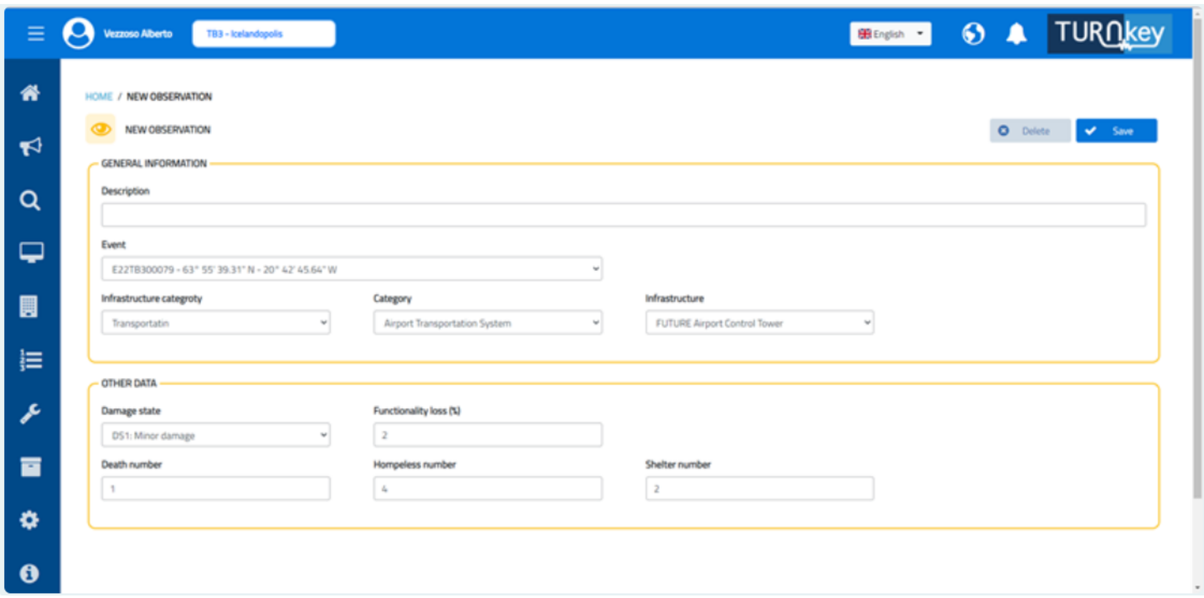

Figure 26 Response dashboard: data can be triangulated via the app (3)

They were shown a screenshot (Figure 27, below) of the tab, which shows all measures that have been taken during the response (e.g., "damage has been verified"). They were told that there is the option to view all related activity.

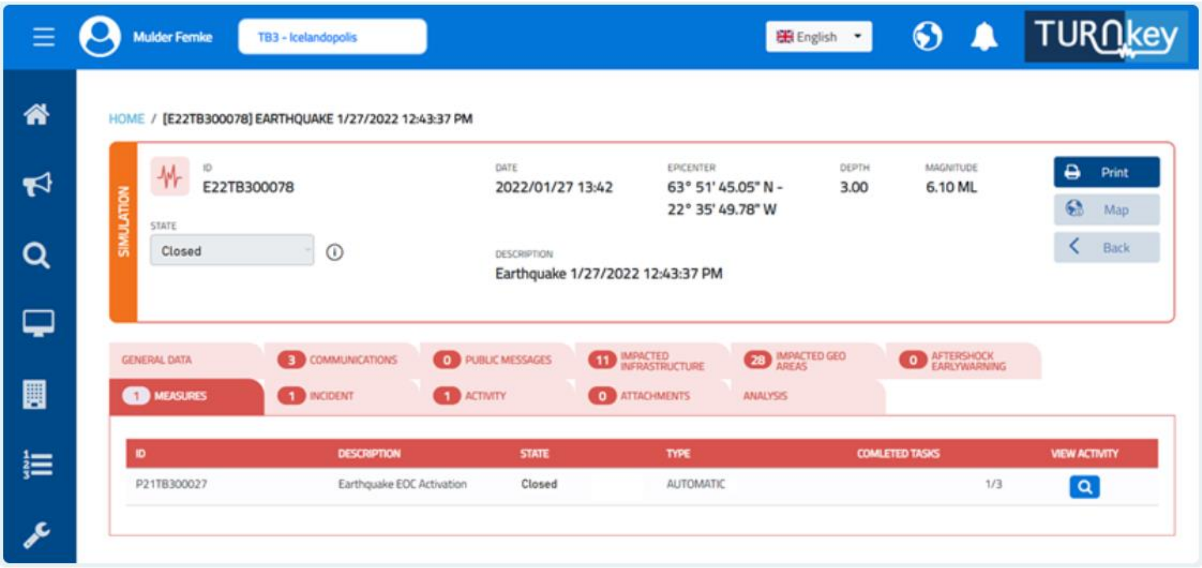

Figure 27 Response dashboard: measures taken

They were shown a screenshot (Figure 28, below) of the tab, which shows all communications that have been sent to actors involved in the response (e.g., the EOC).

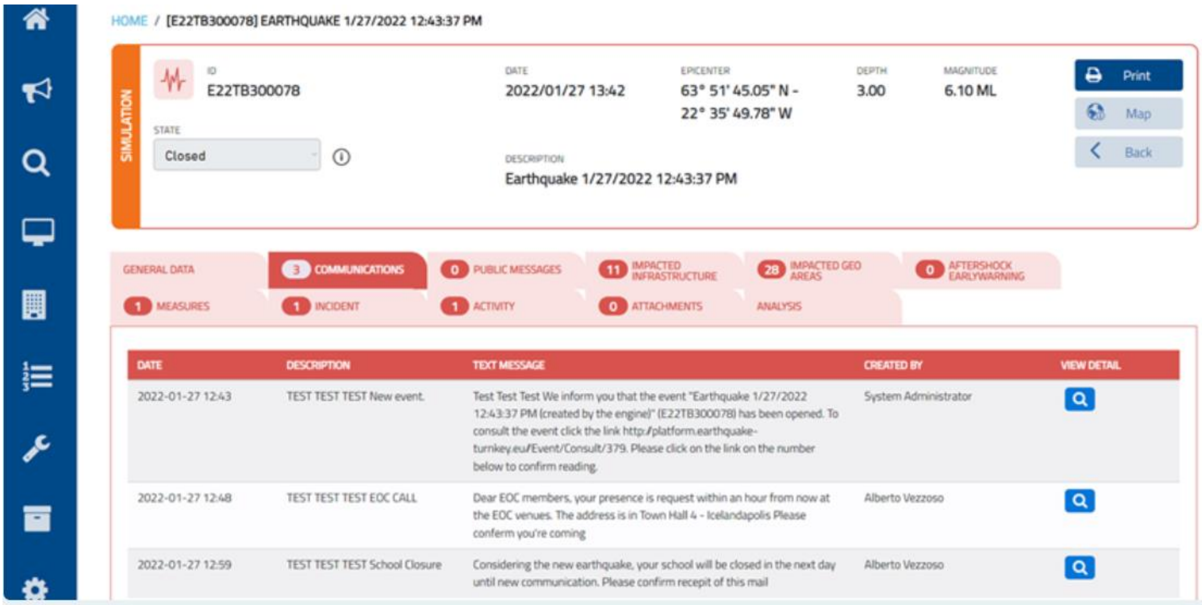

Figure 28 Response dashboard: communications sent

Finally, they were shown a screenshot (Figure 29, below) of the tab, which enables the platform operator to compose and send messages directly to the public, via email or social media.

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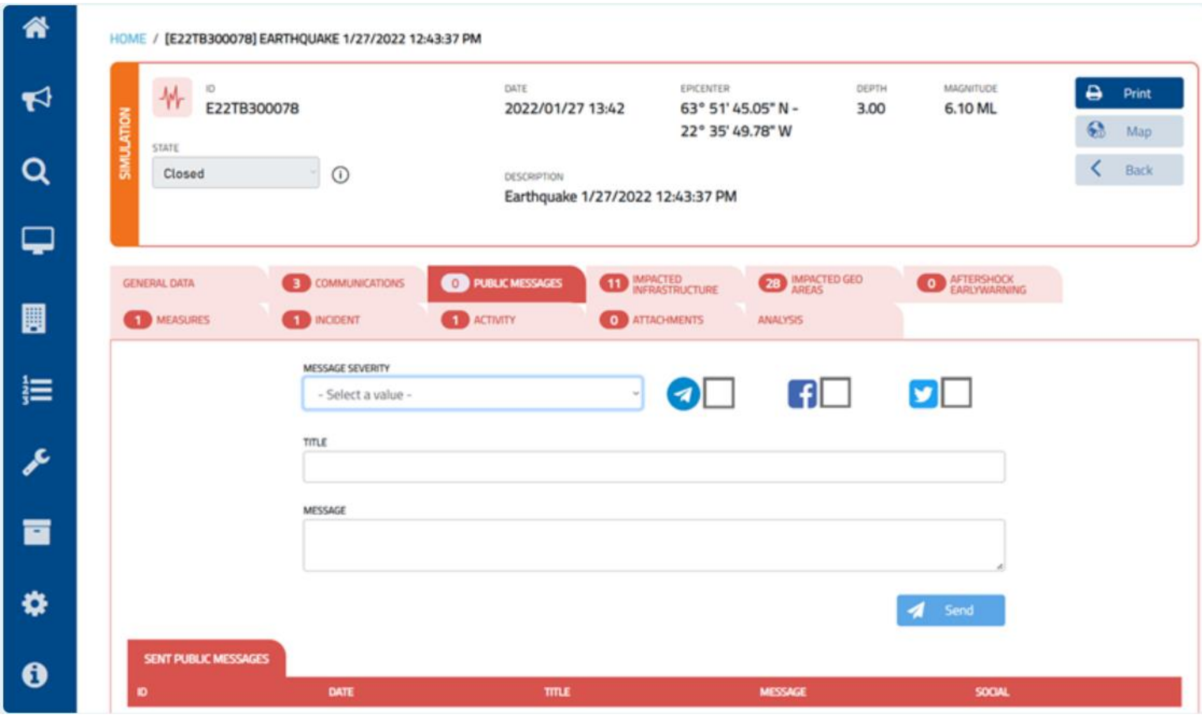

Figure 29 Response dashboard: public messaging

5 AHP model to measure organisational resilience of businesses

As part of PAR Cycle 3, the input and feedback of business organisations on the AHP model of organisational resilience developed for businesses was sought. Representatives from these business organisations were asked to assess the relative importance of the different parts of the model for organisational resilience, based on their expert opinion. Input and feedback was sought from two major operators working in the telecommunications sector, one large fuel company and eight secondary private schools. All participants gave their input and feedback during virtual meetings based on an online quiz, except for one who completed the online quiz independently after having been briefed beforehand. Participants were based in three earthquake-prone European countries. They were asked to make pairwise comparisons between the tier three elements of the AHP model for organisational resilience. The findings of this process are described in this section. Full details of the modelling process can eb found in Deliverable 5.2 (D'Ayala et al., 2020).
For details about the AHP calculation, please refer to Deliverable 5.2 and Saaty, 2014)

5.1 Pairwise comparison of top-level criteria: Organisational Resilience for businesses

Figure 30 was presented to the participants and the organisational resilience of businesses was defined to them as the ability of an organisation to continue to deliver, survive and prosper by absorbing and/or adapting to environmental shocks. It was explained to participants that research to date indicated that organisational resilience depended on three (interrelated) components: 1) physical resilience, 2) operational resilience, and 3) economic resilience. The model, which was developed in Deliverable 5.2 (D'Ayala et al., 2020), had the names of its first version amended to facilitate the discussion with the stakeholder: complex constructs were replaced by descriptive terms that aimed to clarify the difference between the model's branches. *"Corporate Resilience"* was replaced by the easier to understand term *"Economic Resilience"*. As *"Resource Management"* is key to both *"Contingency Planning"* and *"Disaster and Recovery Management*" was removed from the former so as to prevent stakeholders from assuming that it was not also part of the latter.

The participants were invited to indicate which between two components was more important for the organisational resilience of their business. The result of the three comparisons is the following.

- Physical resilience is considered to be slightly more important than operational resilience
- Physical resilience is considered to be moderately more important than economic resilience
- Operational resilience is considered to be slightly more important than economic resilience

The participants' judgements were internally consistent (consistency ratio 0.0089) and resulted in the following priority vector.

Physical resilience	0.5390
Operational resilience	0.2973
Economic resilience	0.1638

The discussions with business stakeholders indicated that they considered physical resilience to be slightly more important than operational resilience. As most provided public services / public goods, government support in times of disaster was assumed, which may account for the fact that most considered economic resilience to be the least important branch of organisational resilience (although, still important).

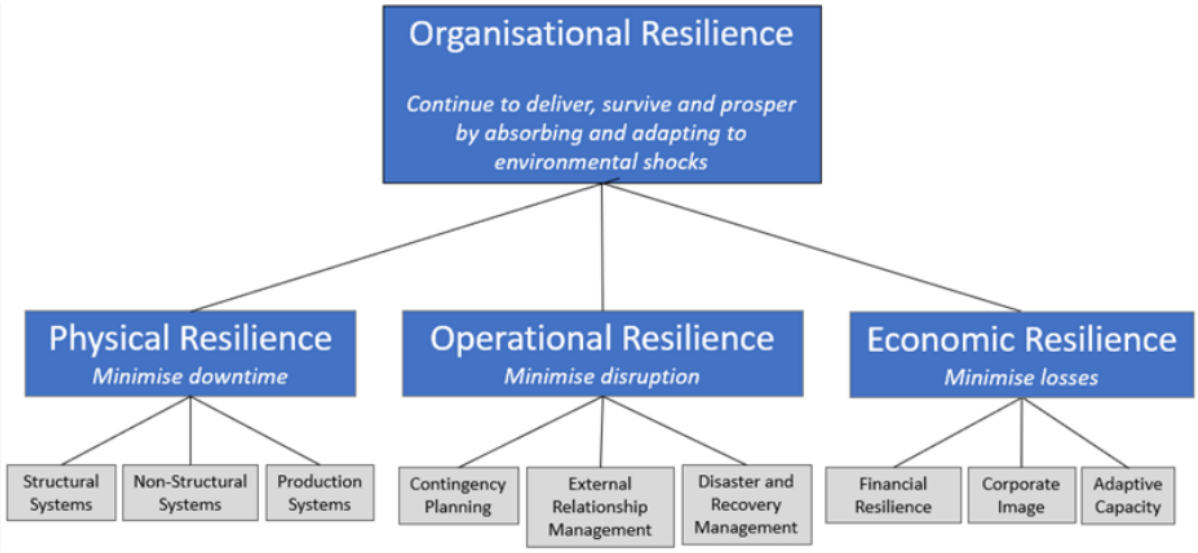

Figure 30 AHP Model for Organisational Resilience

5.2 Physical Resilience

A more detailed figure of the component 'physical resilience' (Figure 31, below) was presented to interviewees and the definition of 'physical resilience' as the organisation's ability to minimise downtime as a result of damage to its physical structures. Finally, the classification of physical resilience in three subcategories was explained: 1) structural systems, 2) non-structural systems, and 3) production systems.

For clarification, they were told that the component 'structural systems' referred to their primary building structures, such as their buildings and their roads, the component 'non-structural systems' encompassed building systems and architectural components, such as ceilings, lights, shelving, heating and plumbing and the component 'production systems' referred to the tools, records and equipment they used to deliver their goods or services, such as their inventory, their computers and their machinery.

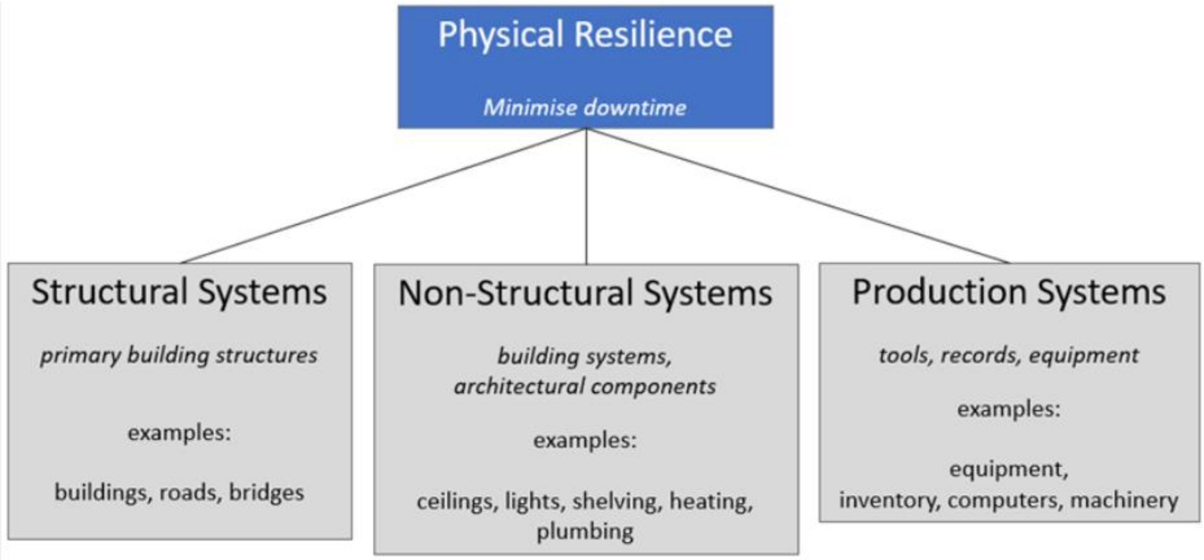

Figure 31 Physical Resilience: Tiers 2 and 3 of the AHP Model for Organisational Resilience

After this brief explanation, the participants were asked to consider the impact of significant damage to each of the three components of physical resilience on organisational resilience to complete pairwise comparisons of those three categories by asking the damage on which between two categories would have higher impact on their organisation product/service delivery. They were told that they could also say that this would be 'equally bad' or that they did not know.

The average values of each comparison are reported below for clarity.

1. Structural Systems vs Non-Structural Systems

	Structural Systems	Non-Structural Systems	Equally Bad	Don't know
Two telecommunications providers	100%			
Fuel company	100%			
Eight private secondary schools	75%	25%		

Table 1 Structural systems vs non-structural systems

The experts of the operators of the telecommunication sector, who had a technical background, noted that if structural systems fail, so do non-structural systems.

2. Structural Systems vs Production Systems

	Structural Systems	Production Systems	Equally Bad	Don't know
Two telecommunications providers	100%			
Fuel company		100%		
Eight private secondary schools	87.5%	12.5%		

Table 2 Structural Systems vs Production Systems

3. Non-Structural Systems vs Production Systems

	Non-Structural Systems	Production Systems	Equally Bad	Don't know
Two telecommunications providers		100%		
Fuel company		100%		
Eight private secondary schools	75%	25%		

Table 3 Non-Structural Systems vs Production Systems

In conclusion, the participants ranked the importance of the three components of Physical Resilience for Organisational Resilience as follows:

	Structural Systems	Non-Structural Systems	Production Systems
Two telecommunications providers	1st place	2nd place	3rd place
Fuel company	2nd place	3rd place	1st place
Eight private secondary schools	1st place	2nd place	3rd place

Table 4 Ranking of Components of Physical Resilience for Organisational Resilience

The average results of the three comparisons, which were internally inconsistent (consistency ratio 0.1065>0.05 which is the limit for consistent judgement), resulted in the following priority vector

Structural Systems	0.7510
Non-structural Systems	0.0643
Production Systems	0.1847

The meaning of internal inconsistency in the judgement matrix had been discussed in Deliverable 5.2 (D'Ayala et al., 2020) and it is clarified in Saaty, 2016. The internal inconsistency of the judgement about physical resilience is due to a different background of the interviewees. An inconsistent judgement mean that the interviewees' answers contradict each other. Whilst some of the interviewees have technical background, the others do not and their prospective is more operational than technical. It is worth to remind that the data presented for the organizational resilience of businesses are aggregated data collected in different interviews with stakeholders of different countries and background.

5.3 Operational Resilience

A more detailed figure of the component 'organisational resilience' (Figure 32, below) was then presented to the interviewed stakeholders and organisational resilience was defined to them as the organisation's ability to minimise disruptions caused by failures in its operational processes. They were told that 'organisational resilience' depends on three different components: 1) contingency planning, 2) external relationship management, and 3) disaster and recovery management. It was clarified that at the component 'contingency planning' referred to designing of procedures to follow in case of contingencies, the component 'external relationship management' is the strategic development and maintenance of connections with key stakeholders (e.g., in supply chain, business customers and local authorities) and the component 'disaster and recovery management' indicated the strategic management of resources and responsibilities for disaster preparedness, response and recovery. After this brief explanation, respondents were asked to consider the impact of a (major) shortcoming in each of the three components of operational resilience on organisational resilience and assessing in which between two paired components the shortcoming would have produced the higher negative impact on the ability of the business to deliver its service or product. They were told that they could also say that this would be 'equally bad' or that they did not know.

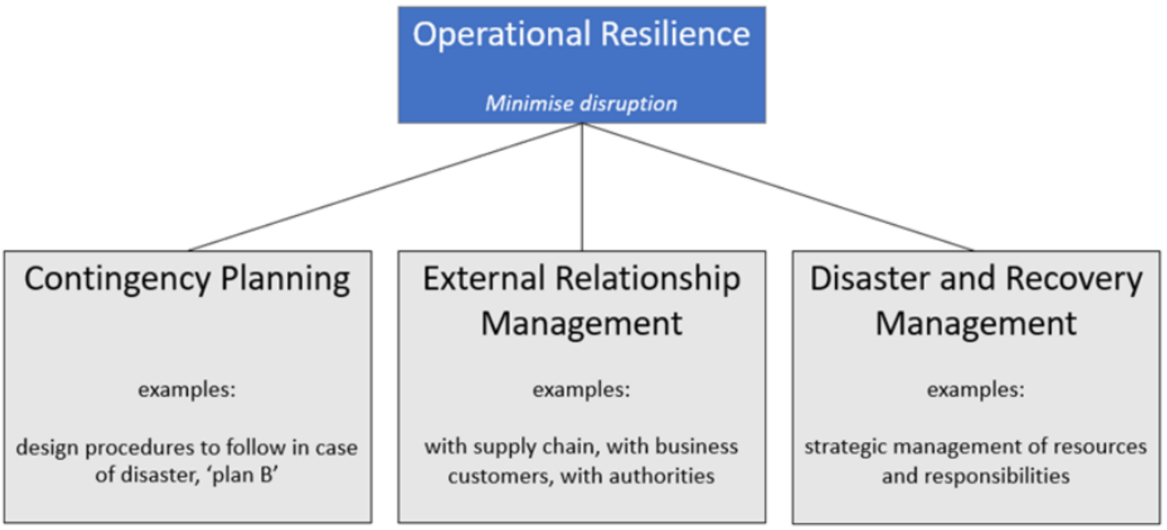

Figure 32 Operational Resilience: Tiers 2 and 3 of the AHP Model for Organisational Resilience

For sake of clarity the average values of each comparison are reported in the following tables.

1) Contingency Planning vs External Relationship Management

	Contingency Planning	External Relationship Management	Equally Bad	Don't know
Two telecommunications providers			100%	
Fuel company		100%		
Eight private secondary schools	62.5%		37.5%	

Table 5 Contingency Planning vs External Relationship Management

The expert working in the telecommunication sector pointed out that a failure in contingency planning would likely lead to a failure in external relationship management, which indicates more a cascade effect relationship between the two components than pairwise.

2) Contingency Planning vs Disaster and Recovery Management

	Contingency Planning	Disaster and Recovery Management	Equally Bad	Don't know
Two telecommunications providers		100%		
Fuel company		100%		
Eight private secondary schools	25%	37.5%	37.5%	

Table 6 Contingency Planning vs Disaster and Recovery Management

3) External Relationship Management vs Disaster and Recovery Management

	External Relationship Management	Disaster and Recovery Management	Equally Bad	Don't know
Two telecommunications providers		100%		
Fuel company		100%		
Eight private secondary schools	12.5%	62.5%	25%	

Table 7 External Relationship Management vs Disaster and Recovery Management

In conclusion, the participants ranked the importance of the three components of Operational Resilience for Organisational Resilience as follows:

	Contingency Planning	External Relationship Management	Disaster and Recovery Management
Two telecommunications providers	shared 2nd place	shared 2nd place	1st place
Fuel company	3rd place	2nd place	1st place
Eight private secondary schools	2nd place	3rd place	1st place

Table 8 Ranking of Components of Operational Resilience for Organisational Resilience

The three comparisons resulted in judgments which were internally consistent (consistency ratio 0.00) and produced the following priority vector.

Contingency Planning	0.1000
External Relationship Management	0.1000
Disaster and Recovery Management	0.8000

5.4 Economic resilience

The stakeholder was presented with a more detailed figure of the component 'economic resilience' (Figure 33, below). They were told that 'economic resilience' refers to an organisation's ability to minimise financial losses as a result of damage to - or failure of - its economic assets and capabilities. They were told that 'economic resilience' comprised 1) financial resilience, 2) corporate image, and 3) the ability to adapt. For clarification, it was indicated that the component 'financial resilience' covered issues such as financial planning, having a financial safety net and insurance; the component 'corporate image' referred to an protection of the organisation's brand, its public relations and its social responsibility (in a disaster context); and the component 'ability to adapt' referred to organisation's ability to change its asset base and learn from past experience, adopt innovation, be flexible. The usual set of pairwise comparisons followed where the interviewees had to define in which between two components the occurrence of a (major) shortcoming would have produced the worse impact on the organisation's principal objective: deliver its product or service. It was mentioned to the responders that they had the option to indicate that a shortcoming in both the two components would have produced the same negative impact or they could have said they did not know the answer.

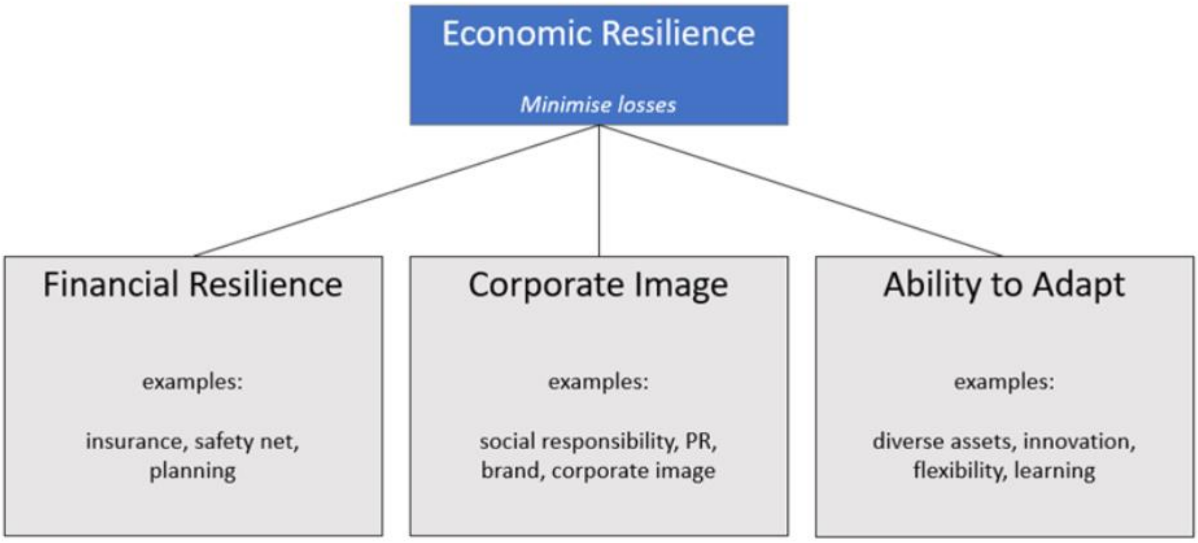

Figure 33 Economic Resilience: Tiers 2 and 3 of the AHP Model for Organisational Resilience

The tables below report the average values obtained from all interviews for sake of clarity.

1) Financial Resilience vs Corporate Image

	Financial Resilience	Corporate Image	Equally Bad	Don't know
Two telecommunications providers	100%			
Fuel company		100%		
Eight secondary schools	75% (6)			25% (2)

Table 9 Financial Resilience vs Corporate Image

The telecommunications providers noted that if an organisation has an established brand, it should be able to 'take a hit' when it comes to its corporate image.

2) Financial Resilience vs Adaptive Capacity

	Financial Resilience	Ability to Adapt	Equally Bad	Don't know
Two telecommunications providers		100%		
Fuel company	100%			
Eight secondary schools	50% (4)	12.5% (1)	12.5% (1)	25% (2)

Table 10 Financial Resilience vs Adaptive Capacity

3) Corporate Image vs Ability to Adapt

	Corporate Image	Ability to Adapt	Equally Bad	Don't know
Two telecommunications providers		100%		
Fuel company	100%			
Eight secondary schools	25% (2)	37.5% (3)		37.5% (3)

Table 11 Corporate Image vs Ability to Adapt

In conclusion, the participants ranked the importance of the three components of Economic Resilience for Organisational Resilience as follows:

	Financial Resilience	Corporate Image	Ability to Adapt
Two telecommunications providers	2nd place	3rd place	1st place
Fuel company	2nd place	1st place	3rd place
Eight secondary schools	1st place	3rd place	2nd place

Table 12 Ranking of Components of Economic Resilience for Organisational Resilience

The average values resulted from the three comparisons for all interviewees resulted internally inconsistent (consistency ratio 0.2181>0.05 which is the limit to consider the judgement consistent) and produced the following priority vector.

Financial Resilience	0.7077
Corporate Image	0.2089
Ability to Adapt	0.0835

The interviewees' judgement of the economic resilience of the businesses is not consistent. As for the Physical Resilience, the aggregated data used for the assessment are collected in interviews with senior and not senior managers of the participating stakeholders: not senior manager are not aware of financial details of the organisation and are not strongly involved in decision related to the organisation ability to adapt.

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5.5 *The potential impact of TURNkey FWCR platform on organisational resilience of businesses*

After the respondents had given their views on the relative importance of the different components of the above presented AHP model for organisational resilience for businesses, they were shown the latest version of the TURNkey FWCR Platform on the basis of screenshots. The platform's various functionalities were explained to them. After the participants had been given this detailed explanation of the platform they were asked to rate to what extent (if at all) the TURNkey FWCR Platform would contribute to organisational resilience, in their expert opinion. For this rating the AHP model for organisational resilience of businesses was shown again block by block (see Figure 30). The rating was made using a 1-5 Likert scale to indicate to what extent TURNkey could boost the resilience of each of the tier 3 items. It was also clarified that the answer 'not at all' was also possible. The results collected in this exercise are summarized in Table 13 below.

	Not at all	Slightly	Moderately	Very	Extremely
Structural systems			Telecoms 100% Fuel Comp 100% Schools 25%	Schools 37.5%	Schools 37.5%
Non-structural systems		Telecoms 100% Schools 12.5%		Fuel Comp 100% Schools 50%	Schools 37.5%
Production systems	Telecoms 50%	Telecoms 50%	Fuel Comp 100% Schools 12.5%	Schools 62.5%	Schools 25%
Contingency planning			Telecoms 100% Schools 12.5%	Fuel Comp 100% Schools 37.5%	Schools 50%
External relationships	Schools 14.3%		Telecoms 100% Schools 14.3%	Fuel Comp 100% Schools 57.1%	Schools 14.3%
Disaster Management			Telecoms 100% Schools 37.5%	Fuel Comp 100% Schools 25%	Schools 37.5%
Financial resilience			Telecoms 100% Fuel Comp 100%	Schools 25%	Schools 37.5%

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			Schools 37.5%		
Corporate image	Schools 14.3%	Telecoms 100%	Schools 28.6%	Fuel Comp 100% Schools 28.6%	Schools 28.6%
Ability to adapt		Telecoms 100% Schools 12.5%	Fuel Comp 100% Schools 25%	Schools 37.5%	Schools 25%

Table 13 Stakeholder responses for impact of TURNkey FWCR platform on organisational resilience

The following table summarizes the outcomes of the AHP model for organisational resilience of business as resulted from the interviews.

Criteria	**Sub-Criteria**	**Impact of TURNkey**	**Impact Score**	**Weighted Score**	**Impact of TURNkey on Criteria**
Physical Resilience	Structural Impact	Moderate	0.42	0.32	0.42
	Non-structural Impact	Moderate	0.42	0.03	
	Production Impact	Moderate	0.42	0.08	
Operational Resilience	Contingency Planning/RM	High	0.66	0.07	0.47
	Supply Chain/ER	High	0.66	0.07	
	Disaster Response/Recovery	Moderate	0.42	0.34	
Corporate Resilience	Financial Resilience	Moderate	0.42	0.30	0.44
	Adaptive Capacity	Moderate	0.42	0.09	
	Corporate Image (CSR)	High	0.66	0.05	
Impact on Organisational Resilience of Businesses					0.44

Table 14 TURNKey impact on organisational resilience based on AHP

The result of the AHP calculation indicates that the impact of the TURNkey FWCR platform on the Organisational Resilience of Businesses is 0.44. Therefore, the platform has moderate positive impact of the resilience of businesses, i.e., it will moderately improve it.

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6 AHP model to measure organisational resilience of CI

A critical infrastructure provider operating in the mass transport sector across border was interviewed as part of Participatory Action Research Cycle 3. Based on his expert opinion The operator was invited to assess the relative importance of the different parts of the AHP model to measure the critical infrastructure resilience developed in Deliverable 5.2 (D'Ayala et al., 2020). The stakeholder was asked to make pairwise comparisons between the tier three elements of the model. The findings of this process are described in this section.

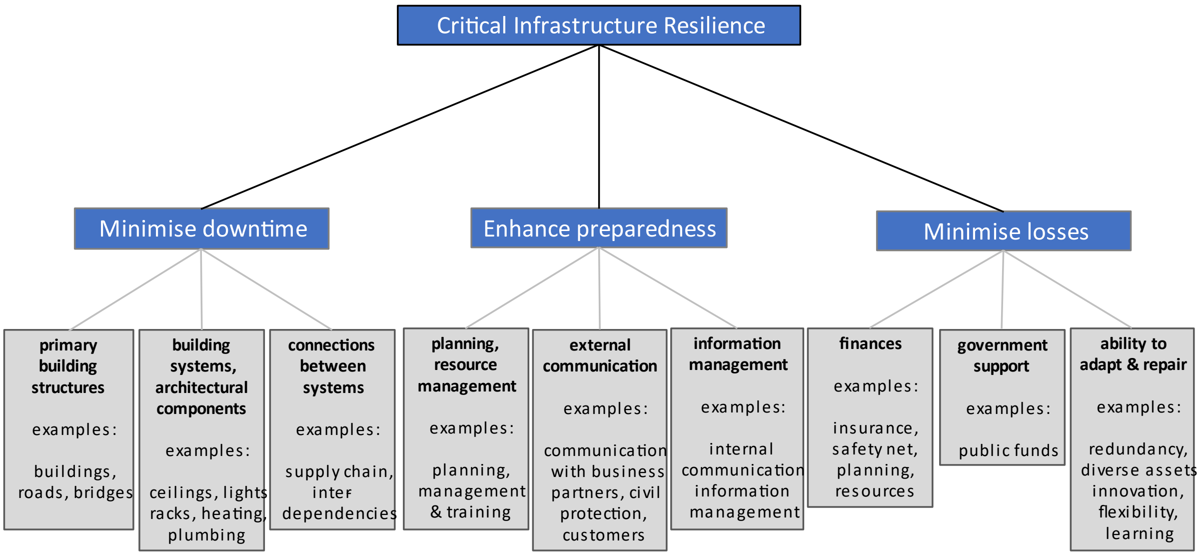

Figure 34 AHP Model for Critical Infrastructure Resilience

6.1 Pairwise comparison of top-level criteria

The stakeholder was presented with Figure 34, which shows the CI resilience developed in Deliverable 5.2 (D'Ayala et al., 2020). A definition of CI resilience as the CI provider's ability to continue to deliver, survive and prosper in an earthquake scenario by absorbing its impact or adapting its operations. The first level of components of the AHP model were listed to stakeholder: 1) minimize downtime, 2) enhance preparedness, and 3) minimize losses. The names of these three components were amended with respect to those presented in D5.2 (D'Ayala et al., 2020): the new names indicated the effect on the produced on the CI. Specifically, *"physical resilience"* was changed to *"minimising downtime"; "organisational resilience"* was changed to *"enhancing preparedness"*; and *"financial resilience"* to *"minimising financial losses"*.

The stakeholder was prompted to rank the importance of each of the components in the CI resilience model through pairwise comparison. The results of the three comparison is reported here*:*

- Minimising downtime is considered to be moderately more important than enhancing preparedness

- Minimising downtime is considered to be strongly more important than minimising financial losses
- Enhancing preparedness is considered to be moderately more important than minimising financial losses

The ranking calculated through the AHP method leads to the following priority vector.

Minimising downtime	0.6333
Enhancing preparedness	0.2605
Minimising losses	0.1062

The judgement was found internally consistent (consistency ratio 0.04<0.05).

6.2 Minimising downtime

The stakeholder was first asked to reflect on how physical damage and failures in operating procedures could lead to downtime during an earthquake. As minimize downtime depends on 1) primary building structures; 2) building systems and architectural components; and 3) connections between systems, the stakeholder was involved in a pairwise evaluation of damage or failure of which between two of those components would have the worse impact in the ability of the infrastructure to deliver its service. It was highlighted that possible answer were also "equal impact" and "not sure". While presenting the comparison for each of those three components a clearer definition of the each of them was proposed. In particular, the component 'primary building structures' referred to items such as their buildings, roads and bridges; 'building systems and architectural components' comprised items such as ceilings, lights, racks, heating and plumbing; and component 'connections between systems' indicated issues related to interdependencies and supply chain.

The stakeholder ranked the importance of the three components of 'Minimising Disruption' for CI Resilience as follows:

- Primary building structures are considered to be moderately more important than building systems
- Primary building structures are considered to be moderately more important than connections between systems
- Building systems are considered to be equally important as connections between systems

The judgements were internally consistent (consistency ratio 0.00<0.05) and resulted in the following priority vector.

Primary building structures	0.6000
Building systems	0.2000
Connections between systems	0.2000

It is important to point out that the CI provider indicated that a major damage to primary buildings structures would be worse because any civil structure collapse (a bridge, a tunnel, a viaduct) could lead to fatalities and the company's inability to provide its services for some times. On the other

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hand, the stakeholder was quite confident about the seismic resistance of the primary building structures as they were designed according to EC8 provisions.

How the CI provider minimises downtime resulting from physical damage and failures in operating procedures

The stakeholder explained that CI buildings were not open to the public, but only to the staff and occasional visitors. The CI main buildings comprise 1) headquarters where all the IT systems are based, and 2) the operations control centre. The CI also has 'technical rooms' (small buildings) along transit lines (i.e., every two kilometres) for equipment and telecommunications. The CI other primary structures include bridges, tunnels, viaducts and flyovers. If the organisation were to lose its headquarter main building it would lose people, which the organisation regards as the 'worst case'. However, because no equipment is stored at headquarter it would not actually impede the organisation's services. However, if they were to lose the control centre or the technical rooms, the organisation would not be able to provide mass transit for a period of time to estimate, likely until the damage had been repaired. The horizontal part of the infrastructure is designed and built to withstand ground shaking according to current standard as well the buildings. The parts of the horizontal infrastructure (such as electricity lines) are designed to withstand earthquakes and other hazard like wind. Both primary buildings and horizontal component of the infrastructure are designed to withstand an earthquake of intensity greater than any historically happened in the area. The CI has redundancy of some systems and in supply chain, e.g., power from more than one provider plus an emergency system.

6.3 Enhancing Preparedness

The exercise for the stakeholder was to reflect on how management could enhance earthquake preparedness. It was clarified to the stakeholder that "enhance preparedness" included the following components: 1) planning and resource management, 2) external communications, and 3) information management and for each of those components a further clarification was provided. The component 'planning and resource management' was explained as the CI ability to plan for and manage resource (either financial, physical or human) and train human resources. The component 'external communication' was defined as communication activities with business partners, customers and civil protection. The component 'information management' was explained as the set of communications internal to the infrastructure. The stakeholder was asked to consider the impact of each of the three components of 'enhancing preparedness' on CI resilience and identify in which component between two compared a major shortcoming would have the worse impact the preparedness enhancement of the infrastructure. It was also indicated to the interviewee the possible replies could also be 'equally bad' and 'not sure'.

The stakeholder's ranking of the importance of the three components of 'Enhancing Preparedness' for CI Resilience is the follow:

- Planning is considered to be moderately more important than information management
- Planning is considered to be strongly more important than external communications
- Information management is considered to be moderately more important than external communications

The judgements were internally consistent (consistency ratio 0.04<0.05) and resulted in the following priority vector.

Planning	0.6333
Information Management	0.2605
External Communications	0.1062

The stakeholder indicated that information management has the greatest impact on preparedness as the quality of rescue efforts depends on the quality of information and information flow.

How the CI provider enhances preparedness through planning and resource management, external communications, and information management

The stakeholder explained that their organisation conducts evacuation drills two to three times a year to protect their personnel. These drills are not specific to earthquakes: the risk of other hazards (e.g., fire) is much greater. The organisation conducts one exercise with the fire brigade each year in addition to internal exercises. The stakeholder further explained that the organisation has contingency plans for different crises, including earthquakes. These contingency plans have been developed together with the fire brigade and other first response services. As such, detailed instructions and guidelines exist to protect the users and equipment in case of an earthquake. After each training (and real incident) disaster procedures are revised and updated. In terms of external communications, the stakeholder explained that, as soon as the organisation becomes aware of the crisis, prewritten messages are sent to operational partners (e.g., power supply). As part of the drills (described above) the organisation checks that messages are sent to all affected parties. The stakeholder explained that, once an incident has occurred, rescue organisations take over. Which recue organisation takes over depends on the location of the incident. The organisation has designated information managers / spokespeople in case of disasters. Their role is to manage information and liaise with rescue services. Written information management documents to support these efforts exist. In terms of public communications, the stakeholder explained that the organisation has an external communications plan as well as designated spokespeople to respond to enquiries (e.g., from journalists) about limited aspects of the crisis (e.g., rescue operations). The organisation has several channels for external communications, including their website where the publish the current status of their operations (e.g., if there are any delays). However, the interviewed stakeholder stressed that many aspects of crisis communication (e.g., numbers of fatalities) are the responsibility of government authorities.

6.4 Minimising Financial Losses

The stakeholder was next asked to reflect on how the ability to absorb and adapt to the impact of the earthquake could help minimise financial losses. It was clarified that financial losses were dependent on three components according to the resilience model presented: 1) finances, 2) government support, and 3) the ability to adapt and repair. For clarification, the component 'finances' was explained as the CI ability to prepare a financial planning and access to financial resources, insurance and financial safety net (this should not have been confused with "planning and resource management", which was a component related to the management). On the other

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hand, the component 'government support' was explained as to opportunity to access to public funds and the component 'ability to adapt and repair' as the inherent redundancy, diverse assets, innovation, flexibility and learning capacity". A next step, the stakeholder was asked to consider the impact of each of the three components on the CI ability to minimise losses and strive for resilience. For this purpose, the stakeholder was asked what to identify in which component a major shortcoming would worse impact the CI ability to minimize financial losses and as consequence the CI resilience. The answers 'equally bad' or 'not sure' was indicated as possible ones.

The results of the pairwise comparisons of the three components of 'Minimising Losses' for CI Resilience are so summarized:

- Government Support is considered to be moderately more important than Finances
- Government Support is considered to be strongly more important than Ability to Adapt and Repair
- Finances is considered to be moderately more important than Ability to Adapt and Repair

The judgements were internally consistent (consistency ratio 0.04<0.05) and resulted in the following priority vector.

Government Support	0.6333
Finances	0.2605
Ability to Adapt and Repair	0.1062

Further comments expressed by the interviewed stakeholder during the pairwise comparison are here reported.

Government support is the most important of the three components to minimise losses. This was justified by the fact that the interviewed shareholder provides a public service (mass transit), so it receives government support despite being a private company. As such, the interviewed CI does not have a large financial reserve. Furthermore, the stakeholder explained that insurance may take up to five years to pay, so the government would need to cover the costs initially. They stated that insurance aims to pay as late and as little as possible, so the company do not count on it. The government is necessary for interim financing.

It was not possible to ask about the legal framework regarding insurance in the sector which is not related to civil liability; moreover, the legal framework for CI insurance coving damages other that civil liability is not equal in all Europe.

Finances are more important for minimising financial losses. The stakeholder expressed the view that the ability to adapt and repair was more of a technical problem and asserted that the company can solve technical problems in its own time. The stakeholder explained that they have insurance for damage and civil liability. The stakeholder expressed the view that the ability to adapt and repair was more of a technical problem. When prompted, the interviewee stated that 'adapt and repair' should be listed under 'minimising downtime' components rather than under 'minimising losses' one.

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How the CI provider minimises losses through 1) financial management, 2) government support, and 3) the ability to adapt and repair.

The stakeholder explained that the CI operator, which is a private company, has insurance for damage and civil liability, which is expensive (millions of euros per year). However, because it provides a public service (indeed it is classified as a CI), it receives government support. Therefore, in case it was to run a deficit (even during non-crisis time) the government would step up. As such its financial reserve is not large. The stakeholder explained that insurance may take up to five years to pay, so the government would cover the costs initially. When asked about their ability to adapt and repair, the stakeholder responded that the infrastructure equipment is redundant.

6.5 The potential impact of TURNkey on Critical Infrastructure resilience

The second phase of the assessment saw the stakeholder involved in rating, on a 1-5 Likert scale, to what extent TURNkey FWCR Platform could boost the resilience of the CI measured using the components of the AHP model for the CI resilience (see Figure 34, above). The platform's various functionalities were explained to them again. At the end of that part the stakeholder was also asked to comment on the business and CI use cases that had been developed during the preceding two rounds of PAR with potential end-users of the TURNkey FWCR Platform. These further findings about the are presented in the section 'End-user use cases Critical Infrastructure'. The results of the assessment the boost of the use of platform on the CI resilience are collected below:

	Not at all	Slightly	Moderately	Very	Extremely
Structural systems					
Non-structural systems					
Production systems					
Contingency planning					
External relationships					
Disaster Management					
Financial resilience					
Corporate image					
Ability to adapt					

Table 15 Stakeholder responses for impact of TURNkey FWCR platform on CI resilience

The stakeholder responded with a grade '4' of the Likert scale, i.e., 'very', for each component of the CI resilience model. The interviewee clarified that the rating of 4 referred to how TURNkey could improve critical infrastructure resilience globally and not just in the specific case of their organisation. They expressed the view that a platform like TURNkey would also be useful for other natural hazards.

Results of the AHP model for CI resilience are summarized in the table below.

Criteria	**Sub-Criteria**	**Impact of TURNkey**	**Impact Score**	**Weighted Score**	**Impact of TURNkey on Criteria**
Minimise Downtime	Primary building structures	High	0.66	0.39	0.66
	Building systems	High	0.66	0.13	
	Connections between systems	High	0.66	0.13	
Enhance Preparedness	Planning	High	0.66	0.42	0.66
	Information Management	High	0.66	0.17	
	External Communications	High	0.66	0.07	
Minimise Losses	Government Support	High	0.66	0.42	0.66
	Finances	High	0.66	0.17	
	Ability to Adapt and Repair	High	0.66	0.07	
Impact on Critical Infrastructure Resilience					0.66

Table 16 TURNKey impact on CI resilience based on AHP

The impact of the TURNkey FWCR platform on the CI Infrastructure Resilience calculated the AHP model afore presented is 0.66; this value indicate that the platform has moderate-high positive impact on the CI resilience. Thus, the implementation of the platform is advantageous for CI that would like to enhance their residence to earthquakes

7 End-User Use Cases Business and Critical Infrastructure Providers

During PAR cycles 1 and 2, a series of end-user use cases for the TURNkey FWCR Platform were developed for civil protection stakeholders, first responders, business organisations and critical infrastructure providers. The last rendition of these use cases is presented in D2.8 (Jones et al., 2021). As part of PAR cycle 3, these use cases were triangulated one final time. This section presents the findings of the final round of PAR with business and critical infrastructure providers. Participants for PAR cycle 3 comprised telecommunications providers, private secondary education providers, a mass transit provider and an energy producer. They were based in Romania (1), Greece (8), France (1) and Iceland (2). ARU researchers conducted PAR online as described in the section on data collection. Work with the Romanian stakeholder was supported by INFP and work with the Greek stakeholders was supported by NOA. The purpose of this final round of PAR is to validate the end-user use cases and to inform the development of the business models tools presented in this deliverable

7.1 Operational Earthquake Forecasting (for aftershocks)

After the business and critical infrastructure providers were presented with an overview of OEF, as provided by TURNkey, they were asked whether, if their organisation had the ability to run probabilistic earthquake forecasts and simulations, they would it use that information to inform the following mitigation actions. These mitigation actions are part of the OEF use case for business and critical infrastructure providers (presented in Deliverable 2.8, Jones et al., 2021) which centres on "activating disaster management and business continuity plans in a timely manner before and after an earthquake event". The scale of possible answers ranged from "definitely not" to "definitely".

The response are presented in Figure 35.

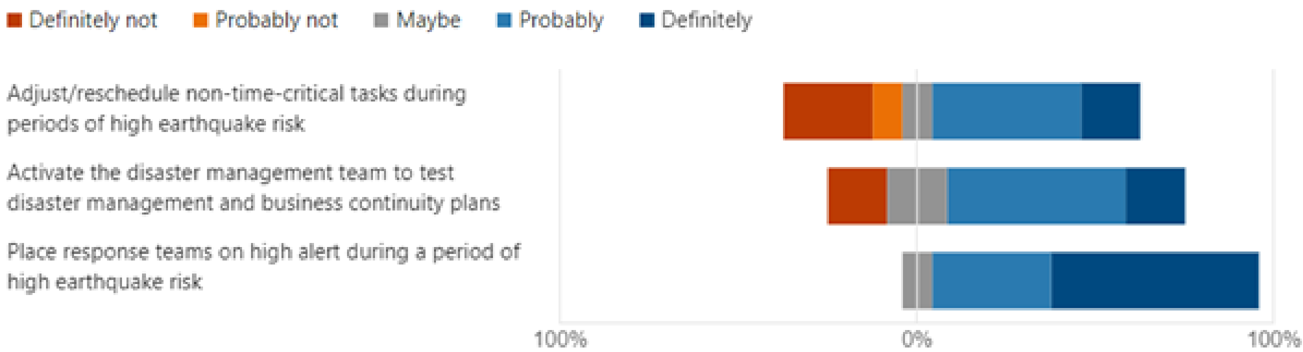

Figure 35Responses OEF use cases business

Reasons participants gave for 'probably not' or 'definitely not' comprise, 1) organisations are located in earthquake-prone regions and are 'earthquake ready' at all times, and/or 2) they don't want to be legally liable for disruptions in service (if the forecasted earthquake does not materialise). They stated that the instruction to reschedule tasks should come from government authorities. Caveat for 'probably' and 'definitely': this depends on the number of false alerts. If there are too many, organisations will not rely on it. Participants mentioned that they would also use the information to inform their enterprise-wide risk management framework.

7.2 Earthquake Simulations

After the business and critical infrastructure providers were shown TURNkey's features for earthquake simulations, they were presented with three end-user use cases identified during PAR cycles 1 and 2 and asked to rate them on a Likert scale (1 -"Definitely not", 2 - "Probably not", 3 - "Maybe", 4 - "Probably", 5 - "Definitely"). They were asked whether, if their organisation had the ability to run earthquake simulations, they would it use that information to inform the mitigation actions below. These mitigation actions are part of the Simulations use cases for business and critical infrastructure providers (presented in Deliverable 2.8, Jones et al., 2021). which centre on 1) planning disaster risk management before an earthquake event; and 2) supporting the business case for (investing in) mitigation before an earthquake event. The interviewees' responses are summarized in Figure 36

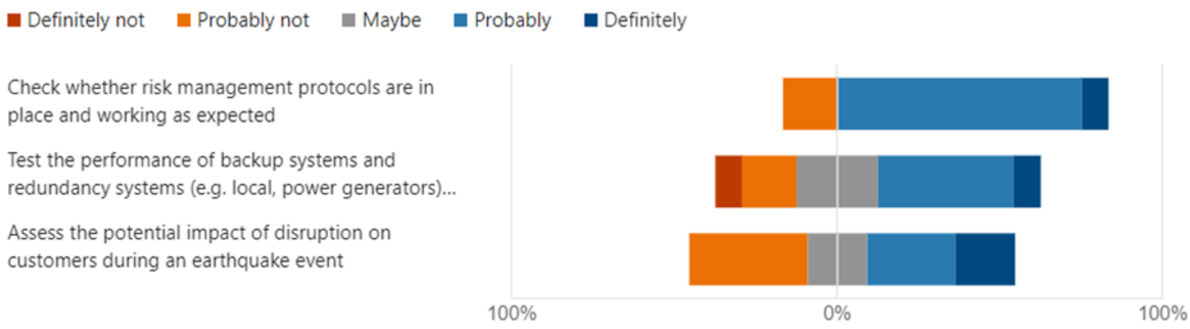

Figure 36 Responses Simulations use cases business

Reasons participants gave for 'probably not' or 'definitely not' comprise: 1) organisations already receive this information from other trusted sources (e.g., the MET) and/or 2) have existing processes and systems in place for testing disaster protocols, backup systems (etc.) and do not want duplication.

One participant (education provider) also stated that they would not use it if doing so risked 'spreading panic in the community'. Another participant (education provider) stated that earthquake risk management was the responsibility of civil protection and not their organisation.

One respondent (energy provider) stated that they would use it for impact assessments and to improve mitigation and response measures.

7.3 Earthquake Early Warning

After the business and critical infrastructure providers were shown TURNkey's features for EEW, they were presented with eight mitigation actions identified during PAR cycles 1 and 2 and asked to rate them on a Likert scale (1 -"Definitely not", 2 - "Probably not", 3 - "Maybe", 4 - "Probably", 5 - "Definitely"). They were asked whether, if their organisation had the ability to receive early warning alerts for mainshocks and aftershocks, it would use that information to inform these actions These mitigation actions are part of the EEW use cases for business and critical infrastructure providers (presented in Deliverable 2.8, Jones et al., 2021) which centre on 1) improving the personal safety of employees and members of the public during an earthquake event; 2) reducing damage to critical systems during an earthquake event so as to allow for a faster recovery. The responses collected are presented in Figure 37.

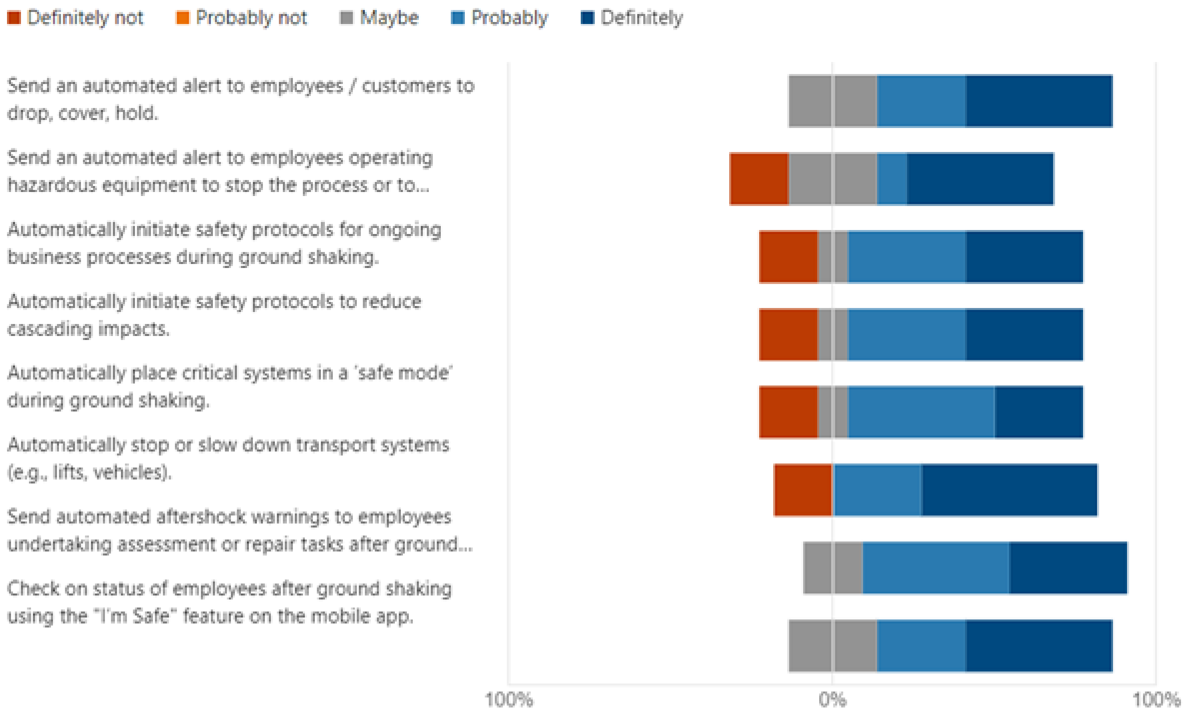

Figure 37 Responses EEW use cases business

Reasons participants gave for 'probably not' or 'definitely not' comprise: 1) organisations are located in earthquake-prone regions and are 'earthquake ready' at all times and/or 2) organisations do not have hazardous/vulnerable systems.

One participant (education provider) stated that they would use the information to send emails or text messages to customers (i.e., students' parents). Another (education provider) stated that they would not use it if doing so risked 'spreading panic in the community'.

7.4 Rapid Response to Earthquakes

After the business and critical infrastructure providers were shown TURNkey's features for RRE, they were presented with six response actions identified during PAR cycles 1 and 2 and asked to rate them on a Likert scale (1 -"Definitely not", 2 - "Probably not", 3 - "Maybe", 4 - "Probably", 5 - "Definitely"). They were asked whether, if their organisation had access to the rapid response dashboard, they would use that information to inform those actions. These mitigation actions are part of the RRE use cases for business and critical infrastructure providers (presented in Deliverable 2.8, Jones et al., 2021) which centre on 1) monitoring the progress of response and recovery activities, including employee safety; and 2) initiating a rapid activation of disaster management plans during and after an earthquake event. The stakeholders' responses are collected in Figure 38.

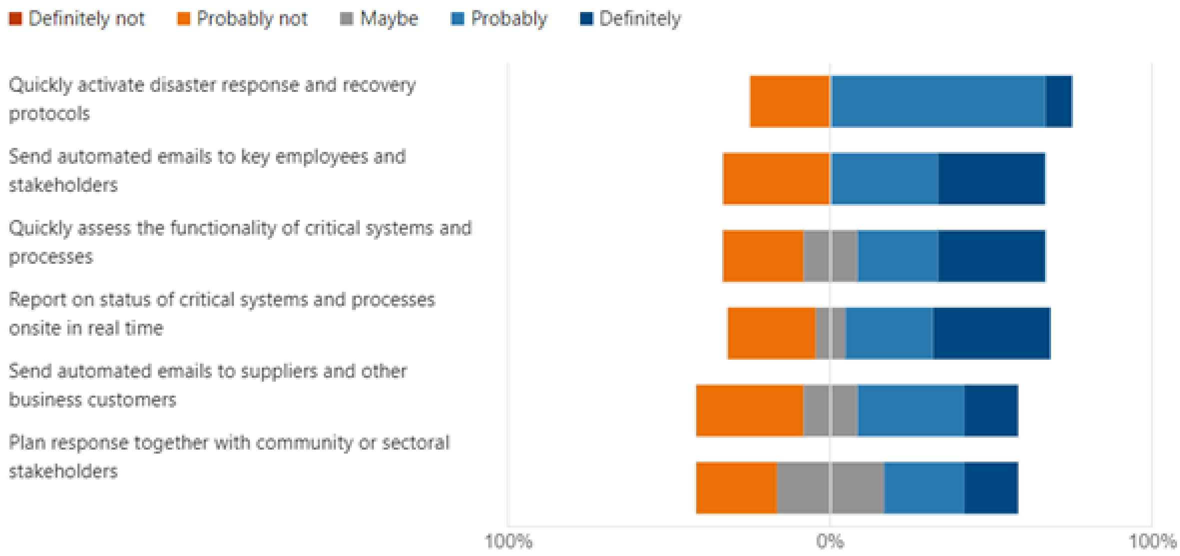

Figure 38 Responses RRE use cases business

Reasons participants gave for 'probably not' or 'definitely not' comprise: 1) critical infrastructure and business organisations already had systems in place and wanted to avoid duplication. 2) Some also emphasized that crisis response is the legal responsibility of government authorities (e.g., civil protection) and should be led/coordinated by them. One participant (education provider) stated that they would use the information to send emails or text messages to customers (i.e., students' parents).

The findings of PAR Cycle 3 validate the end-user use cases developed during PAR Cycles 1 and 2, which were published in D2.8 (Jones et al., 2021). TURNkey FWCR Platform was found to be helpful in supporting business organisations' and critical infrastructure providers' efforts to 1) plan disaster risk management before an earthquake event; 2) support the business case for (investing in) mitigation before an earthquake event; 3) activate disaster management and business continuity plans in a timely manner before and after an earthquake event; 4) improve the personal safety of employees and members of the public during an earthquake event; 5) reduce damage to critical systems during an earthquake event so as to allow for a faster recovery; 6) monitor the progress of response and recovery activities, including employee safety; 7) initiate a rapid activation of disaster management plans during and after an earthquake event.

Table 17 below outlines how the actions described above map against the use cases, TURNkey's features and the AHP metrics for organisational resilience.

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Use Case	Actions	TURNkey features	AHP metrics
Plan disaster risk management before an earthquake event;	Check whether risk management protocols are in place and working as expected. Test the performance of backup systems and redundancy systems (e.g., local, power generators) during an earthquake event. Assess the potential impact of disruption on customers during an earthquake event.	Simulations	Minimising Downtime Minimising Disruption
Support the business case for (investing in) mitigation before an earthquake event;	Assess the potential impact of disruption on customers during an earthquake event.	Simulations	Minimising (Financial) Losses
Activate disaster management and business continuity plans in a timely manner before and after an earthquake event;	Place response teams on high alert during a period of high earthquake risk; Adjust/reschedule non-time-critical tasks during periods of high earthquake risk Activate the disaster management team to test disaster management and business continuity plans	OEF	Minimising Disruption Minimising (Financial) Losses
Improve the personal safety of employees and members of the public during an earthquake event;	Send an automated alert to employees/customers to drop, cover, and hold. Send an automated alert to employees operating hazardous equipment to stop the process, or to initiate shut down. Automatically stop or slow down transport systems (e.g., lifts, vehicles).	EEW	Minimising Disruption
Reduce damage to critical systems during an earthquake event so as to allow for a faster recovery;	Automatically place critical systems in a 'safe mode' during ground shaking.	EEW	Minimising Downtime

Monitor the progress of response and recovery activities, including employee safety	Send automated aftershock warnings to employees undertaking assessment or repair tasks after ground shaking. Report on the status of critical systems and processes onsite in real-time	RRE	Minimising Downtime Minimising Disruption
Initiate a rapid activation of disaster management plans during and after an earthquake event	Automatically initiate safety protocols for ongoing business processes during ground shaking. Automatically initiate safety protocols to reduce cascading impacts. Quickly activate disaster response and recovery protocols Send automated emails to key employees and stakeholders Quickly assess the functionality of critical systems and processes Plan response together with community or sectoral stakeholders Send automated emails to suppliers and other business customers	RRE	Minimising Downtime Minimising Disruption

Table 17 The connection between the use cases, TURNkey's features and the AHP metrics for organisational resilience.

As outlined, not all features offered by TURNkey FWCR Platform were considered useful to all organisations, highlighting the importance of sector in which the stakeholder operate. Given that the TURNkey FWCR Platform was designed up to technology readiness level 5, the analysis presented is largely theoretical as the platform is not yet end-user ready. Deliverable 2.8 (Jones et al., 2021). (Appendix G) presents the consensus by the end of the project in terms of what features are possible from an engineering/ scientific point of view and how they should be optimally organised from a governance/management perspective. Stakeholders' view was that TURNkey FWCR Platform (when fully developed and available) would contribute most to organisational resilience in terms of minimising disruption, followed by minimising downtime. This is illustrated in Figure 39 below.

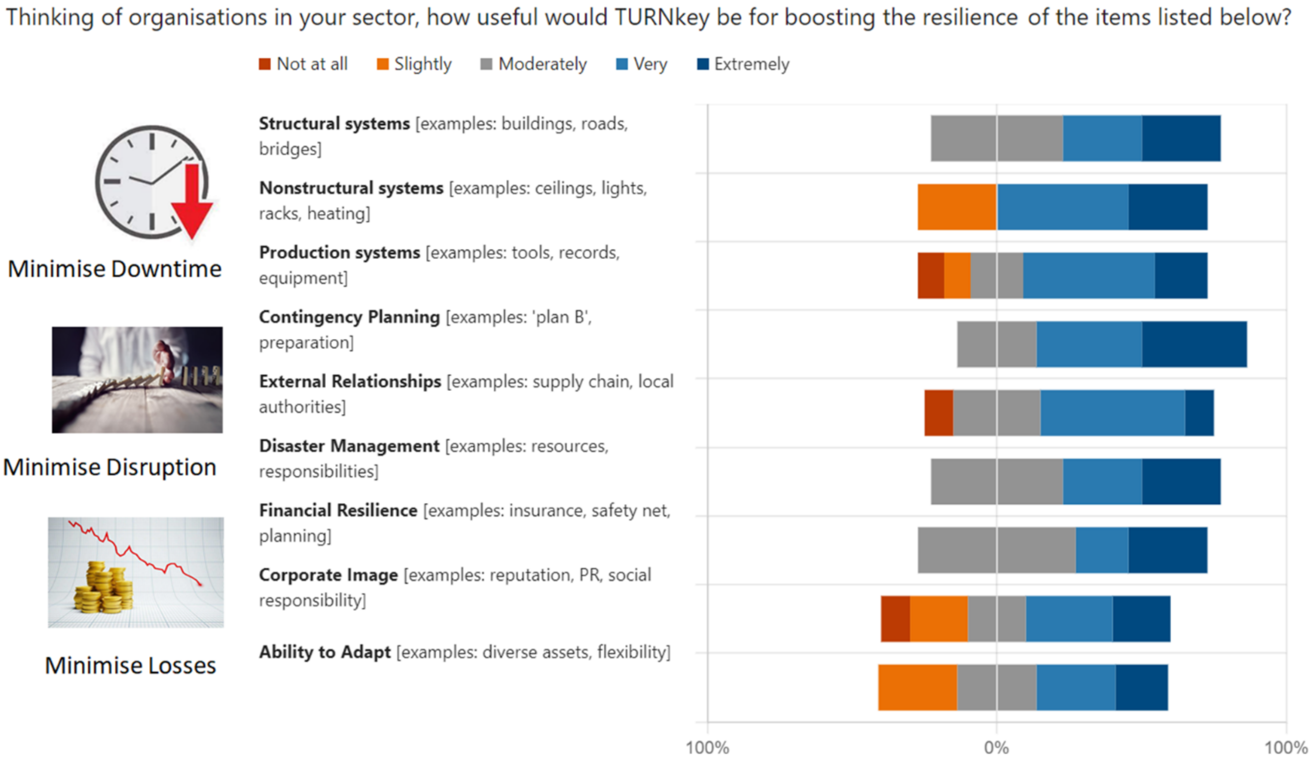

Figure 39 Responses impact TURNkey on organisational resilience

8 AHP model to measure community resilience & TURNKey with Civic Protection

On the basis of a review of the literature and practitioner standards and guidelines, the TURNkey research team at ARU had developed an AHP model for community resilience (see Figure 40, below). This work is presented in TURNkey Deliverables 5.1 (Jones et al., 2020) and Deliverable 5.2 (D'Ayala et al., 2020) . As part of PAR Cycle 3, the input and feedback of government authorities on this model was sought. An ARU researcher met with one civil protection stakeholder to get this organisation to assess the relative importance of the different parts of the model for community resilience, based on their expert opinion. The stakeholder was asked to make pairwise comparisons between the tier three elements of the model. The findings of this process are described in this section. The research conducted for D7.7. with the civic protection stakeholder built on research conducted with civic protection and first responder organisations by NTC during PAR cycles 1 and 2. The section on the civic protection use cases confirms the findings from this earlier research with these particular end-user groups. The AHP modelling for community resilience was an additional, separate, activity, which was carried out in tandem.

8.1 Pairwise comparison of top-level criteria

The stakeholder was presented with Figure 40 and given the following definition of community resilience: "community resilience refers to a community's ability to prevent, prepare for, respond to, and recover from disasters". The ARU researcher explained that research to date indicated that community resilience depended on three (interrelated) components: 1) governance and management, 2) planning and design, and 3) disaster preparedness. The stakeholder was told that their input would be sought on each of those three components in turn, starting with governance and management.

This model is the same as the one discussed in Deliverable 5.2 (D'Ayala et al., 2020) . The terms were amended to facilitate the discussion with the stakeholder: complex constructs were replaced by descriptive terms that aimed to clarify the difference between the model's branches. The model's top-level criteria were changed from *"1) city governance, 2) integrated planning and 3) response planning"* to *"1) governance & management, 2) planning & design and 3) disaster preparedness*. The purpose of this change was to clarify the difference in scope between these three top-level criteria. Minor changes to the sub-level criteria were made for the same reason, e.g., "organise for resilience" was changed to "organizing & planning.

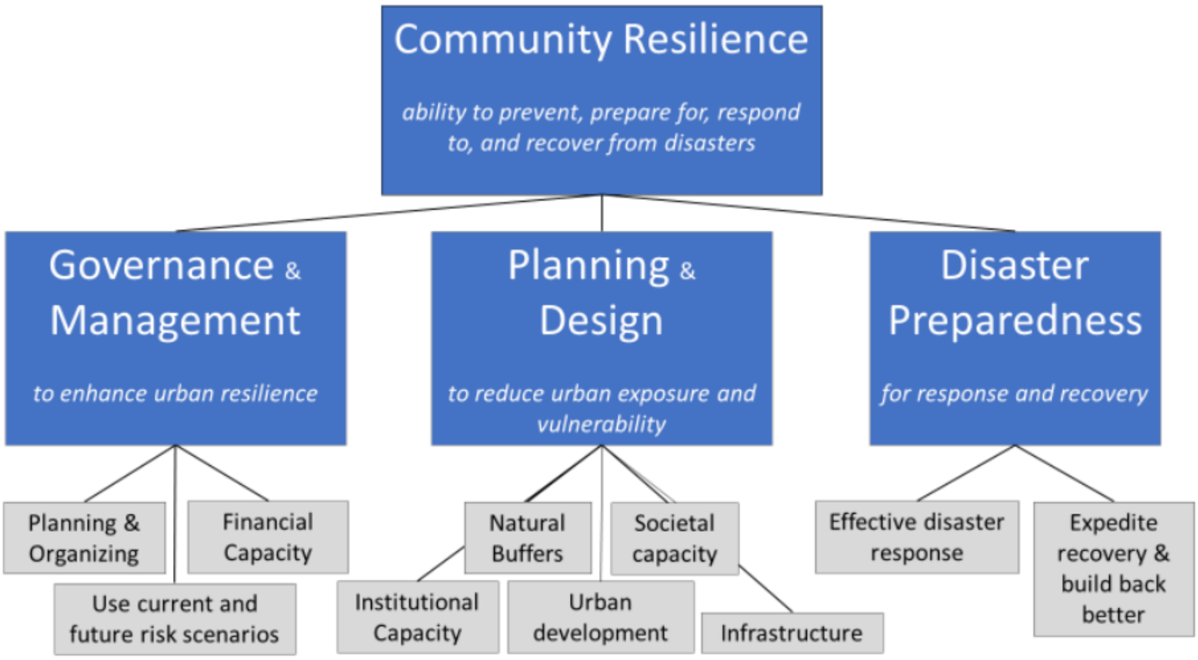

Figure 40 AHP Model for Community Resilience

The discussion with the civil protection stakeholder led to the ranking of the relative importance of the governance, planning and preparedness branches of the UNDRR to the overall resilience of the city in relation to disaster risk reduction criteria in the UNDRR Scorecard (see table below). The stakeholder indicated that, in their view, planning was most important to the overall resilience of the city in relation to disaster risk reduction criteria in the UNDRR Scorecard, primarily because this top-level criterion includes the sub-criterion 'societal capacity' which they believed to be most important for community resilience.

The stakeholder answers are summarized below:

- Governance is considered to be moderately less important than Planning
- Governance is considered to be equally as important as Preparedness
- Planning is considered to be moderately more important than Preparedness

The judgements were internally consistent (consistency ratio 0.0<0.05) and resulted in the following priority vector.

Governance	0.1991
Planning	0.6012
Preparedness	0.1997

8.2 Governance and Management

The stakeholder was presented with a more detailed figure of the component 'governance and management' (Figure 41, below). The ARU researcher asked the stakeholder to reflect on how the governance and management of urban areas affects community resilience. They were told that research to date indicated that successful governance and management for resilience depended on three interconnected parts: 1) planning and organisation, 2) the use of current and future risk scenarios, and 3) financial capacity. For clarification, they were told that 'planning and organisation' covered issues such as interagency coordination, the participation of community stakeholders in urban resilience initiatives, the integration of different stakeholders' activities and the management of data.

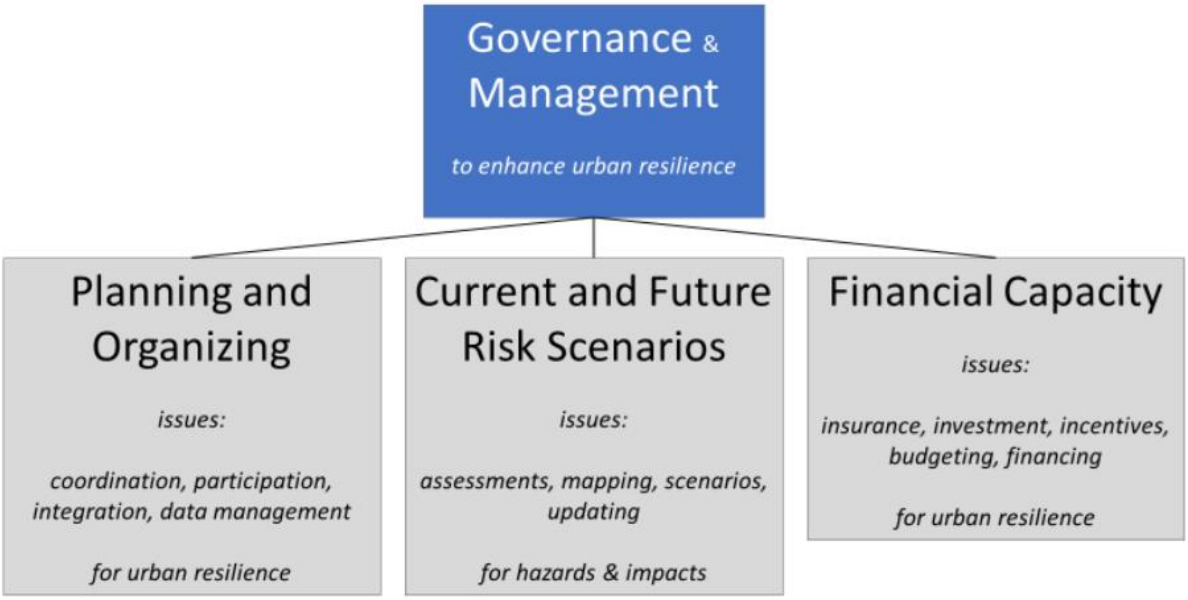

Figure 41 Governance and Management: Tiers 2 and 3 of the AHP Model for Community Resilience

It was also explained to them that the component 'current and future risk scenarios' encompassed risk assessments, hazard mapping, the use of scenarios and the regular updating of all the above. Finally, they were told that the component 'financial capacity' referred to issues such as investment in urban resilience, incentives to invest in urban resilience, the budgeting for and financing of financial resilience, as well as insurance for earthquake events. After this brief explanation, the stakeholder was asked to consider the impact of a (major) shortcoming in each of the three components of urban governance and management on community resilience. Making pairwise comparisons, they were asked what would be worse, a major shortcoming in component A, or a major shortcoming in component B. They were told that they could also say that this would be 'equally bad' or that they did not know.

The stakeholder ranked the importance of the three components of Governance & Management for Community Resilience as follows:

- Planning & Organisation was considered to be a lot more important than Risk Scenarios
- Planning & Organisation was considered to be moderately more important than Financial Capacity
- Risk Scenarios was considered to be moderately less important than Financial Capacity

The judgments obtained from three pairwise comparisons were internally consistent (consistency ratio 0.037<0.05) and resulted in the following priority vector.

Organise for Resilience	0.6333
Risk Assessment	0.1062
Financial Capacity	0.2605

8.3 Planning and Design

The stakeholder was presented with a more detailed figure of the component 'planning & design' (Figure 42, below). The stakeholder was asked to reflect on how the planning and design of urban areas affects community resilience and was told that research to date indicated that successful planning and design for resilience depended on five interconnected parts: 1) urban development, 2) natural buffers, 3) social capacity, 4) institutional capacity, and 4) infrastructure. For clarification, the stakeholder was informed that 'urban development' covered issues such as land use, new developments and the existence and enforcement of building standards.

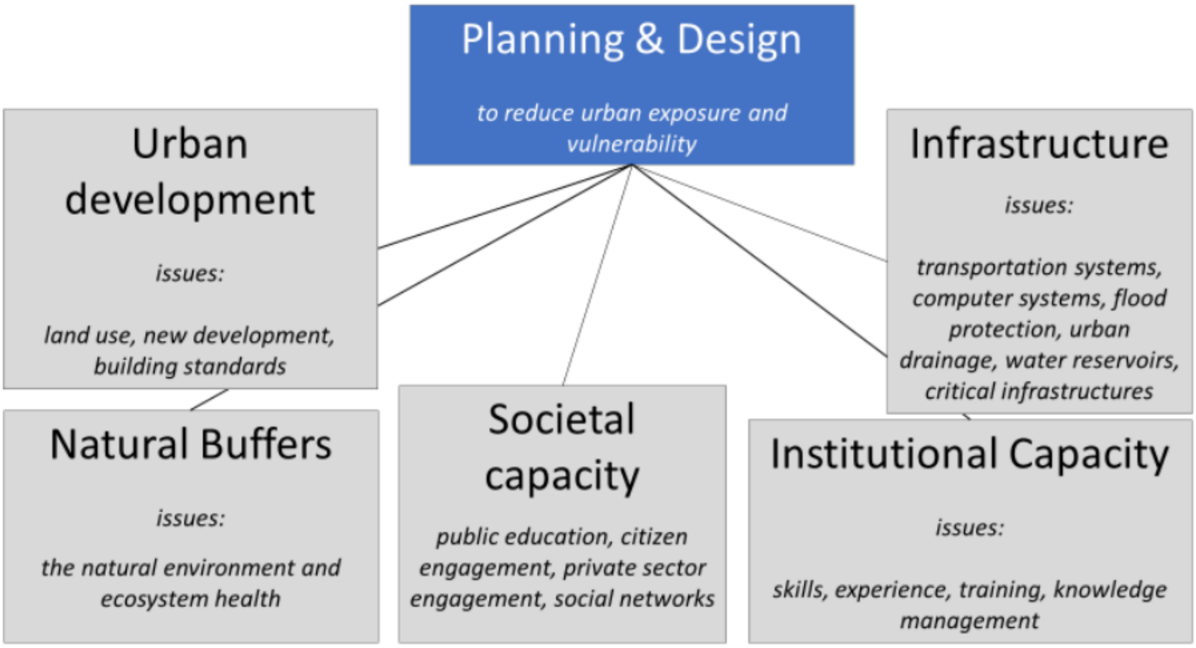

Figure 42 Planning & Design: Tiers 2 and 3 of the AHP Model for Community Resilience

It was also explained to him that the component 'natural buffers' referred to efforts to preserve the natural environment and ensure the health of ecosystems. Examples were provided of natural buffers that protect against the direct impact (or resulting cascading effects) of earthquakes, such as dunes and floodplains. They were told that the component 'societal capacity' covered things such as social networks, public education campaigns, citizen engagement and the engagement of the private sector. In addition, it was explained to them that the component 'institutional capacity' referred to the presence of skills, experience, training, knowledge and management capabilities of responsible authorities and organisations. Finally, the participant stakeholder was told that the component 'infrastructure' included items such as transportation systems, computer systems, flood protection, urban drainage, water reservoirs and (other) critical infrastructure. After this brief explanation, the stakeholder was asked to consider the impact of a (major) shortcoming in each of the five components of urban planning and design on community resilience. Making pairwise comparisons, they were asked what would be worse, a major shortcoming in component A, or a major shortcoming in component B. They were told that they could also say that this would be 'equally bad' or that they did not know. As this component required a pairwise comparison between five items, this part of the workshop was quite laborious.

In conclusion, the stakeholder ranked the importance of the five components of Planning & Design for Community Resilience as follows:

- Urban Development is considered to be equally important as Natural Buffers
- Urban Development is considered to be moderately less important than Institutional Capacity
- Urban Development is considered to significantly less important than Societal Capacity
- Urban Development is considered to be moderately less important than Infrastructure
- Natural Buffers are considered to be a lot more important than Institutional Capacity
- Natural Buffers are considered to be slightly more important than Societal Capacity
- Natural Buffers are considered to be equally important as Infrastructure
- Institutional Capacity is considered to be significantly less important than Societal Capacity
- Institutional Capacity is considered to be equally important as Infrastructure
- Societal Capacity is considered to be significantly more important than Infrastructure

The judgments resulting from the 13 pairwise comparisons were not internally consistent (consistency ratio 0.30) and resulted in the following priority vector.

Urban Development	0.0941
Natural Buffers	0.3075
Institutional Capacity	0.1064
Societal Capacity	0.3403
Infrastructure Resilience	0.1517

The internal inconsistency of the judgements is caused by the number of pairwise comparisons which might be results in a missed full understanding of each component.

8.4 Disaster Preparedness

The stakeholder was presented with a more detailed figure of the component 'disaster preparedness' (Figure 43, below). The ARU researcher asked the stakeholder to reflect on how the disaster preparedness of urban areas affects community resilience. They were told that research to date indicated that successful disaster preparedness for resilience depended on two interconnected parts: 1) preparedness for effective disaster response, and 2) preparedness to expedite recovery and build back better. For clarification, they were told that the component 'preparedness for disaster response' covered issues such as early warning, response planning, surge capacity, inter-agency working and drills. They were also told that the component 'preparedness to expedite recovery and build back better' included items such as recovery planning and learning.

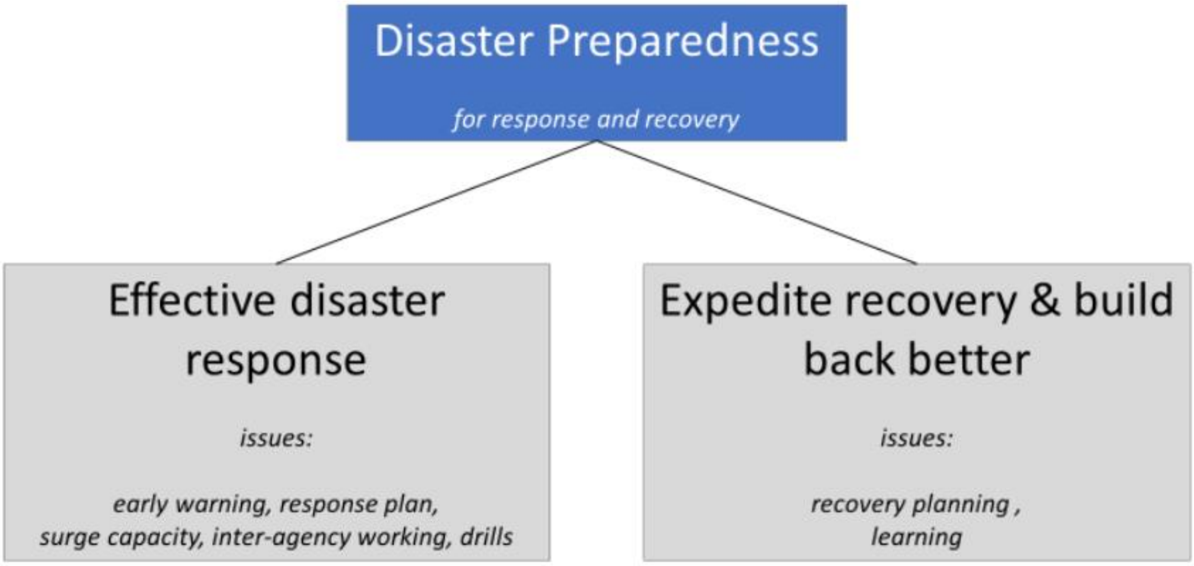

Figure 43 Disaster Preparedness: Tiers 2 and 3 of the AHP Model for Community Resilience

After this brief explanation, the stakeholder was asked to consider the impact of a (major) shortcoming in each of the two components of disaster preparedness on community resilience. Making a pairwise comparison, they were asked what would be worse, a major shortcoming in component A, or a major shortcoming in component B. They were told that they could also say that this would be 'equally bad' or that they did not know.
The stakeholder answer is

- Disaster Response is considered to be equally important as Expedite Recovery.

As there are only two sub-criteria, internal consistency is guaranteed and resulted in following priority vector:

Effective Disaster Response	0.5
Recovery and Build Back Better	0.5

8.5 The potential impact of TURNkey on community resilience

After the stakeholder had given their views on the relative importance of the different components of the AHP model for community resilience that the TURNkey team at ARU had developed, they were shown the latest version of the TURNkey platform on the basis of screenshots. The platform's various functionalities were explained to them. They were also asked to give their views on the civic protection use cases that had been developed during the preceding two PAR rounds with potential end-users of the TURNkey FWCR Platform. These findings are presented in the section 'Use Cases Civic Protection and First Responders'. After the stakeholder had been given this detailed explanation of the platform - and after the civic protection use cases had been discussed with them - they were asked to rate to what extent (if at all) the TURNkey FWCR Platform would contribute to community resilience, in their expert opinion. They were shown the AHP model for community resilience again (see Figure 40, above) and asked to rate, on a 1-5 Likert scale (e.g. 1 -"Definitely not", 2 - "Probably not", 3 - "Maybe", 4 - "Probably", 5 - "Definitely"), to what extent

TURNkey could boost the resilience of each of the tier 3 items. The ARU researchers emphasized that it was fine if their answer was 'not at all'. Please find below the results:

Criteria	Sub-Criteria	Impact of TURNkey	Impact Score	Weighted Score	Impact of TURNkey on Criteria
Governance	Planning & Organizing	High	0.66	0.42	0.60
	Risk Scenarios	High	0.66	0.07	
	Financial Capacity	Moderate	0.42	0.11	
Planning	Urban Development	High	0.66	0.06	0.50
	Natural Buffers	Moderate	0.42	0.13	
	Institutional Capacity	High	0.66	0.07	
	Societal Capacity	Moderate	0.42	0.14	
	Infrastructure Resilience	High	0.66	0.10	
Response	Disaster Response	High	0.66	0.33	0.66
	Expedite Recovery	High	0.66	0.33	
Impact on Community Resilience			0.55		

Table 18 TURNKey impact on community resilience based on AHP

The overall impact of the TURNkey FWCR platform with the community and civil proception calculated through the AHP model is 0.55, i.e. moderate to high positive impact. Thus, the implementation of the platform moderately-highly increases the community resilience.

Sub-Criteria	Impact of TURNkey	Justification
Planning & Organizing	High (0.66)	They said that they would use OEF to inform 'thinking' before a mainshock.
Risk Scenarios	High (0.66)	Simulations (regular and those informed by OEF) can be used by the stakeholder to inform planning.
Financial Capacity	Moderate (0.42)	TURNkey could inform budgeting/financing investment in urban resilience.

Urban Development	High (0.66)	The stakeholder clarified that urban planning, retrofitting (etc.) did not fall within their remit. However, they expressed the view that the local authority that was responsible for earthquake safety in the built environment would "definitely" run earthquake simulations, if they had the ability to do so, to analyze how areas and assets would be affected.
Natural Buffers	Moderate (0.42)	The stakeholder saw natural buffers as serving the same function as protective infrastructure. They believed that simulations could provide information on how natural assets would be affected.
Institutional Capacity	High (0.66)	TURNkey would contribute to the stakeholder's knowledge and skills in earthquake management.
Societal Capacity	Moderate (0.42)	They would use EEW to inform public communications. Often, citizens read about the earthquake on social media (Twitter) before the stakeholder has issued an official message. The stakeholder said that they believed that EEW could speed up this process.
Infrastructure Resilience	High (0.66)	They would use simulations informed by OEF to check the forecasted impact on vital infrastructures, such as gas and water. They would use regular simulations to assess the impact on critical and vulnerable infrastructure, including hospitals, schools and childcare facilities, to inform planning. They would forward EEW (main and aftershock) alerts to chemical plants and similar high danger assets. They believed that TURNkey would be useful for identifying priority infrastructure for monitoring and tracking their evolution over time, integrating the information provided by eyewitnesses.
Disaster Response	High (0.66)	They would use OEF to inform response preparations. They would use OEF for aftershocks to inform ongoing response efforts. They would run earthquake simulations to develop and revise their disaster response plans. They would use TURNkey to identify priority areas for intervention, assess the number of casualties and the type of medical assistance required; monitor the status of key response decisions, players and equipment
Expedite Recovery	High (0.66)	They would use EEW aftershock alerts to ensure first responders' and citizens' safety. First responders would use the 'I'm safe' function on the TURNkey app. Simulations could inform building back better.

Table 19 Impact of TURNkey on community resilience

9 Case Study Civil Protection

9.1 End-User Use Cases Civil Protection

During PAR cycles 1 and 2, a series of end-user use cases for the TURNkey FWCR Platform were developed for civil protection stakeholders, first responders, business organisations and critical infrastructure providers. The last rendition of these use cases is presented in Deliverable 2.8 (Jones et al., 2021). . As part of PAR cycle 3, these use cases were triangulated one final time. *How this research was carried out is described in the section PAR Cycle 3 – Data Collection.* This section presents the findings of the final round of PAR with a civil protection stakeholder. The main purpose of this research was to validate the AHP model for community resilience presented in Deliverable 5.2 (D'Ayala et al., 2020) . This stakeholder is a large organisation that employs around 300 members of staff as well as around 700 volunteers (primarily firefighters). It is responsible for regional disaster management and response in a Western European Country. An ARU researcher conducted PAR with staff responsible for earthquake management. The purpose of this final round of PAR is to validate the end-user use cases and to inform the development of the business models tools presented in this deliverable

9.2 Operational Earthquake Forecasting (for aftershocks)

After the civil protection stakeholder was presented with an overview of OEF, as provided by TURNkey, they were asked: "If your organisation had the ability to run probabilistic earthquake forecasts, how would it use this information (if at all)?"

The stakeholder responded that they would use OEF to inform response preparations. Specifically, they would check the forecasted impact on vital infrastructure, such as gas and water. They said that they would use OEF it to inform 'thinking' before a mainshock - and OEF for aftershocks to inform ongoing response efforts. They stated that, in their view, OEF is valuable for major earthquakes, but not for minor ones.

9.3 Earthquake Simulations

After the civil protection stakeholder was shown TURNkey's features for earthquake simulations, they were presented with two end-user use cases identified by NTC during PAR cycles 1 and 2 and asked to rate them on a Likert scale (1-5). They were asked: "If your organisation had the ability to run earthquake simulations, would it use that information to inform the following two mitigation-actions?" The scale of possible answers ranged from "definitely not" to definitely".

<u>Simulation Use Case 1: use simulations to analyze how areas and assets would be affected</u>

The stakeholder clarified that urban planning, retrofitting (etc.) did not fall within their remit. However, they expressed the view that the local authority that was responsible for earthquake safety in the built environment would "definitely" run earthquake simulations, if they had the ability to do so, to analyze how areas and assets would be affected.

<u>Simulation Use Case 2: use simulations to develop or revise disaster response plans</u>

The stakeholder noted that this did fall within their remit and that they would "definitely" run earthquake simulations, if they had the ability to do so, to develop and revise their disaster response plans.

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After the stakeholder had rated the existing use cases, they were asked: "If your organisation had the ability to run earthquake simulations, would it use that information to inform any other mitigation actions?"

The stakeholder said that they would use it to assess the impact on critical and vulnerable infrastructure, including hospitals, schools and childcare facilities, to inform planning.

9.4 Earthquake Early Warning

After the civil protection stakeholder was shown TURNkey's features for EEW, they were presented with four end-user use cases identified by NTC during PAR cycles 1 and 2 and asked to rate them on a Likert scale (1 -"Definitely not", 2 - "Probably not", 3 - "Maybe", 4 - "Probably", 5 - "Definitely"). They were asked: "If your organisation had the ability to receive early warning alerts for main shocks and aftershocks, would it use that information to inform the following four mitigation actions?" The scale of possible answers ranged from "definitely not" to definitely".

EEW Use Case 1: Use EEW aftershock alerts to ensure first responders' safety
The stakeholder said that they would "definitely" use EEW alerts for this purpose.

EEW Use Case 2: Use EEW aftershock alerts to ensure citizens' safety
The stakeholder said that they would "definitely" use EEW alerts for this purpose.

EEW Use Case 3: Forward EEW (main and aftershock) alerts to chemical plants and similar high danger assets
The stakeholder said that they would "definitely" use EEW alerts for this purpose.

EEW Use Case 4: On site responders use the 'I'm safe' function on the TURNkey app to notify their teams of their status.
The stakeholder said that they would "definitely" use EEW alerts for this purpose.

After the stakeholder had rated the existing use cases, they were asked: "If your organisation had the ability to receive early warning alerts for main shocks and aftershocks, would it use that information to inform any other mitigation actions?"

The stakeholder responded that they would use it for communication purposes. They explained that they currently receive earthquake alerts via text message from the relevant authority (the national institute for weather and seismology). They explained that they always have someone on call to receive such messages and initiate action. However, according to the stakeholder, this process is too slow. Often, citizens read about the earthquake on social media (Twitter) before the stakeholder has issued an official message. The stakeholder said that they believed that EEW could speed up this process. However, they made it clear that they did not want EEW to trigger any automated communications directed at the public.

9.5 Rapid Response to Earthquakes

After the civil protection stakeholder was shown TURNkey's features for RRE, they were presented with six end-user use cases identified by NTC during PAR cycles 1 and 2 and asked to rate them on a Likert scale (1-5). They were asked: "If your organisation had access to the rapid response dashboard, would it use that information to inform the following response actions?" The scale of possible answers ranged from "definitely not" to definitely".

RRE Use Case 1: Identify priority areas for intervention
The stakeholder said that they would "definitely" use the RRE dashboard for this purpose.

RRE Use Case 2: Identify priority infrastructure for monitoring
The stakeholder clarified that engineering, structural health monitoring, repairs (etc.) did not fall within their remit. However, they expressed the view that the local authority that was responsible for earthquake safety in the built environment would "definitely" use the RRE dashboard for this purpose.

RRE Use Case 3: Monitor the status of vulnerable buildings and their evolution over time
The stakeholder clarified that engineering, structural health monitoring, repairs (etc.) did not fall within their remit. However, they expressed the view that the local authority that was responsible for earthquake safety in the built environment would "definitely" use the RRE dashboard for this purpose.

RRE Use Case 4: Assess the number of casualties and the type of medical assistance required
The stakeholder said that they would "definitely" use the RRE dashboard for this purpose.

RRE Use Case 5: Monitor the status of key SAR decisions, players and equipment.
The stakeholder clarified that urban search and rescue (USAR) did not fall within their remit. However, they expressed the view that the national USAR team would "definitely" use the RRE dashboard for this purpose.

RRE Use Case 6: Integrate SAR team verifications of assets' damage status
The stakeholder clarified that urban search and rescue (USAR) did not fall within their remit. However, they expressed the view that the national USAR team would "definitely" use the RRE dashboard for this purpose.

After the stakeholder had rated the existing use cases, they were asked: "If your organisation had access to the rapid response dashboard, would it use that information to inform any other response actions?"

The stakeholder noted that it would be helpful if the different organisations responsible for earthquake management in the region (i.e., civic protection, the local authority that responsible for earthquake safety in the built environment, USAR) could coordinate their efforts via TURNkey. They explained that all disaster management organisations in the country have access to one integrated disaster information platform. As such, they expressed the view that it would be valuable if TURNkey could be integrated into that existing system.

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9.6 *Specific needs of communities to plan for and manage seismic events*

The findings of PAR Cycle 3 validate the end-user use cases developed during PAR Cycles 1 and 2, which were published in Deliverable 2.8 (Jones et al., 2021). TURNkey was found to be helpful in supporting civil protection and first responders' efforts to 1) prevent damage; 2) respond on time and accurately; and 3) prioritisation, resource allocation and coordination.

Use Case	Actions	TURNkey features	AHP metrics
To prevent damage	Use simulations (informed by OEF) to assess forecasted impact on critical infrastructure Use simulations to analyze how areas and assets would be affected Use simulations to develop or revise disaster response plans	OEF, Simulations	Risk Scenarios Urban Development Natural Buffers Institutional Capacity Infrastructure Resilience
To enable a more timely and accurate response	Use EEW aftershock alerts to ensure first responders' safety Use EEW aftershock alerts to ensure citizens' safety Forward EEW alerts (main shock and aftershock) to high danger infrastructure Use RRE (ShakeMaps) to identify priority areas for intervention Use RRE (ShakeMaps) to identify priority infrastructure for monitoring	EEW, RRE (ShakeMaps)	Societal Capacity Infrastructure Resilience Planning and Organizing Institutional Capacity Disaster Response
To support prioritisation, resource allocation and coordination	On site responders use the "I'm safe" function on their TURNkey app	RRE (TURNkey smartphone app + dashboard)	Planning and Organizing

	to notify their teams of their status Use RRE (dashboard) to monitor the status of vulnerable buildings and their evolution over time Use RRE (dashboard) to monitor the status of key SAR decisions, players and equipment Use RRE (TURNkey app + dashboard) to integrate SAR team verifications of assets' damage status Use RRE (dashboard) to assess the number of casualties and the type of medical assistance required.		Institutional Capacity Disaster Response Expedite Recovery

Table 20 The connection between use cases, TURNkey features and AHP metrics - for community resilience.

10 Model BCP and RP and DMP framework

10.1 TURNkey FWCR platform integration in BCP and DMP framework

The experience of other countries presented in the section *"Plan for and survive to seismic events: experience in other countries"* indicates EEW systems and RRE systems had been successfully integrated into national and local or organisational DMP. The same section highlights EEW are issued through special receivers (for example in Mexico) or broadcasted through radio and television (for example in Japan, USA and Mexico) or mobile phone app (Japan and USA). Following the EEW, emergency procedure described in BCP and DMP are activated.in infrastructure and businesses. The experience of other countries earlier described, in particular Japan and USA, demonstrates the willingness of businesses and critical infrastructure to use services based on OEF to increase their alert level without stopping their services or production. TURNkey Deliverable 1.2 (Jones & Morga, 2019) also pointed out how mobile apps and customized mobile apps that provide OEF and EEW alerts are a business opportunity.

The general legal framework that led to the current international standards for BCP and disaster management is presented in Section "*Planning for organisation resilience"*, while Section "*Business Continuity and Disaster Management Planning: ISO 22316"* focuses on the preparation process of BCP according to ISO 22316 (2020). In that TURNkey FWCR Platform functions are mapped against that international standard for BCP and the needs for RP and DMP. The results of the PAR cycle 3 in terms of enhanced resilience for businesses, CI and communities measured by AHP models indicates the platform would have a positive impact on all society sectors. Finally, the specific use cases indicate that TURNkey FWCR Platform could support the BCP, DMP and RP at business, CI and community level.

Those findings suggest that TURNkey FWCR Platform features can be integrated in the BCP, DMP and RP at the different society level. Figure 44 summarizes how each TURNkey FWCR platform feature can be integrated in Business Continuity, Disaster Management and Resilience planning process.
The 5 steps of the process to prepare the BCP and DMP proposed in the framework in Figure 44 are similar to the steps to prepare the BCP proposed by Ready (Ready, 2021)), the USA federal campaign to educate and empower the population safety. The campaign proposes four steps to the definition of the BCP: 1) Business Impact Analysis (BIA), 2) Recovery Strategies, Plan Development, Testing & Exercise. The BIA of the Ready campaign is equivalent to the "Pre-earthquake Planning and Coordination" and "Analyze Hazard Threat" steps of the framework in Figure 44, and part of the step "Assess Business Impact and Mitigation Option". The BIA is the first phase of the preparation of a BCP according to ISO22301: 2019 (2019). The "Plan development" of the Ready campaign includes to the mitigation planning activity of the steps "Assess Business Impact and Mitigation" **Feil! Bokmerke er ikke definert.**and "Develop Emergency Management and Recovery Plans" of the framework proposed in Figure 44. Finally, "Testing and Exercises" phase of the campaign Ready is equivalent to the step "Implement and Maintain Plans" of the framework proposed here.

In light of requirements of ISO22301 (2019) and ISO 22316 (2017) for the BCP and the framework proposed to integrate the TURNkey FWCR Platform in Business Continuity, Disaster Management and Resilience Planning (see Figure 44), a model BCP is proposed in the following subsection.

10.2 Model BCP with integrated TURNkey FWCR platform features

10.2.1 Definition of disaster management and emergency planning team

The CEO or the executive board of director of the organisation appoints the members of the business continuity planning team.
The owners of small businesses can appoint external experts; while large organisations can opt for senior managers such as chief engineer, risk manager, built asset manager etc.. working in the organisation. The names of this team members can be stored in the TURNkey FWCR Platform.
The team meets and prepares a BIA questionnaire.

10.2.2 Preparation of the BIA questionnaire

The BIA questionnaire asks to identify threats to the organisation. For each threat, the questionnaire is used to assess the hazard intensity, its impact on the organisation physical assets, the operations it might affect, the impact on organisation finances, and the losses in terms of number of causalities and injuries it causes.

10.2.3 Administration of the BIA questionnaire

The BIA questionnaire should be filled in by organisation department managers or hired external experts in large organisations; small organisations can opt for the most knowledgeable person working for them or use an external expert. The

The TURNkey FWCR Platform can be used to assess the hazard intensity to which the organisation's physical assets might be exposed with a given return time and losses. The platform simulation features can be used to assess the probable damage to the organisation's physical assets and estimate losses based on earthquake scenarios.

10.2.4 BIA questionnaire analysis

The results of the BIA questionnaire are analyzed by the planning team, which defines the priorities and identifies the criticalities. Then the planning team defines long-term and short-term options.

The TURNkey FWCR Platform simulation feature can be used to estimate the reduction of fragility of the organisation's physical asset and losses due to strengthening interventions proposed by the planning team or the BIA questionnaire respondents. The platform can store this information. Then the planning team estimates the resources needed for the recovery after an earthquake. These include human resources, equipment, technology, raw materials, utilities and third-party services (DHS, 2022). This estimate also includes the time needed to access the resources in case they are damaged or lost during the earthquake. These details can be stored by the TURNkey FWCR Platform.

10.2.5 BCP and emergency plan preparation

The planning team must develop a plan to recover the resources lost during an earthquake. This includes definition of alternative supply chains; development of a relocation plan, if it is possible; planning for a redundant copy of digital and physical data; planning raw materials stocks lasting for the time the supply chain might be out of service or a new supplier is identified. Finally, the members of the EOC must be appointed. These data must be included in the BCP, which can be stored by the TURNkey FWCR Platform. Moreover, the platform can store pre-set communications to send to customers if a disruption in the production or service delivery occurs after an earthquake. The platform can send these messages automatically after an early estimate of the damage is assessed through the simulation feature of the platform. In case services and equipment in the physical asset of the organisations supports automatic or manual triggered shut off function, the BCP can include the shut-off procedure and the reactivation procedure after the earthquake. The TURNkey FWCR Platform has an EEW feature which can be integrated with automatic shut off systems.

The emergency plan includes appointment of the emergency team; preparation of emergency procedure/ rescue; writing of pre-set communications to send to first responders to trigger RRE actions. The TURNkey FWCR Platform can store contacts of the emergency team members and emergency procedures. The platform can also send the pre-set massages to first responders.

10.2.6 Exercises and training

BCP and emergency plan must be tested, and emergency and EOC team must be appropriately trained, and periodic exercises must be run. The TURNkey FWCR Platform can be used to simulate an early warning during the periodic exercises.

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A Framework to integrate the TURNkey FWCR Platform in Business Continuity, Disaster Management and Resilience Planning

BCP / DMP Process		TURNkey Role
Pre-earthquake Planning / Coordination	Details of the disaster management and emergency planning team can be entered into TURNkey, along with details of their roles before, during and after an earthquake. Contact details of key internal and external contacts can also be entered along with pre-written communications (e.g., email, social media etc.) that will be sent when an earthquake occurs. Final working versions of the Disaster / Emergency Management and Business Continuity Plans can also be uploaded.	Coordination
Analsye Hazard Threat	Details of the organisations built assets (physical, operational and economic) can be entered into TURNkey and earthquake simulations can be run to assess the potential impact that a range of earthquake scenarios could have across a city/region and on individual buildings or the organisation's building portfolio. The outputs (PGA and damage level) can be used by the organisation to assess the general level of hazard threat.	Simulation and OEF features
Assess Business Impact and Mitigation Options	The earthquake simulations will also generate estimated damage states and loss metrics that can be used as inputs to assess the potential impact that an earthquake could have on the organisations functional performance. If the impact or losses are considered unmanageable then generic mitigation options can be evaluated by changing the built assets physical characterises. If the impacts are deemed manageable then disaster / emergency management and business continuity mitigations can be developed.	Simulations and post shaking data collection for identify Damage States and Loss Metrics
Develop Emergency Management and Recovery Plans	If the organisation has integrated TURNkey's EEW function into its disaster / emergency management plans it will receive an alert if an earthquake is detected and it is expected to exceed an pre-defined magnitude. The alert can be used to warn building occupants to prepare for ground shaking and if appropriate initiate auto-shut down or 'safe-mode' for critical systems. TURNkey's RRE functions can be used to coordinate and manage the short-term recovery process, including monitoring for after shocks and issuing warning alerts.	EEW, RRE also for Recovery Coordination
Implement and Maintain Plans	As business and critical infrastructure providers will be secondary users of the TURNkey FWCR Platform they will be part of an integrated community of users (i.e., other similar organisations, civil protection and first responders) and as such will be able to benefit from regional (or national) earthquake simulation exercises where they can test their business continuity and disaster /emergency management plans and refine them in rsponse to any observed failures or weaknesses.	Training Simulations

Figure 44Framework to integrate the TURNkey Platform in Business Continuity and Disaster Management Planning

11 Cost Benefit Analysis

11.1 Introduction

This section provides an overview of the Cost Benefit Analysis (CBA) technique and detailed explanations of how CBA could be used together with the data and information provided by the TURNKey FWCR Platform to evaluate a range of earthquake risk reduction interventions.

CBA is a comprehensive process that requires significant time and effort. Therefore, it is recommended that organisations use this and similar guidance to perform antecedent CBAs for a range of possible disaster risk reduction interventions to identify beneficial interventions that could be integrated within their disaster management and business continuity plans.

In addition, the last part of this section provides guidance on estimating the cost of implementing and maintaining the TURNKey FWCR Platform and the infrastructure supporting the platform. If a region decided to implement the TURNKey FWCR Platform, a bespoke cost estimate would need to be developed based on a customised technical implementation plan that reflects the specific context of the region.

11.2 Overview of CBA

Various types of interventions to built environments, their contents and operations could reduce the impact and resultant losses from earthquakes. Whilst interventions such as structural retrofitting or implementation of early warning systems involve long lead times, other interventions to the building's contents (e.g., fixing water heater to a wall) and operations (e.g., shut down sensitive equipment, initiate automatic back up of data) could be accomplished with relatively short lead times. Those interventions which are deemed as cost-effective through the use of a CBA could be integrated into an organisation's disaster management and business continuity plans.

Different types of intervention require different levels of resource (cost) and result in different levels of benefit (reduced losses). Whilst the cost occurs when the intervention or action is taken, benefits are only realised if a destructive earthquake occurs. Therefore, a systematic approach such as CBA could help organisations appraise a range of risk reduction interventions as part of their disaster management and business continuity planning.
CBA refers to a major and well-recognised option appraisal technique to compare the costs and resultant benefits of alternative development/mitigation interventions assessed over their lifetime. It involves estimating the costs of undertaking and maintaining the development/mitigation intervention and comparing these to the benefits offered by such interventions over their economic life. Costs and benefits are estimated using a common financial currency (such as €, $, and £) and discounted to a Net Present Value (NPV) using a suitable discount rate. The discounted benefit to cost ratio (B/C) provides an indicator that can be used to help inform the business decision on whether a development/mitigation intervention should be funded or not. A B/C ratio greater than one suggests a net beneficial impact to the business. The higher the B/C ratio, the more beneficial the intervention is expected to be. Estimating costs associated with implementing and maintaining interventions are easier than estimating the benefits (Moench, et al., 2007). Costs can be estimated through quotations provided by specialist organisations implementing such solutions; be based on published cost data; or on the knowledge of in-house cost consultants'. Maintenance costs can be

estimated from historic data for similar projects and/or manufacturers' literature. A range of valuation methods could be used to estimate the monetary value of tangible and non-tangible benefits offered by different interventions. Wanigarathna et al (2018) describes 3 approaches (the market approach; the income approach; and the cost approach) to estimate the monetary value of tangible benefits or products based on guidance from the International Valuation Standards Council (IVSC). Wanigarathna et al (ibid.) also described 3 broad approaches that can be used to monetise non-tangible benefits. They include revealed preference approaches; stated preference approaches; and subjective well-being approach/life satisfaction approach.

CBA has been widely applied to evaluate disaster risk mitigation interventions to assess the financial viability and potential returns on investment before the interventions are implemented (Mechler, 2016). In disaster mitigation CBA costs refer to the costs of planning, designing, implementing, and maintaining the interventions and benefits refer to avoided potential losses of implementing such interventions. A revealed preference-based method known as 'damage cost avoided' is used to estimate benefits of interventions. For example, in the case of technical interventions such as structural retrofitting, the avoided damage cost is the repair costs required to reinstate the damaged buildings to their pre-disaster status (Ramirez et al., 2012). Avoided losses in the broader term should also cover direct economic losses (such as damage to building, infrastructure, and business interruption), environmental losses (damage to watercourses, eco systems and habitats), social losses (deaths and injuries, increase in crime, family violence etc), and heritage losses (such as damage to cultural, historic and world heritage assets) (De Grove et al., 2015). However, due to difficulties associated with evaluating the monetary value of these benefits, many CBA investigations only assess benefits accrued through avoided damage to buildings / contents and avoided deaths and injuries (Wanigarathna, et al., 2022). Cost of designing, implementing and maintaining interventions are often based on local knowledge from those who provide intervention solutions or from market literature (ibid.). Exemplar applications of including well thought through maintenance costs of interventions are limited. Kappos and Dimitrakopoulos (2008) for example considered a simple assumed value for operation and maintenance costs per year for both buildings and the mitigation interventions. Operating cost of a built asset over its life include costs associated with necessary repair and refurbishment, regular services and maintenance, utilities costs if applicable (such as energy, water), and disposal costs. Since operating and maintenance costs are substantially higher compared to capital costs (Hughes et al., 2004), not including these within economic appraisal may provide an inaccurate basis for decision making.

Few scholars (Wethli 2014; Hawley et al. 2012; Mechler 2005; Mechler 2016) have reviewed applications of CBA for disaster mitigation intervention appraisal. Wethli's (2014) review concluded that previous studies show mean benefit to cost ratios of 3.1, 11.1 and 5.1 for interventions designed to mitigate earthquakes, floods and tropical storm risks respectively. Mechler (2016) by reviewing 52 benefit cost studies across a range of disasters, concluded that disaster risk mitigation investments in general (39 out of 52) would lead to a B/C ratio of close to 4 (3.7). Whilst, CBA has been widely used to evaluate technical interventions (such as structural improvements to buildings) where costs and benefits are easy to assess, the application of CBA to evaluate operational interventions is comparatively limited.

The next sections of the report explain how CBA could be used to evaluate a range of risk reduction interventions based on the data and information generated by the TURNkey FWCR platform.

11.3 CBA to evaluate interventions derived through simulations

One of the key functions of the TUNRkey FWCR Platform is earthquake simulation. This function allows the user to model the potential impact of a range of earthquake scenarios on their organisation as part of their preparations for future earthquake disasters. Users define scenarios by setting values for parameters such as the magnitude, location, depth and fault mechanism for a potential earthquake. They could then input data related to the characteristics of their assets and operations, to enable the software platforms to perform simulations to predict damage and losses (such as damage to physical assets, death or injuries, functional performance).

Data and results generated through the earthquake simulation function of the TURNkey FWCR Platform could be used to identify the need for interventions and appraise a range of mitigations to reduce the potential impact of an earthquake on the organisation. Such simulations could be beneficial in identifying long-term risk reduction interventions such as structural retrofitting or changes to business, operational or production models to improve the resilience of assets and operations.

11.3.1 Simulation of technical interventions and appraisal

In a disaster risk mitigation intervention appraisal context, CBA is predominantly used to evaluate technical interventions such as structural retrofitting of buildings. Methodological details of the application of CBA for structural retrofitting is well reported. Various authors have provided exemplar applications of CBA to evaluate risk mitigation interventions applied to individual buildings. For example, Paxton et al (2015) explained how CBA could be used to evaluate three retrofitting options (Parapet bracing, Partial retrofit, and Full retrofit) using a hypothetical two-storey building in downtown Victoria. Smyth et al (2004) explained how CBA could be used to evaluate three retrofitting options (bracing, partial retrofitting shear walls, full retrofitting sheer walls) using a real 5 story concrete frame building located in Caddebostan, Turkey. Cardone et al (2019) evaluated two structural retrofitting options (strengthening of infills and partitions, and seismic isolation technique) applied to three archetype reinforced concrete frame residential buildings typical for Italy.

Application of CBA to evaluate large building stocks is also reported. For example, Leil and Deierlein (2013) explained how CBA could be applied to evaluate retrofitting a stock of older concrete frame buildings in Los Angeles. Authors evaluated the benefit to cost ratio for 6 retrofitting options. Kappos and Dimitrakopoulos (2008), demonstrated how CBA could be applied to retrofitting a region by modelling a stock of old (low-code) reinforce concrete buildings in Thessaloniki Greece. Authors evaluated three retrofit levels (Not retrofit, retrofit level 1, retrofit level 2). Calculations and the CBA approach used during these examples are similar to the building level CBAs. Cost of retrofitting individual buildings and benefits (loss avoided) resulting from retrofitting individual buildings are aggregated to calculate costs and benefits for a large building stock across a region.

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The following sub-sections further explain how costs and benefits could be estimated for technical interventions with the aid of the simulation function of the TUNRkey FWCR platform.

11.3.1.1 Cost analyses for technical interventions

Many previous examples have computed the cost of interventions primarily based on the cost of the intervention itself. Costs associated with background planning and evaluation works or the cost of facilitators such as cost of conducting a structural survey to assess the need for intervention/retrofitting or the cost associated with engineering modelling of the damage and losses before and after retrofit scenarios were often omitted from the CBA calculations. Table 21 provides cost estimating guidance for a wide range of cost constituents for commissioning an intervention based on the RICS NRM 1 guidance for Order of Cost Estimating and Cost Planning.

Cost component	Estimating method
Cost of feasibility study This will involve surveying the status of structural vulnerability, development of retrofitting alternatives, and assessment of improved vulnerability status for key retrofitting options	Survey of the building to determine the vulnerability – End users may have some of these available (in this case the cost is 0), if these details are not available end users need to commission a building surveyor. The cost of the surveyor could be identified by inviting quotations. Based on local market knowledge, it could be expected that such a survey could cost £1000 per small scale building and about £5000 for a large mid-rise building to conduct such a survey in the UK. End users may identify the cost of the survey based on their local knowledge. Assessment of the ex-ante damage and loss level – Provided by the TURNkey simulation function Assessment of reduced damage and loss levels following potential interventions - Provided by the TURNkey simulation function (Note - A proportion of the overhead cost of implementing and maintaining the TURNkey software over the economic life of the estate may need to be considered as a cost. See Section 11.7 (Cost of implementation and maintenance of the TURNkey FWCR platform for the overhead costs associated with implementing, maintaining and operating the TURNkey platform).
Facilitating works estimate This involves the cost of preparatory work required to facilitate the main work (such as temporary diversion of roads, temporary evacuation of buildings)	The cost of temporary evacuation of the building (full or partial) could be estimated based on local rental rates for short term relocation, mobilising and demobilising costs for equipment (see example and guidance in Erdurmus 2005). Any other facilitating work cost could be identified by inviting specialists' quotations.
Main retrofitting cost estimate This includes cost paid to a builder to conduct the retrofitting including preliminaries costs such as builder's accommodation, supervision, utilities use during the retrofitting period, and builder's overhead and profit.	A precise cost estimate would be provided by the builder or specialist contractor as a quotation based on the design and specification information. In antecedent assessments, an approximate estimate could be developed based on: - published cost data or historic project costs (Leil and Deierlein 2013), - approximate quotations gathered through local builders (Smyths et al., 2004), or - by building up the cost based on resource requirements such as supervision and labour, material and plant resources (Martins 2018). For example, Leil and Deierlein (2013) assumed that the cost of retrofitting concrete frame buildings on a site with very high seismicity would ranges between \$35/ft2 and \$70/ft2 (2006, Los Angeles price levels in US dollars). Historic data will need to be adjusted for inflation and location based on cost indices. Expert knowledge is required to adjust rates for other building specific factors. These rates could then be multiplied by the gross internal floor area of the building to estimate the total cost required for the building works. These estimates or information will not be provided by the TURNkey FWCR platform, However, the site-specific exposure excel (see Deliverable 2.6) may contain some useful information.

Design fees This involves cost associated with designing the retrofitting solution (structural and/or MEP engineer's fee) and the cost of the other consultants involve during the design and construction phase on behalf of the client (e.g. cost consultant to evaluate payments) or local authorities.	Design fees could often be estimated as a % of the building works estimate (retrofitting in this case) explained in the previous step. Structural engineer's fee for small scale projects is around 2.5- 2.9 % of the building works estimate (2019, outer London price level – source, AECOM, 2019). Services engineer's fee for small scale projects is around 2.0- 2.6 % of the building works estimate (2019, outer London price level – source, AECOM, 2019). The input table for site-specific exposure partially account for this
Other development costs	Cost of finance and any other cost not considered above need to be added here.
Risk estimate A contingency is normally added to accommodate the changes made to the design and construction, and to cover other weaknesses of the estimate.	Whilst typical construction projects assume about 5% (of the building works cost) design related risk and 10% (of the building works cost) construction related risk. Refurbishment projects (including retrofitting) need to be allowed for higher level of risk estimates to accommodate unforeseen situations due to lack of understanding about the features, design and nature of existing buildings. The input table for site-specific exposure partially account for this
Inflation estimate This allowance would cover the changes to the construction prices during the design and construction period after the original estimate.	Published Inflation indices or construction cost indices could be used to estimate this cost constituent. These indices are often published quarterly and can be accessed free of cost. The input table for site-specific exposure partially account for this
Maintenance cost estimate Certain interventions may need maintenance, checks or repairs.	Kappos and Dimitrakopoulos (2008) for example have considered a simple assumed value of operation and maintenance costs per year for the buildings and interventions they have selected. In-house knowledge on cost spent towards the maintenance and operation of existing buildings could be used identify the repair and maintenance costs for new elements and equipment added during the retrofitting. The input table for site-specific exposure partially account for this

Table 21 Cost estimate for technical interventions

11.3.1.2 Benefit estimation for technical interventions

Direct benefit - Avoided property damage

Technical interventions could reduce the direct damage to property in case of an earthquake event. Therefore, direct benefit of the intervention is equivalent to the difference between antecedent damage level before the intervention is implemented and the reduced damage level after the interventions are implemented. The TURNkey FWCR Platform provides an estimate of the damage grade for buildings and equivalent economic losses based on the data provided by the end user during the software configuration. In particular, end users need to provide characteristics about each of their buildings (e.g., floor area, number of stories, frame material) and the construction cost per floor area (m2) rate and total replacement cost for each building in order to calculate the economic loss. See the TURNkey Deliverable 6.6 (Huang et al., 2022) for a full list of data required to perform earthquake simulations. Simulations could be performed with antecedent building conditions initially and then repeated for improved building conditions to establish damage levels and economic losses before and after the intervention. The difference in the damage and loss values is equivalent to the direct benefit of the intervention simulated[1].

Avoided non-structural damage - Earthquakes cause damage to non-structural components within the buildings. Any element or component that does not form part of the structural system is called a non-structural element or component. They may include MEP systems, windows, partitions, ceilings, etc… In many instances, non-structural failures have accounted for the majority of earthquake damage (FEMA, 2012). the TURNkey FWCR Platform estimate non-structural damage assume they behave as same as structural elements when exposed to a shock. Further, damage to non-structural elements are not provided to the end users. Therefore, end users need to calculate the reduction of damage and equivalent loss (benefits) associated with non-structural damage.

Published data may provide some indication and guidance to calculate damage costs of non-structural components within buildings. For example FEMA P-58 guidance (2012) provides indicative estimates for components and contents that are likely to present within a square foot (of the floor area) for few key selected buildings such as commercial offices, educational facilities, healthcare buildings, etc.. However, bespoke estimates would be more accurate than generic values. For example, Di Ludovico et al (2020) analysing the repair cost data for the 2009 earthquake in L'Aquila, Italy reported that the majority of earthquake repair costs were related to the repair of infill partitions. Therefore, in the Mediterranean regions, repairs to plumbing and electrical systems integrated with infill partitions and windows, doors and other enclosure systems could represent 81%–89% of the total building repair costs. In addition,

[1] **Replacement cost** could be identified using in-house knowledge, local market knowledge or published construction prices. For instance, replacement cost for an acute services hospital in the UK could range from £3350 -£4500 per m2 of floor area **(**2022, outer London price levels – Source: ARCADIS, 2022). These are equivalent to €2385 - €3175 for Amsterdam, €1860- €2480 for Bucharest, €1670 - €2225 for Porto, and €1550 - €2065 for Valencia. (These are converted average construction prices based on International Construction Cost Index, 2022 by ARCADIS and XE currency conversion). Total replacement cost could be calculated by multiplying cost/per m2 rate by total gross internal floor area of the building. Local market knowledge could provide more accurate prices reflecting building characteristics and local market conditions.

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special buildings such as hospitals may have extra equipment integrated within them that may be damaged during earthquakes.

Avoided damage to contents - This is often estimated by multiplying the total value of contents within the buildings by a content damage factor for each damage state. It is fair to assume that organisations would calculate the value of their contents for various purposes such as accounting, inventory or insurance.

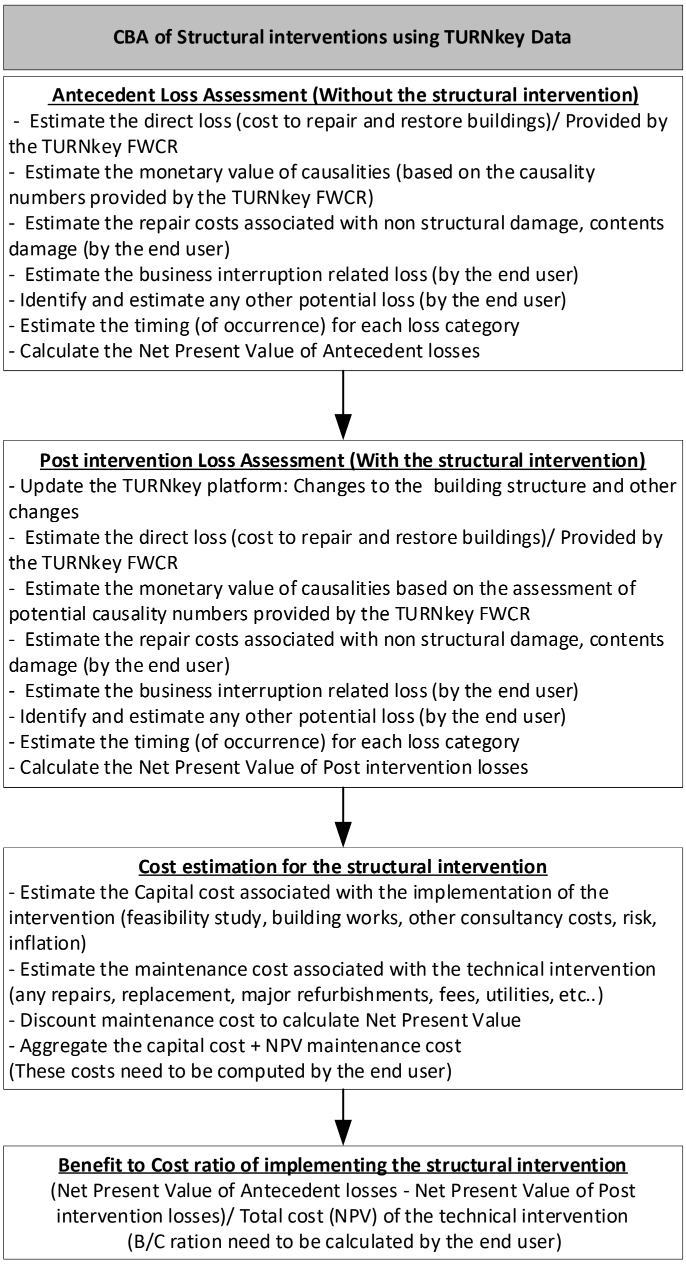

Figure 45 CBA steps for evaluating structural retrofitting interventions

Figure 45 summaries the steps of conducting a CBA to evaluate technical interventions such as structural

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Other considerations

In addition risk mitigation, interventions also provide benefits such as reduction in (people) displacements, emergency management costs etc.. These could be accounted within the benefit estimate if historic data is available from similar contexts.

Social benefit - Avoided deaths and injuries

By reducing property damage, technical interventions could consequently reduce deaths and injuries to the people occupying those buildings. Based on the building occupancy details (such as Occupants Per Asset during Day, Occupants Per Asset during night, occupancy classes) and building characteristics provided by end users, the TURNkey FWCR Platform provides an estimate of the expected causalities on a scale of SL0 (no injuries), SL1 (light injuries), SL2 (injuries requiring hospitalisation), SL3 (life threatening injuries), SL4 (death). Simulations performed with the antecedent building conditions and then repeated for improved building conditions would establish causality levels before and after an intervention. These causality numbers could then be multiplied by equivalent monetary values (see below) to estimate the total social loss related to deaths and injuries. The difference between the antecedent loss and the reduced loss following the technical intervention is considered as the social benefit[2].

In addition, end users may consider manually adding other social benefits such as reduction in mental health issues. FEMA BCA guidance (2019) value disaster related mental stress and anxiety at USD 2,443/ person and loss of productivity at USD 8,736/ person.

Reduction in Business Interruption

Assessment of business interruption due to earthquakes is complicated. In addition to the impact of damaged buildings, businesses could be affected by many other factors such as damage to neighbouring buildings (Chang and Falit-Baiamonte, 2002; Seville et al., 2014b), disruption to lifelines (Whitman et al., 2013), disruption to supply chain (Mayer et al., 2008; Zhang et al., 2009, Domandy et al, 2019), risk mitigation tactics implemented by business owners (Rose and Huyck 2016; Domandy et al., 2019), other conditions that prevail during the response and recovery period (Cremen et al., 2020).

The TURNkey FWCR platform can provide the estimates of the functionality level for essential facilities and critical infrastructures or the user can update their estimated downtime for general buildings, essential facilities and critical infrastructures into the turnkey database . However, potential damage estimates to buildings, infrastructure and estimated causality numbers provided by the TURNkey FWCR Platform could assist estimating the business interruption.

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[2] The number of avoided deaths and injuries are converted into monetary losses based on suitable monetary values. They could be identified from the sources such as court judgements related to damages paid for loss of life or injuries, earning potential of individuals or per capita income of the country. For example, Leil and Deierlein (2013) assumed an implied costs per life saved of between $4 and $6 million per life (for Los Angeles in USD). FEMA CBA guidance (FEMA, 2009) provides indicative values of $6.6 million per death, $5.032 million per critical injured person, and $13,000 per minor injured person. Wethli (2014) used a range of values between $1000 and $5000 based on the Copenhagen Consensus for the value of human life per disability adjusted life year (DALY).

Simplified approach – Based on a simplified coefficients-based approach, end users could establish an approximate value for the business interruption due to a disaster. During this approach, end users first establish coefficients or percentages for the potential business interruption in relation to the key building damage status categories. For example, end users may assume that if all the buildings have collapsed (the damage status), then the business will be interrupted 100% (the coefficient for the collapsed damaged status). The total value of the business could then be multiplied by the respective business interruption coefficient to assess the monetary value of the business interruption. Meslem et al (2021) used this approach within their computational platform to assess liquefaction-induced losses. Authors (ibid.) used mean loss ratios for key damage status multiplied with the total monetary value of the business to compute the business interruption losses. Whilst rapid loss assessment software may come up with default values for mean loss ratio for businesses, bespoke values developed for organisations may increase the accuracy of simplified estimates.

Detailed approach - End users can also use the building damage and causality numbers provided by the TURNkey FWCR Platform to estimate a detailed and more accurate business interruption estimates.
The majority of existing guidance related to business interruption following disasters use business down time modelling as the basis for calculating business interruption. Some recent work has considered relocation time and building repair times (Cutfield et al 2016), and impact of risk mitigation tactics implemented by business owners in reducing down time and overall business interruption (Rose and Huyck 2016; Domandy et al., 2019) within their analyses.

The REDi™ Rating System developed by Almufti and Willford (2014) provides a detailed list of factors causing downtime and impeding recovery times together with a downtime assessment methodology. This method first assigns Repair Classes for building components exposed to key damage states. These data are then used to calculate down times associated with re-occupancy, functional recovery, or full recovery. In order to support existing downtime assessment frameworks (such as REDi) Almufti et al. (2016) later developed a survey tool to gather comprehensive data related to the primary contributors for business interruption, downtime, and recovery, based on the data from the 2014 South Napa Earthquake. Kajitani and Tatano (2014) developed an analytical framework for estimating industrial production capacity loss considering the facility recovery times and lifeline disruptions. By investigating the business interruption following the Christchurch Earthquake Sequence in 2012, Cremen et al (2019) developed a comprehensive framework to estimate business downtime based on a range of internal and external factors (see Figure 46).

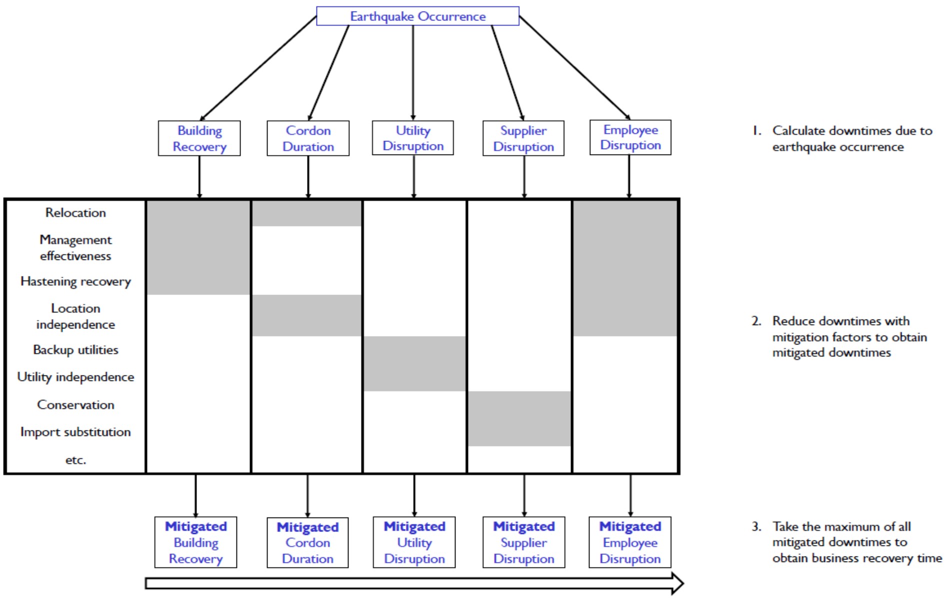

Figure 46 Business down time modelling following disasters (Source Cremen et al., 2019)

Dormady et al. (2019) provides a microeconomic (firm-level) approach to measure the cost effectiveness of resilience tactics to disasters, using Superstorm Sandy in USA in 2012 as a case study. Authors found that the conservation tactic (maintaining intended production or service levels using lower amounts of an input or inputs) as the most cost-saving resilience tactic and reported that the 'conservation' contributes to 60% of avoided losses of an average firm. They found that 'resource Isolation' (modifying a portion of your business operations to run without a critical input) as the least cost-effective tactic.

11.3.2 Evaluation of non-technical earthquake risk mitigation interventions using CBA

Research into how the CBA could be applied to evaluate operational interventions is limited. The TURNkey FWCR Platform does not facilitate simulating non-technical interventions. However, certain functions of the TURNkey FWCR Platform could assist conducting CBA for non-technical earthquake risk mitigation interventions together with the approaches adopted by previous researchers.

Community level CBA for non-technical interventions

Non-technical interventions or 'soft disaster risk reduction interventions' (Moench, et al. 2007) may form a significant part of the disaster risk reduction plans within individual organisations. These interventions offer additional benefits as they may be prepared with multi hazards in mind (Moench, et al. 2007) as opposed to technical interventions which aim at reducing the impact of a single hazard such as flooding or earthquakes.

Non-technical interventions could take many forms. In their study of flood risk mitigation interventions, Pesaro et al. (2018) categorised non-technical interventions into 4 categories: riverine environment based (e.g. river management), built environment based (e.g. building regulations), social involvement-based (e.g. education programs) and economic-based (e.g. risk transfer through insurance).

Whilst, traditional CBA methodology is reasonably capable of evaluating technical interventions', evaluating non-technical interventions for their costs and benefits is complicated. Examples of conducting antecedent forward looking CBAs for non-technical interventions at community level are limited (Ghesquiere et al, 2006)have used CBA to evaluate the World Bank financed Bogotá Disaster Vulnerability Reduction Project. Authors evaluated the Benefit to Cost ratio for structural (e.g. basic reinforcements to existing buildings) and functional interventions (e.g. business continuity planning, emergency access) financed by the programme using a randomly selected sample of 388 buildings (including 63 fire stations, 65 hospitals, 9 schools, and 251 administrative buildings). Impact of the functional interventions were assessed based on the assumptions made in relation to the lives saved and injuries avoided as a result of the interventions. These were then converted to quantitative monetary values using appropriate norms. In this study, authors assumed that a combination of structural and functional interventions would save about 5,000 lives (1,000 lives in schools and 4,000 lives in hospitals) and avoid about 50,000 injuries. Figure 47 shows the steps of conducting a forward-looking CBA to evaluate non-technical risk reduction interventions.

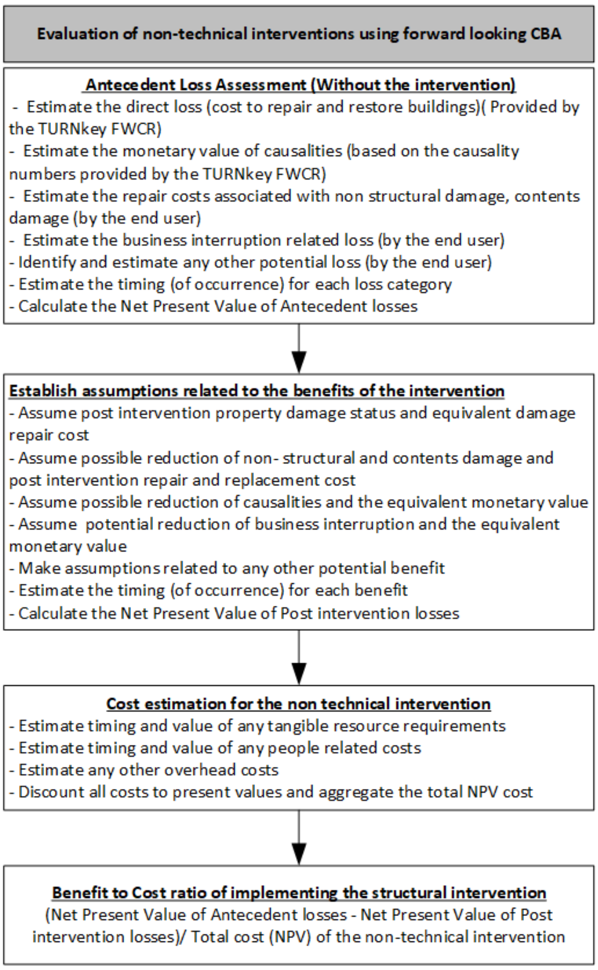

Figure 47 Steps for conducting a forward-looking CBA to evaluate non-technical risk reduction interventions.

Backward looking approach to CBA to evaluate the non-technical risk reduction interventions

Examples of using a Backward looking approach to CBA related to flood mitigation interventions provide further insights that could be applied to earthquake disasters risk reduction. During a backward looking approach costs and benefits associated with similar previous interventions are used to establish potential benefits and costs of new interventions. If similar interventions are not available at a regional level, international case studies could be used with carefully made adjustments.

- Whilst the TURNkey FWCR Plattform does not support simulating the impact of non-technical
- interventions, the interventions on the buildings could be estimated and input into the simulation activities to identify social and economic loss data. However, this would only support a marginal step of a complicated analysis. See Figure 48 for the steps of conducting a backward-looking CBA to evaluate non-technical risk reduction interventions.

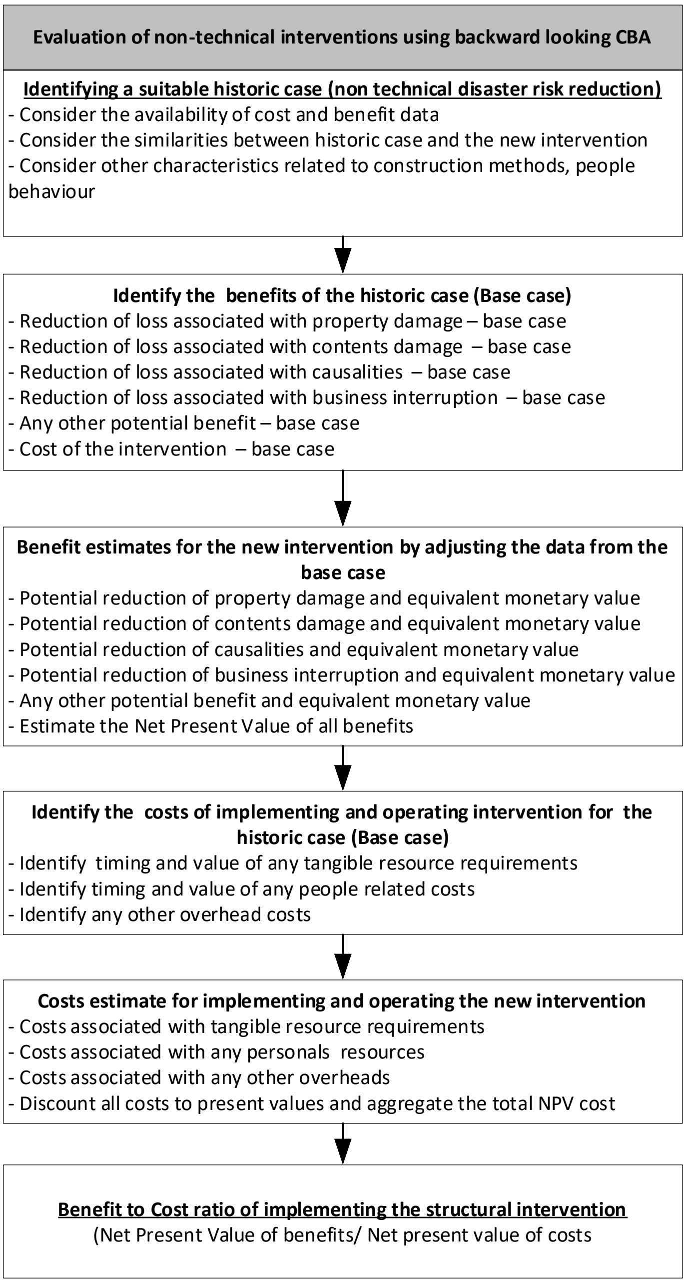

Figure 48 The steps of conducting a backward-looking CBA to evaluate non-technical risk reduction interventions.

Evaluation of organisational level non-technical interventions

Existing examples of CBA application to evaluate non-technical interventions are primarily related to the interventions aimed at reducing business interruptions and the assessment of business interruption losses.

- Eyer and Rose (2018) investigated the impact of a large-scale electricity outages on the potential business interruption. Authors have used Benefit Cost Ratios to identify optimum level of risk mitigation tactics to improve resilience.
- Dormady et al. (2019) explained earlier in this section provides a microeconomic (firm-level) approach to measure the cost effectiveness of resilience tactics to disasters, using Superstorm Sandy in USA in 2012 as a case study.

11.4 CBA for Operational Earthquake Forecasting (OEF)

Operational Earthquake Forecasting (OEF) refers to the dissemination of authoritative information about time-dependent earthquake probabilities over time scales of hours to decades to inform the decisions that people, organisations and stakeholders make to mitigate or manage seismic risk. OEF is an advancing and growing scientific area. For disasters such as flooding or high winds mitigations actions taken based on short term early warnings proved to be beneficial since the probability of such hazards occurring is much higher compared to that of earthquake (Douglas and Alireza, 2020). Whilst it is possible to observe seismic activities and forecast the possibility of an earthquake in short (days), medium (weeks) and long (months/year) in advance, researchers often investigate the modelling and usefulness of short-term forecasts as OEF. Short-term earthquake forecasts (hours to days) provide very low (typically less than 1%) absolute probability of occurrence of a damaging earthquake (REAKT,2015). The work presented within the TURNkey Deliverable 3.1 investigated the short term OEF potential.

Whilst the TURNKey FWCR Platform would not issue time bounded alerts before a (first) major earthquake event, periodic updates of seismic activities in the form of probability gain could be used and interpreted by the end-users to identify earthquake probabilities. Structural improvements to buildings cannot be undertaken based on OEF information due to the (long) time required to accomplish such interventions. End user can take certain short-term actions to minimise losses in case of an earthquake. The TURNKey project identified a range of actions that could be taken in a short notice based on OEF information (see Deliverable 2.8, Jones et al., 2021).

11.4.1 CBA for technical interventions taken based on the OEF data

The TURNkey platform provides information to support OEF. In particular, it produces regular reports on heightened seismicity and probability gain, which would need to be interpreted by individual end users to judge the possibility of an earthquake; this function is also active after an earthquake event to forecast heightened seismicity during the short-term (24 hours) disaster response phase.
Due to the nature of the actions that could be implemented during a short period of time, most of these actions have one off expenditure (cost) and a one-time potential benefit. Therefore, for many interventions costs and benefits of the interventions do not have to be estimated over a long period of time and then discounted to calculate Net Present Values (NPVs) to calculate the benefits to cost ratio. It is assumed that the actions taken within a short window of time will limit impact of inflation (Azarbakht et al, 2020).. Previous researchers (Marzocchi and Woo 2009; Woo 2013) have hence used a simplified approach to calculate the Benefits to Cost ratio (R) for the interventions taken based on OEF data. This simplified approach would not be accurate for some actions with long term costs or benefit implications, or in situations where discount rates are high Fiore et al, 2019). This simplified Benefit to Cost ratio is here reported

$$R = \frac{p * L}{C},$$

Where L is the reduced loss due to an action or intervention; C is the cost of taking an action that leads to a reduction of that loss by an amount L; and p is the probability of a destructive earthquake.

Due the lack of certainty of the forecasts based on OEF data, in many cases p is almost always very low, and hence CBAs will show that most mitigation actions are not beneficial compared to their cost (Marzocchi and Woo, 2009). Also, this simplified approach only considers the direct losses associated with reduction in deaths, injuries and some other direct losses such as damage to sensitive equipment.

Some indirect losses associated with business interruption or other social and environmental losses, which could be considerable, are not considered.

Brooks et al. (2016) conducted a simple cost-benefit analysis to assess whether a water heater should be secured against earthquake shaking. They concluded that for areas of low seismic hazard, such as Chicago, this action is not beneficial, but in areas of higher seismic hazard, it could be (Cited in Deliverable 3.1,). The TURNKey project (Azarbakt et al., 2020) provides an exemplar application of this simplified approach to CBA to economically evaluate 4 selected technical interventions stated below.

1) Removal of heavy objects from shelves or securing the objects so that they cannot fall in case of an earthquake. (Hence L/C=20 (minimum) but it could be much higher if people are at risk of injury or there are knock-on costs.)
2) Removal or securing of nonessential exterior or interior elements at height from buildings (e.g. signs, plant pots and air-conditioning units). (Hence L/C=500 but it could be much higher if this is a busy street or the sign can be removed easily.
3) Securing (even temporarily) or removal (out of endangered area) of gas cylinders (or other dangerous product) so that they cannot fall over or be damaged. (Hence L/C=500 but it could be much higher if the building is very valuable or lower if the cylinders are more robust)
4) Securing (even temporarily, e.g., putting into a padded box) or removal (out of endangered area) of a precious artistic or heritage objects (e.g., sculptures). Hence L/C=1,000 but it could be much higher if the sculpture is very valuable or lower if it is difficult to remove.

Benefit cost ratios developed for individual actions would only be valid if the OEF infrastructure is nationally available, and not considered in the cost calculations (Azarbakht et al., 2020).
Deliverable 3.1 developed a range of generic CBA maps for short (7days) and long (30 days) crisis periods, to identify the locations where the actions related to 10, 100, 1,000, and 10,000 loss to cost ratio (L/C) would be beneficial. Simulations were performed for two PGA thresholds (46 cm/s2 and 154 cm/s2), and for four probability gains (1 (no increase), 10, 100 and 1,000). Crisis period here referred to the duration which heightened seismic activities are detected. Probability gain refers to the increase in Peak Ground Acceleration (PGA). Deliverable 3.1 provided following recommendations.

- "..Areas of high seismic hazard will benefit from OEF if there are low-cost (cost ratios < 0.1%) short-term mitigation actions that can be performed even if the increase in the weekly probability of an earthquake is moderate".
- "..Areas of moderate seismic hazard would only benefit from OEF in the case of very large increases in weekly probabilities and only if low-cost actions are possible (here, the triggers would occur infrequently, i.e. less often than once every 50 years)"."..If the crisis period (heightened hazard) persists for a number of weeks, more expensive actions become cost-beneficial."

In their later work, Azarbakht et al. (2020) further analyzed the probabilistic Cost Benefit ratios for response actions taken based on OEF using a set value of loss to cost ratio (1000) in case an event happens. Authors concluded that everything else being equal, actions are more justifiable for long crisis periods (30 days) than for short crisis periods (7 days).

Deliverable 3.1 and the later work of Azarbakht et al. (2020) has not included the cost of infrastructure related to implementing, operating, and maintaining the OEF infrastructure systems.

11.4.2 CBA for non-technical interventions taken based on the OEF data

Marzocchi and Woo (2009) have used the same formula and the simplified approach explained earlier to evaluate a non-technical intervention (a decision to evacuate far from a probable earthquake source). Authors claimed that some low-cost actions may be taken by the end uses based on their risk aversion with the intention of reducing potential loss, even if the probability of realising benefits is very low. Marzocchi and Woo (2009) explained this using a simple scenario of a local resident living in a seismically vulnerable building temporarily moving out of the house in response to an OEF alert. The resident may stay for a short while in a safer place at no cost (e.g. with a neighbour or a family member) or at a low cost hotel. Even if the weekly probability of a destructive earthquake is 0.1%, since the cost is low, a risk averse person would consider checking into a low-cost hotel, to avoid a slighted probability of death or injury.

Whilst this simple example of evacuating a building has short term implications, some actions such as rescheduling production or service provisions may have long term business implications. Therefore, in those situations this simplified approach to CBA may not provide strong evidence to support decisions.

11.5 Real time Earthquake early warning

Earthquake Early Warning (EEW) refers to alerting people and systems that an earthquake has happened, and strong shaking is on the way. Earthquakes first cause a milder S-Wave seconds before the destructive shaking (called P-Wave). Seismic activity observing equipment could detect S-Waves and using communication systems that are faster than P-Wave could alert people that destructive shaking is on the way hence allowing certain actions to be taken before the destructive shaking.

Alert time and warning time are key measures to identify the effectiveness of an EEW system. Alert time (or latency) refers to the time the system takes to notice and recognize the seismic signal and estimate the shaking elsewhere. So, the alert time is the elapsed time between when an earthquake begins and when the alert is issued (Minson et al., 2018). Warning time (also called as lead time) refers to the number of seconds from the time the first wave is measured and the warning released and the arrival of S-wave arrival at any given location (Kamigaichi et al., 2009). In simple terms, it is the time available for end users to take an action.

Depending on the efficiency of the system and other characteristics related to the earthquake, end user's location and geological circumstances, EEW systems could give warnings of few seconds to few minutes. The alert could trigger fast emergency actions, such as Drop Cover Hold (DCH) or manual or automatic shout down of equipment or even placing them in safe position (e.g. elevators going to ground level) (Allen and Melgar, 2019). These alerts are also helpful in shortening the time required to start emergency response and reinstate critical infrastructure such as roads, hospitals.

During the last decade the implementation of EEWs has increased around the world. Currently countries such as Japan (Hoshiba, 2014), Mexico (Cuéllar et al., 2014), California (Kohler et al., 2017), Taiwan (Wu et al., 2014) and Romania (Böse et al., 2007) have operating EEW systems. Several other countries such as Turkey, Switzerland, North Korea, China, Ibero-Maghrebian region, Greece, Southern Italy are also developing EEW systems. Earthquake early warning for Bucharest, Romania is the earliest widescale application in the Europe. Romania's EEW system is run by the National Institute for Earth Physics (NIEP), established to observe seismic activities emanating from the Vrancea area to provide warnings for Bucharest. See Bose et al (2007) for further details. In 2013, this system further advanced to include PRESTo (PRobabilistic and Evolutionary early warning SysTem). PRESTo is a free and open-source software platform facilitating EEW and capable of modelling real-time, rapid earthquake location, magnitude estimation and damage assessment. This software was piloted in some European countries (such as Southern Italy, Greece, Istanbul) within Europe. For further reading, Clinton et al (2016) provide a comprehensive reviews of earthquake early warning advancement in the Europe.

11.5.1 CBA of interventions/actions taken based on EEW

The benefits of EEW systems depend on the warning time. A few seconds warning could save some lives and avoid injuries by following Drop Hold Cover, whilst longer warning periods could allow other actions such as automatic shutdown of certain equipment and operations. In addition, a combination of these actions may reduce the downtime for the businesses. See the TURNKey Deliverables 2.6 (Jones & Mulder, 2021), and Deliverable 2.8 (Jones et al., 2021). summaries a range potential actions that could be taken based on EEW alerts by the business organisations, critical infrastructure organisations and civil protection authorities. TURNkey Deliverable 3.4 (Molina-Palacios et al., 2020) identified an approach to estimate three key benefit categories of EEW systems (see Table 22 below).

Benefit Category	Description	Estimating methods and other remarks
Social benefits (Reduction in causalities)	Estimated causalities due to an earthquake without early warning – Expected causalities due to estimated earthquake that cannot be reduced with EEW	Simulation function of the TURNkey FWCR Platform could estimate antecedent (without EEW) causality numbers. These numbers could then be adjusted to estimate the avoided causality numbers using suitable assumptions. (see Section "Estimating social benefits associated with Drop Cover Hold) Avoided causality numbers could then be converted to economic losses (or avoided losses) by assuming a suitable monetary value for life and injuries. (see FEMA 2009; Wethli, 2014)
Indirect Economic benefits (Reduction in downtime)	Expected downtime due to estimated earthquake – (expected downtime due to potential false alarm + expected downtime due to estimated earthquake that cannot be reduced with EEW)	A combination of business downtime modelling approaches (e.g. Cremen et al., 2019; Almufti and Willford (2014) and economic modelling approaches (such as Dormady et al., 2017) to convert downtime days into economic losses could be used to estimate the total benefit associated with reduction in down time. **Note -** Some research considers that the disruption caused by the false alarm outweighs the benefit of false alarm
Direct Benefits (Reduction in direct cost)	Expected repair cost due to estimated earthquake – (Expected restoration cost due to potential false alarm + expected repair cost due to estimated earthquake that cannot be reduced with EEW)	Benefits and costs in this category are related to avoided damage to equipment by automatic shut down mechanisms. These will be rare and specific to individual organisations, and actual damage and cost should be estimated by the end users in-house.

Table 22 Benefits of EEW (Source: Adapted from table 23/ Deliverable 3.4, Molina-Palacios et al., 2020

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11.5.2 Estimating social benefits associated with Drop Cover Hold

Social benefits of EEW associated with the avoided deaths and injuries is well reported. Longer alerts have been more beneficial compared to the short few seconds alerts. For instance, Fujinawa& Noda (2013) reported that several million people received about 15-20 seconds warning ahead of the Mw 9.0 Tohoku (Japan) earthquake in 2011, and 90% of people were able to take actions to save their lives and alert family members by initiating previously planned/trained actions, while Suarez et al (2018) reported that the Mexico's early warning system SASMEX was able to give 2 minutes warning ahead of the earthquakes on the 7th September 2017 and this triggered also evacuation actions.

Modelling the number of causalities based on an EEW effectiveness matrix

Causalities without EEW could be estimated based on the simulation function of the TURNkey FWCR platform. The platform could provide an estimate of the expected causalities for 4 injury levels and number of potential deaths ((SL0 (No Injuries), SL1 (Light Injuries), SL2 (Injuries Requiring Hospitalisation), SL3 (Life threatening injuries), SL4 (Death).

These antecedent causality numbers could then be adjusted to potential causality numbers using suitable assumptions related to the effectiveness of EEW. End users could identify the applicability of these factors to their own context and develop an EEW effectiveness matrix as explained later in this section. Alternatively, the TURNkey FWCR Platform also provides three potential causalities estimates: low case, best case and high case. End users may use these numbers for their calculations as opposed to their own matrix.

Wald (2020) proposed a comprehensive account of practical limitations of earthquake early warning and McBride et al. (2022) for protective actions taken based on EEW alerts.

Lieberman and Calkins (2015) presented a methodology and a framework to estimate reduced causality considering the effectiveness of early warning alerts. Authors developed effectiveness indicators for different scenarios considering the uptake, people's ability to take action and distance from the earthquake source (see Table 23). Authors have justified the numbers used in their matrix for the Washington USA circumstances. These numbers may need to be altered by the end users for their own circumstances. For example, it is claimed that Japanese people who are familiar with frequent EEW alerts would react differently compared to an individual from a region with less frequent earthquakes. For example, individuals in a business organisation may be more (physically) able to take actions based on EEW alerts, compared to a majority of (physically) less able people within a hospital building.

	Alert uptake by alert receivers	Alert receivers' ability to take actions based on the alert	Distance from the earthquake source	Effectiveness indicator
Far away	0.75	0.6	1	0.45
Moderate distance	0.75	0.6	0.75	0.3375
Near Epicentre	0.75	0.6	0.1	0.045

Table 23 An exemplar effectiveness matrix (source: Lieberman and Calkins (2015)

Whilst the majority of the discussions related to the effectiveness of the EEW alerts are people centred limitations; we believe that this matrix needs to be extended to EEW infrastructure related weaknesses as well. Recent research suggests that the performance of the telemetry equipment, sensor network coverage has impact on issuing useful alerts.

11.5.3 Economic value of causalities

Number of causalities are multiplied by economic values assumed for the life. Injuries are classified by levels and to each level an economic value, so their overall economic value is calculated considering their number per level multiplied by their specific value. The sum of all economic value of causalities and injuries produce an estimate of the aggregate losses (or losses avoided). Table 24 below presents exemplar values assumed by previous scholars for the value of avoided deaths and injuries.

Source	Value of avoided death	Value of avoided injuries
FEMA (2019); FEMA (2020)	$ 6,900,000 (per life) Later updated to $7,500,000 in 2020	Hospitalised $ 2,300,000 Treat and release $ 61,000 Self-treat $14,000
Lieberman and Calkins (2015) – For Washington USA FEMA (2009) rates inflated to 2014 US $ levels	$6,418,992.53	• Level 1 (Self-Treatment, minor injury): $13,280.67 • Level 2 (Treat and Release, non-life threatening): $99,605.06 • Level 3 (Hospitalization, life threatening): $1,204,114.46
Wethli et al. (2014) Based on Copenhagen Consensus Disability Adjusted Life Year (DALY)	$1000 and $5000 (per year)	
Leil and Deierlein (2013)	$4 - $6 million	
Erdurmus (2005) For Turkey (values adopted Erdik and Aydınoglu (2002))	250,000 YTL	Severity level 1 (Injuries requiring basic medical aid without hospitalisation) – 500 YTL Severity level 2 (Injuries requiring medical care and hospitalisation) – 2,000 YTL Severity level 3 – Injuries that pose immediate life-threatening conditions – 10,000 YTL
Kappos and Dimitrakopoulos (2008) For Greece (Followed courts awards approach – authors commented the significant differences in awards as well as that many awards are reduced during the appeal process)	€50,000 - €500,000	

Table 24 Exemplar values assumed by previous scholars for the value of avoided deaths and injuries.

11.5.4 CBA of automation of equipment and processes based on EEW alerts

Automatic actions taken in response to an EEW could reduce potential damage. However, this has not been the norm even in Japan. Patchett (2017) translated a number of important documents in Japanese and summarized JMA's survey of business operators—who for over a decade have had access to Japan's advanced-user EEW feeds. Patchett noted that ‘‘initially, an automatic halting of machine operation for production lines was expected to be high; however, the number of controlling operation of machines,

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production lines or halting of elevators are small, and automation of such processes are also low'' (p. 38). (Cited in Wald, 2020).

Minson et al. (2021) modelled how an EEW alert could benefit a rail system in California's San Francisco Bay. Authors found that EEW alert could benefit most by preventing derailment by alerting trains to slow down or stop before they encounter damaged tracks. They also found that on-site sensor based EEW is more beneficial for the rail system than alerts that come via a regional sensor network. Authors also performed a rudimentary cost-benefit analysis by assuming an expected loss for running a train over a damaged track. Results of this analysis is not shared but have been used to define the false alarm tolerance for the train system.

Zulfikar et al. (2016) presented a case study of application of a real-time risk mitigation system (IGRAS) to the Istanbul Natural Gas Company. This system is used in Istanbul since 2013, and regulators can interrupt the gas flow if any leak tolerance is exceeded. Authors (ibid) have explained damage estimating procedure for the pipe works and other components of the gas network based on a range of data sources, modelling techniques and end user made assumptions. This methodology could be extended to convert the damage levels into monetary losses and compared against the cost (of implementing and operating) to established Benefit Cost ratio for similar risk mitigation systems.

Figure 49 shows the steps of evaluating the benefits of EEW based DCHO actions with and without considering the EEW infrastructure costs.

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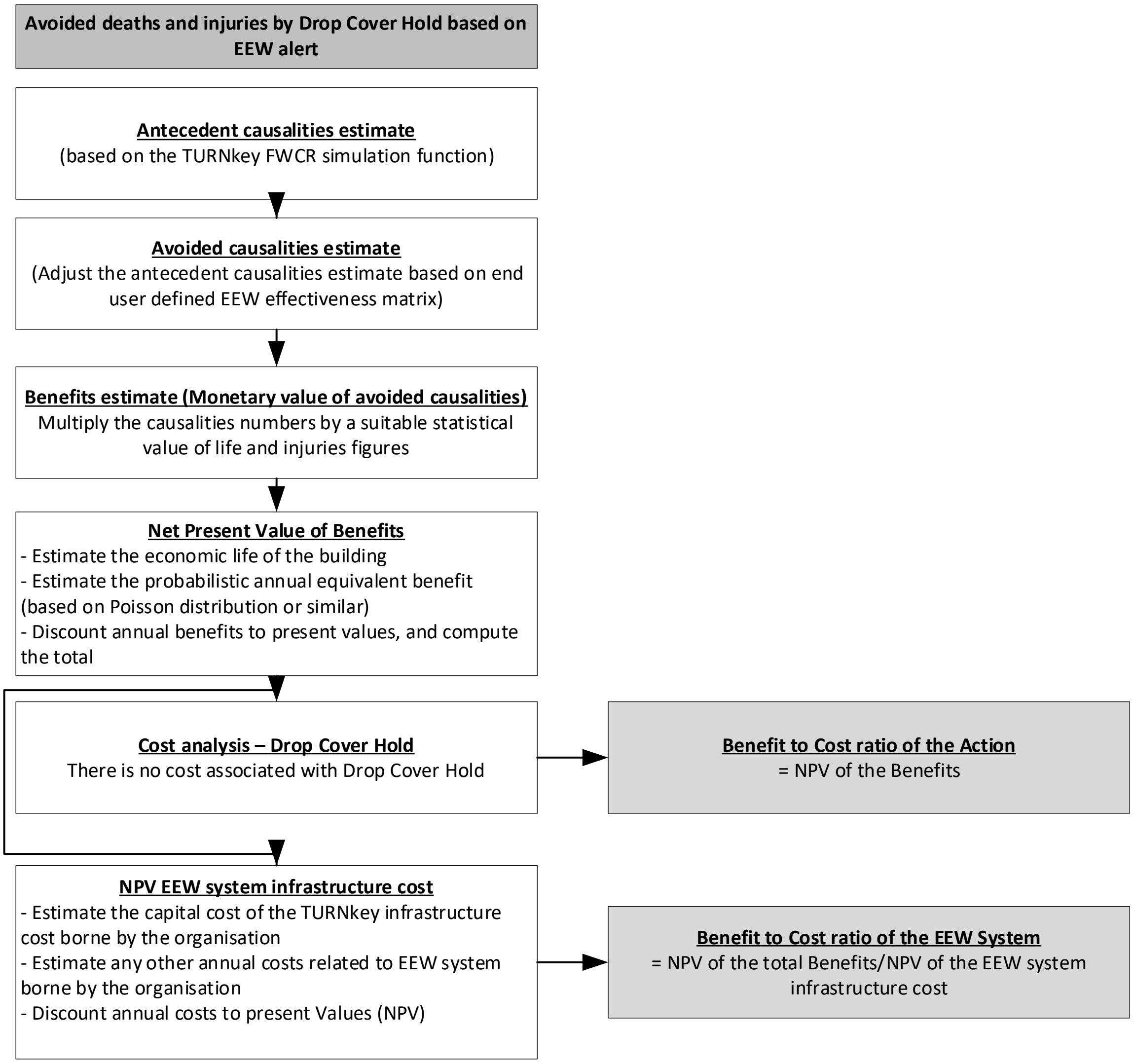

Figure 49 Steps for using CBA to evaluate EEW based Drop Cover Hold actions

11.6 Alternative CBA approach

Traditional and widely used CBA approach involve quantification of monetary value of all the costs and benefits associated with an intervention over the economic life of a building (s). However, many costs and benefits associated with disaster risk reduction interventions are indirect, difficult to identify and measure in financial terms (Moench, et al., 2007). Therefore, many CBA studies tend to limit the scope of analysis to consider only direct benefits associated with avoided damage to buildings and avoided deaths and injuries.

In the traditional CBA approach, an intervention is evaluated by quantifying all the benefits and costs using a common currency such as dollars (Mishan and Quah, 2013). In an AHP based CBA, proposed by Saaty (1994) and Wedley et al. (2001) the same approach is used except that AHP priorities rather than dollars are used as the common currency of comparison. Two AHP hierarchies (one for costs and one for benefits) would be used to evaluate each alternative to calculate benefit priority and cost priority. The alternative with the highest ratio of benefit priority/cost priority is considered as the most beneficial option. Whilst the concept is similar, the benefit to cost ratios derived based on AHP CBA does not reveal the relationship between actual cost and monetary value of resultant benefits. However, If the benefits are much more important than the costs to the decision makers, this approach could be used to evaluate different alternatives (Saaty, 1994).

By incorporating 'a magnitude adjustment process' Wedley et al (2001) demonstrated how to integrate two separate benefits and cost hierarchies into one single hierarchy so that the decision makers could alter intervention details to adjust the benefit/cost ratio without losing the subjective decision making features of the AHP. During this approach, once the priorities are identified based on AHP for the two hierarchies, a top layer is added that links the two hierarchies based on 'which perspective is more important, the aggregate benefits or the aggregate costs and by how much?'. In simple terms this ratio represents the weight between the costs and benefits as agreed by the decision makers. Loh et al (2010) have used this approach to evaluate cost effective refurbishment approaches for a school building. Authors commented that, this approach would allow architects to select the most energy efficient material-design combination that also meets stakeholders' requirements, rather than simply relying on build costs without due considerations given to environmental benefits over the life cycle.

Wedley et al (2001) also presented details of another alternative approach used in the practice, in which decision makers could estimate benefit priorities for various alternatives using an AHP based pair wise comparison, and estimate actual costs in a real currency (e.g. dollars). This approach would provide a measure of benefits per dollar of expenditure. In addition, Wedley et al (2001) presented two more alternative approaches that could be used to evaluate the projects/interventions based on the highest cash flow, and to determine where to spend marginal resources on existing projects.

This approach could only be used to appraise when there is more than on alternative, since the B/C ratio derived using this approach provides values that could not be converted to a real currency. For this reason, the TURNKey FWCR Platform could not be evaluated using an AHP based CBA.

11.7 Cost of implementation and maintenance of the TURNkey FWCR *platform*

This section provides a high-level guidance on significant cost components surrounding the implementation and maintenance of the TURNkey FWCR Platform. The governance of the TURNkey system would establish the payment responsibilities for different end users.

The TURNkey FWCR Platform supported by low cost sensor units and a cloud-based computer system would provide useful information to public authorities/decision-makers, first responders, critical infrastructure providers and general businesses (See Figure 50). The TURNkey platform has three main components: the instrument network managed by GMP, the cloud-based graphical user interface operated by B80, and the scientific engine operated by NORSAR, as shown in the Figure 51 (Deliverable 6.6, Huang et al., 2022).

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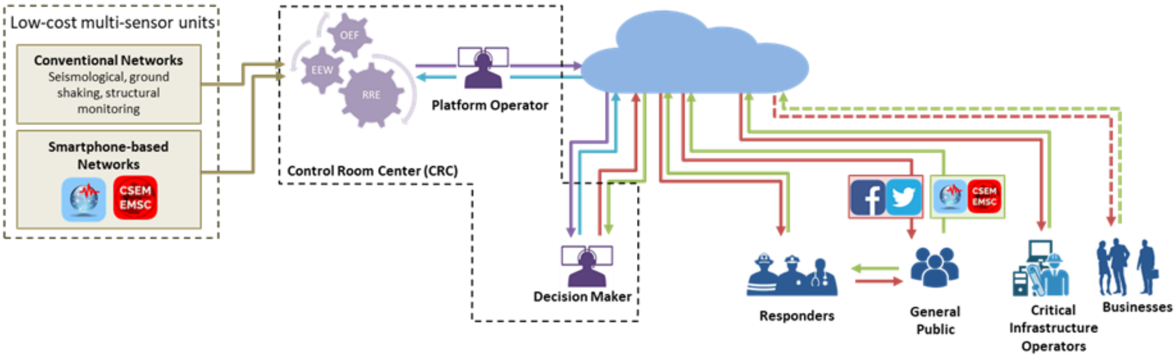

Figure 50 General concept of the TURNkey FWCR platform (Source: Huang et al., 2022)

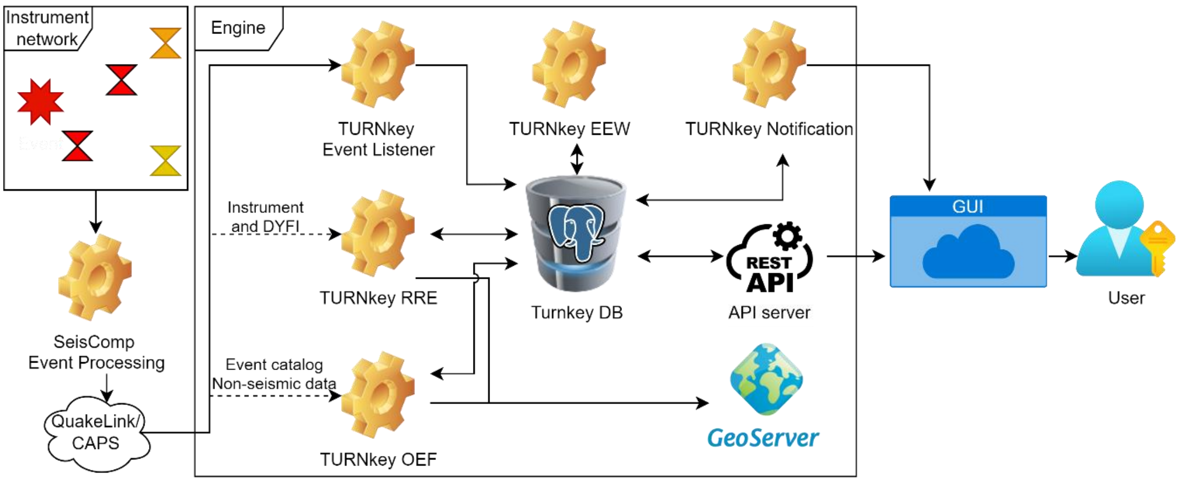

Figure 51 TURNkey system components (Source - Huang et al., 2022, pp. 9)

Instrument network - The instrument network collects and processes the seismic data through the seismic monitoring platform SeisComP3. This is supported by newly developed low-cost multi-conventional sensor units based on the RaspberryShake 4D (RS4D) to continuously monitor seismic activities within the area of interest. It is expected that a dense seismic sensor network could be created using the newly developed low-cost sensors. In addition, the system is extended by the integration of CAPS, a multiformat acquisition platform allowing the integration of additional sensor types like the GNSS sensors.

The graphical user interface (GUI) – GUI is what could be viewed at end user organisations. GUI facilitates and evaluates risk management in real-time and in various risk scenarios. GUI visualizes the results sent by the scientific engine for the decision makers to view and helps the Platform owner (decision makers) to communicate within and across different organisations based on defined rules set up during the platform configuration.

Scientific engine – The scientific engine sits between the GUI and the instrument network. It receives seismic event details (the event magnitude, intensity and location and compute the ground-motion intensity measures) evaluated by the SeisComP3. If the scientific engine receives details of a destructive (a pre-set threshold) seismic event it will then trigger EEW, OEF and RRE functions which are then be shared with the decision makers via GUI.

Implementation and maintenance of the TURNkey system requires hardware, software, and human resources invested by different organisations for various purposes (see Figure 52). Hardware includes seismic sensors and other equipment at seismic stations, telemetry, and other information and telecommunication equipment such as computers and mobile telephones. A range of software would be required to process data received by the sensor network, and intermediate analyses until meaningful information is presented to the end users. Human resource is required for maintaining and upgrading hardware and software; initial set up of the software for the decision maker; facilitating training; continuing research and development; and personnel at the end user for interpreting and maintaining data received through the TURNkey platform.

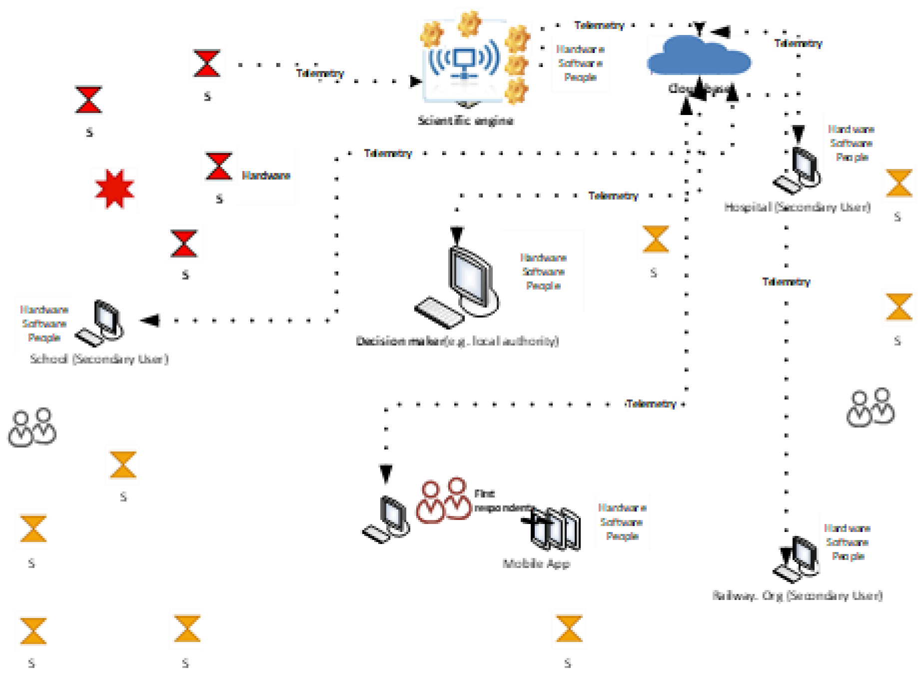

Figure 52 TURNkey resource requirements

11.7.1 Cost associated with the instrument network

Implementation of the TURNkey system will require significant investments to conduct a feasibility study of implementation, capital investment to sensor network (install new sensors and upgrade existing sensors), improvements to telemetry, maintenance and operational cost and research and development costs.

In order for the TURNkey FWCR Platform to provide reliable information, the existing sensor network may need to be updated if they need to be connected to existing seismic sensors, seismic stations, GPS stations and other seismic activity monitoring equipment (Picozzi et al. 2015). Whilst the system could utilise a regional sensor network, some organisations may prefer to install on-site seismic activity

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monitoring sensors for more reliable information in certain situations. The requirement of on-site sensors depends on the geometry of the network and end user organisation's location and other requirements (Source: Bracale et al., 2021).

A detail study will be required to calculate the number of seismic stations required to capture seismic activities within a region. Existing Early Warning Systems around the globe provide some information related to seismic station density (see Li et al, 2021, Kuyuk et al., 2013). These could be used to identify the number of sensors required to establish a good observation coverage to provide reliable information.

Depending on the type of seismic sensor, they may be stationed within a borehole, deep vaults inside tunnels, or on surface vaults. The recent and newly developed TURNkey low-cost sensors may be placed inside buildings without specially built stations. Key cost considerations associated with traditional seismic stations includes a feasibility study (e.g. location selection), design cost of the seismic station, civil works construction cost, installation of sensors and related equipment including other engineering services such as electricity and broadband connection. Average cost per new seismic station planned for the California EEW system ranges from $45,000 - $77,000 (2016 cost level) (Cal OES, 2021). Estimated cost for upgrading existing strong motion stations are costed at $3570.

Actual cost of implementing an instrument network and upgrading existing sensors was not established as a part of this project. A follow up feasibility project could establish a technical implementation plan and corresponding cost estimates. Based on the anecdotal evidence gathered during the final TURNkey workshop it was identified the cost to deploy six TURNkey multi-sensor units of accelerometric sensors with a vertical geophone (RS4D) and four GNSS instruments in a test bed in Gioa Tauro, Italy at approximately €12,000.

Telemetry
Telemetry is the technical term used to identify the equipment associated with the process of transmitting data from the seismic and GPS stations back to the central processing facility. They may include cell modems, conventional internet cables, satellite data transfer systems, fibre optic cable systems or microwave-based systems. Currently in the Europe, satellite and fibre optic cables are used as telemetry between I-NET seismic stations and the data processing unit at KOERI (Zulfikar et al., 2016). For the California EEW system comprising a network of 1115 station, the telemetry improvement plan is estimated at $8.84 million (Blue Sky Consulting, 2018).

11.7.2 Operational and Maintenance costs

The network will require repair and replacement of hardware at seismic stations and for the telemetry. In addition, they may require replacements or upgrades to match with advancement in seismic activity monitoring, EEW and OEF. For instance, California EEW system when relying on cell modems and internet reported a delayed alert of up to 12 seconds in some areas, identifying the need for a State microwave system to support telemetry (Blue Sky Consulting, 2018). In addition, the instrument network (sensors and telemetry) may require ongoing costs related to permissions/fees/licenses, security, regular checks/testing.

TURNkey Work Package 3 (reported in Deliverable 3.1,) and previous research identified that the infrastructure such as instruments, communication networks and personnel are already operating over

much of the Europe and that the additional cost of the additional services expected from these such as OEF related observations is likely to be marginal (Azarbakht et al. 2020) - Deliverable 3.1
However, several researchers have highlighted the importance of upgrading existing sensor and telemetry infrastructure in the Europe, based on their investigations into implementing EEW systems in European locations (Picozzi et al. 2015). For example, Picozzi et al. (2015) reported significant delays in transmitting EEW data through existing telemetry infrastructure which are not originally designed for EEW systems. Authors (ibid) suggested that existing telemetry network need to be upgraded to the standards of networks designed for EEWS. Authors also suggested that an on-site sensor-based system may be used to avoid delays in transmission through existing telemetry.

Once upgraded, hardware and software within the instrument network will need repair and replacement for various reasons including damage caused during a strong earthquake event, end of economic life, etc. Lifetime of components could be used as the basis of calculating the maintenance cost related to the hardware, as well as to determine the opportunities to upgrade hardware. Blue Sky Consulting (2018) has identified life years for the hardware components used for the West Coast EEW system (see Table 25). Other published data by various organisations such as FEMA or RICS UK could also be helpful in identifying the lifetime of hardware components.

Standard Equipment	Useful Life (Years)
Computer Processing Unit	5
Broadband Sensor	10
Accelerometer	10
Data Logger	10
Cables	10
Batteries (4-6 per station)	5-10
Cell Modem	5-10
Radio/Antennas	25
Solar Power System	25

Table 25 Life years for the hardware components used for the West Coast EEW system

One of the main operating cost components related to seismic stations, sensors and other equipment is the utilities such as power and broadband. Some of the sensors developed by the TURNkey could be powered by the solar panels hence could be operated at a low cost.

11.7.3 Research and development costs

Research and development play a major role in a platform like TURNkey. Whilst the research reported in this project developed and tested the TURNkey concept as a proof-of-concept prototype, a follow up exploitation research would be required to identify implementation plan. In addition, ongoing research and development will be required to monitor the status of existing network, and advancement in knowledge. California EEW system for an example is expected to spend $300,000 annually for the research and development.

11.7.4 Summary

Cost centre	Tasks	Output cost
Research and development - Initial	Exploitation research 1.Investigate the scale, conditions and capabilities of existing sensors across the region. 2.Establish a road map for future upgrades for the sensor network to improve the effectiveness of observations, and efficiency of operations and maintenance of the network.	Initial cost of the exploitation research including feasibility study. (Above could establish a capital expenditure plan)
Sensor network	Establish the initial (minimum?) upgrade required for the existing sensor network.	Initial capital expenditure to install new sensors and upgrade existing sensors.
Maintenance costs	Estimate the maintenance requirements to the upgraded (existing and new) sensor network **Considerations** – life time of existing equipment (hardware) and software and their repair replacement costs. • Permissions/fees/licenses • Security, regular checks/testing and services • Other	Annual maintenance costs
Telemetry	Investigate the telemetry requirements to gather data from upgraded sensor network	Cost of feasibility study Initial capital expenditure to upgrade telemetry
Research and development - Ongoing	Ongoing research Identify and establish future upgrade requirements.	Research and development costs (a research or a consultancy project could establish a Future capital expenditure plan)

Table 26 Summary of cost items related to exploitation plan and business case considerations for the Instrument network

11.8 End user cost - Cost associated with the scientific engine and FWCR software platform

	Description	Output cost type
Hardware	Computers, and servers	Initial capital cost Recurrent repair and replacement costs
	Back up storage, consumables	Initial capital cost Recurrent repair and replacement costs
Human cost of regular operation	cost of installation, training, maintenance, and long-term support;	Capital cost to the software developer
	cost of salaries and training for the new scientific and technical personnel	Recurrent overhead cost at the end user organisation

Cost of external services	Google map services	Annual subscription cost
	SMS services	Annual subscription cost
	Notification services	Annual subscription cost
Upgrades	Upgrades based on new requirements and research developments	Capital cost to upgrade at regular intervals
Other	Educating users, trials and drills	Annual cost costs

Table 27 Summary of costs related to the scientific engine and FWCR software

11.9 Overall Costs of similar systems

Table 28 provides details of the total capital and operating costs of similar systems identified as secondary data.

System	Capital cost	Operational and maintenance cost
West coast EEW system (Comprise of 1,675 high quality, real-time EEW-capable ANSS seismic stations—1,115 in California and 560 in the Pacific Northwest)	$42,050,000 spent since 2016-2020 (ceews business plan update)	Earthquake Warning California requires $17,300,000 annual funding to support operations and maintenance, telemetry, outreach and education, research and development, and program management, including a portion of Cal OES staffing. (Newsom & Ghilarducci, 2021) Initial operations budget including upgrades The annual recurring cost of long-term operation and maintenance of the ShakeAlert system infrastructure without the telemetry component is $28.6 million 9,768,717 for telemetry (Blue Sky Consulting, 2018)
Japan EEW Source: World bank	The capital costs of the EEWS was about JPY 11 billion	JPY 280 Million/ year, excluding personnel costs (The O&M costs are borne by JMA and NIED)
Japanese J Alert - Year of Launch February 2007	Development cost: About JPY 472 million	Operation and Enhancement cost - JPY 900 million
Tokushima DIMS: Disaster Information Management System	Development cost: 45 million JPY Cost of System Enhancement: 106 million JPY	Operation and maintenance cost: About 11 million JPY / year
Taiwan EEW https://www.openaccessgovernment.org/earthquake-early-warning-system-taiwan/62414 As of 2017, a total of 650 stations have been deployed and configured.	It cost $160,000~$200,000	

Pilot study – ASTUTI for Costa Rica For a network of smartphones deployed in fixed locations (Source: Brooks et al., 2021)	~USD 22,000	~USD 20,000 per year
TURNkey FWCR Platform and instruments network	Based on the anecdotal evidence gathered during the final TURNkey workshop it was identified that to deploy six TURNkey multisensor units of accelerometric sensors with a vertical geophone (RS4D) and four GNSS instruments in a test bed in of Giaio Tauro, Italy costed approximately €12,000. The cost of the TURNkey FWCR Platform including the scientific engine software may need approximately one person year (depending on the size of the network) and the direct cost to install the platform. (Note : The TURNkey costs observed during the project activities may be different to actual implementation, since the project activities the TURNkey FWCR platform is developed upto the Technology Readiness Level 5/6 only.)	

Table 28 Total capital and operating costs of similar systems identified as secondary data.

Detailed costs related to capital and operating costs of early warning and related systems are not widely available.

Using data from IRIS plan 1990 – 1996 Havskov et al. (2011) presented a cost analysis of establishing and operating a seismic station over 5 years. They estimated that Equipment, Services and operation and maintenance cost of a seismic station is approximately about 39%, 33% and 28% of the total capital and operating cost. Advancement to equipment and practices over the last three decade may have changed some of these costs.

An updated business plan for the California EEW identified that they would need to spend $16.4 million (USD) annually to operate and maintain the system (Newsom & Ghilarducci, 2021). Table 29 shows the distribution of the estimated annual cost (ibid).

Cost constituent	**Estimated annual operating cost**
Seismic Stations	$ 3,800,000
GPS stations	$ 2,300,000
Backbone Telemetry	$ 2,900,000
Outreach and Education	$ 3,500,000
Research and Development	$ 300,000
Programme management	$ 400,000
Contingency	$ 3,200, 000
Total	**$ 16, 400, 000**
***Note**: This estimate is related to a system supported by 1,115 Seismic stations in California and 560 seismic stations in the Pacific Northwest*	

Table 29 The distribution of the estimated annual cost of the California EEW system

11.10 Summary and discussions

The TURNkey FWCR Platform could provide direct and indirect information to evaluate a range of risk reduction interventions (see Table 30). This could form part of an initial feasibility study of indicative levels of earthquake risk and mitigation interventions at the individual built asset, built asset portfolio and regional level. In its current form the TURNkey FWCR Platform should be considered a strategic level decision support tool to help critical infrastructure and business organisations better understand their indicative risks and provide guidance on the potential effectiveness of indicative risk reduction interventions.

The TURNkey FWCR Platform could estimate antecedent and post intervention losses associated with the direct damage to buildings and the causality numbers at the building level and regional level if an intervention has the potential to reduce these types of damage.
These estimates help organisations or regions appraise a range of risk reduction interventions without commissioning specialist consultants, which otherwise would require extra resource and additional lead times (Wanigarathna et al., 2022).

The TURNkey FWCR Platform could be particularly useful to estimate business interruptions with better accuracy by considering the damage to buildings and social loss at the regional level (Cremen et al., 2020).

The TURNkey FWCR Platform could be termed as a platform integrating a range of techniques and functionalities related to earthquake risk mitigation and recovery. The TURNkey FWCR Platform offers a range of soft benefits. The key benefits identified within the Deliverable 2.8 (Jones et al., 2021) are:

- Placing response teams on high alert during a period of high earthquake risk (offered by the OEF functions)
- Activate disaster management team to test disaster management and business continuity plans (offered by the OEF functions)

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- Checking whether risk management protocols are in place and working as expected (offered by the Simulation function)
- Sending an automated alert to employees / customers to drop, cover, hold (offered by the EEW functions)
- Sending automated aftershock warnings to employees undertaking assessments or repairs on the ground (offered by the EEW for aftershock function)
- "I'm Safe" feature on mobile app to check on status employees after ground shaking
- Quickly activate disaster response and recovery protocols (offered by the RRE functions)
- Send automated emails to key employees and stakeholders (offered by the RRE functions)

It is clear that the benefits offered by the TURNkey FWCR extends beyond the tangible benefits (avoiding damage to property and causalities) often estimated within a traditional CBA exercise.

See the Deliverable 2.8 (Jones et al., 2021) for further details of the benefits offered by the TURNkey FWCR Platform through the earthquake simulation, earthquake early warning and rapid response to earthquake functions.

Type of intervention and the approach to CBA		TURNkey FWCR input for the antecedent loss assessment	TURNkey FWCR input for the benefit assessment (Post intervention loss assessment)
Risk reduction interventions with long lead times that could be implemented based on the earthquake simulations	Structural retrofitting based on earthquake simulations	Direct loss associated with the cost to repair and restore buildings Number of causalities estimate (which end users could use to estimate the monetary value of the social loss and other losses related to the staff shortage)	(Reduced) Direct loss associated with the cost to repair and restore buildings Number of (reduced) causalities estimate (which end users could use to estimate the monetary value of the social loss and other losses related to the staff shortage) (Note – these results could be obtained by changing the building characteristics related to the technical intervention)
	Evaluation of non-technical interventions using a forward-looking CBA	Direct loss associated with the cost to repair and restore buildings Number of causalities estimate (which end users could use to estimate the monetary value of the social loss and other losses related to the staff shortage)	Direct loss associated with the cost to repair and restore buildings Number of causalities estimate (which end users could use to estimate the monetary value of the social loss and other losses related to the staff shortage) (Note - End users need to establish the impact of the non-technical intervention on buildings and alter building characteristics for the TURNkey to produce these results).
	Evaluation of non-technical interventions using backward looking CBA	This does not require individual building specific estimates, hence TURNkey FWCR Platform will not provide any input.	This does not require individual building specific estimates, hence TURNkey FWCR Platform will not provide any input.
Risk reduction	Interventions to safeguard	In the current version, the scientific engine of the	In the current version, the TURNkey FWCR Platform does not provide losses

interventions with short lead times that could be implemented based on the OEF data	non-structural elements, components and critical equipment within the buildings	TURNkey FWCR Platform computes the mean damage ratio, damage grade, and economic loss of non-structural elements. However, due to the simplicity in the assumption, these results are not presented in the end-user interface in the current version.	related to the damage to the non-structural elements to the end users, hence will not provide any input
	Non-technical interventions to safeguard the operations and people	Number of causalities estimate (which end users could use to estimate the monetary value of the social loss and other losses related to the staff shortage) TURNkey FWCRPlatform does not estimate the impact of building damage to the business operations. At the current development stage of the platform the used can update its estimated downtime. Building damage and causalities estimates at building level and regional level would provide end users a strong evidence to estimate the business interruption levels. In addition, functionality level estimated based on the end user input downtimes may also be useful to estimate the business interruption.	Number of (reduced) causalities estimate (which end users could use to estimate the monetary value of the social loss and other losses related to the staff shortage) TURNkey FWCR Platform does not estimate the impact of building damage to the business operations. At the current development stage of the platform the used can update its estimated downtime. Building damage and causalities estimates at building level and regional level would provide end users a strong evidence to estimate the business interruption levels. In addition, functionality level estimated based on the end user input downtimes may also be useful to estimate the business interruption.
Immediate risk reduction interventions that could be actioned based on the EEW alerts	Drop Cover Hold based on EEW alert	Number of causalities estimate (which end users could use to estimate the monetary value of the social loss)	Number of (reduced) causalities estimate (which end users could use to estimate the monetary value of the social loss)
	Automatic shutdown of critical equipment	TURNkey FWCR Platform does not estimate the losses related to individual equipment within the buildings, hence will not provide any input.	TURNkey FWCR Platform does not estimate the losses related to individual equipment within the buildings, hence will not provide any input.

Table 30 Summary of TURNkey FWCR input to conduct CBA for the different types of interventions

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12 Conclusions

The TURNkey FWCR Platform is an early prototype integrated earthquake forecasting, early warning and rapid response system for Europe. The platform has been developed using a 3-cycle PAR methodology in which potential end-users of the platform have been actively involved in its development and testing. This report has presented the results from the 3rd phase of the PAR cycle where the final version of the TURNkey FWCR Platform was evaluated against end-user stakeholder expectations and an indicative business model was developed to integrate the platform into business continuity and disaster management plans. This report also presents the results from a series of AHP models that represent an early attempt to assess the potential impact that the platform could have on organisation and community resilience.

The 3rd PAR cycle involved a series of interviews with end-user stakeholders in Greece, France, Iceland, The Netherlands and Romania. For the 3rd PAR cycle interviews the stakeholders were asked to assess the effectiveness of the platform in enhancing their organization or community resilience. The assessment was carried out by applying the AHP models for organizational resilience of businesses, for resilience of Critical Infrastructure (CI) and for community resilience developed in Deliverable 5.2 (2021). The models are composed by three hierarchic levels of indicators. The values of the indicators were estimated through pairwise comparisons among indicators of the same level and group. The stakeholders were asked to complete the pairwise comparisons of the AHP model related to their sector (business, CI, or civil protection). This first assessment reflected their views on which aspects of the models were more important for the resilience of a business or CI organization or community similar to theirs. After this first resilience assessment, the TURNkey FWCR Platform features were presented to the stakeholders through a presentation. At the end of the presentation the stakeholders were asked to assess how much implementation of the TURNkey FWCR Platform in an organization or community similar to theirs would have contributed to each of the indicators of the lowest levels of the AHP models. This second resilience assessment allowed to conclude that the TURNkey FWCR platform has a moderately positive impact on the organisational resilience of businesses; a highly positive impact on the resilience of CI; a moderately to highly positive impact on the community resilience.

The second part of the 3rd PAR cycle interviews the stakeholders, who were presented with screenshots from the TURNkey FWCR Platform, were asked to evaluate the Platforms usefulness against the strategic level use cases that were developed during the 2nd PAR cycle (reported in D2.8) and to comment on whether their organisation would use such a system if it was fully developed and commercially available. Generally speaking, an end-user stakeholders confirmed that most aspects of the strategic level use cases were applicable to their organisation, albeit with important caveats. When it came to OEF, for example, many business and CI organisations recognized its value for rescheduling activities. However, those who provided a public service or good (e.g., public transport or education) stated that they would be unwilling to reschedule based on an inhouse forecast due to legal liabilities: they would, however, be happy to reschedule activities if they were instructed to do so by authorities (based on OEF). Some stakeholders (the education providers) expressed the view that seismic simulations for preparedness were valuable, but that this responsibility should sit with the local authorities: not their organisations. Similarly, some stakeholders (telecommunications provider, mass transit provider, education providers) expressed the view that TURNkey's RRE features were valuable, but that the primary responsibility for an earthquake response should sit with civil protection: and not their organisations. Organisations that did not have hazardous or vulnerable systems (telecommunications providers, education providers) indicated that they would not use EEW to automatically let systems shut down or fail safe, but that they recognized its value for other organisations that did have such systems. Most stakeholders (across the board) stressed the need for TURNkey to be compatible with existing legacy systems and processes. Some stakeholders (telecommunications providers) indicated that they already had in-house and national systems that addressed most of TURNkey's use cases. As such, they would not use TURNkey for many of the issues the use cases cover but stated that they saw the value of TURNkey for organisations in seismic regions that did not have their in-house and national facilities. All these points were identified during PAR Cycle 2 and included in Deliverable 2.8. This final round of PAR validated these insights. The Civic Protection Stakeholder validated all use cases developed for community resilience, with two important caveats: not all aspects of all use cases were within the stakeholder's remit. However, where this was the case, they stated that the feature would be valuable for the relevant local authority that did have that particular responsibility. Furthermore, the civil protection stakeholder responded 'as if' they were based in a high-risk seismic area, when in reality they were based in a low risk seismic region.

Bearing these caveats in mind, stakeholders were positive about using the TURNkey FWCR Platform as part of their earthquake risk management plans. In general, interviewees believed that TURNkey's earthquake early warning and after-shock warnings were the most useful functions of the platform, with the earthquake simulation and rapid response functions being useful when coordinated by civil protection. In conclusion, the strategic level use cases presented in D2.8 remained valid at the end of the project, with the TURNkey FWCR Platform demonstrating its potential to deliver against the use case requirements.
Business continuity and disaster management plans formed the basis by which organisations prepare for, manage, respond to and recover from disaster events. Whilst there are numerous examples and templates available online, and from national governments/agencies to help organisations develop their BCPs and DMPs, they all tend to follow the generic approach outlined in ISO 22301 - Business continuity management which identifies the need for organisations to improve their resilience to disaster events through effective pre-disaster planning, hazard threat analysis, business impact assessment and mitigation option appraisal, emergency management planning, an short and long-term business recovery plans. Figure 45 presents a business continuity and disaster management framework that summarises the potential role of the TURNkey FWCR Platform to the different stages in business continuity and disaster management planning. The framework was used as the basis to explore the potential role of the TURNkey FWCR Platform to a hypothetical hospital scenario. The hypothetical hospital scenario was presented during the final stakeholder workshop in Orihuela, Spain. The hypothetical hospital scenario gave a more detailed description of how the turnkey FWCR platform could be applied at the different stages in the development of business continuity and disaster management plans. Full details of this process can be found in TURNkey deliverable D7.6.

The last part of the report explored how the TURNkey platform could support the evaluation of a range of disaster risk mitigation interventions based on the principles of Cost Benefit Analysis (CBA). The simulation function within the TURNkey platform helps end users appraise a range of risk reduction interventions without commissioning specialist consultants, which otherwise would require extra resources and additional lead times. Furthermore, high-level guidance on how to identify and estimate cost constituents for implementing and operating the TURNkey FWCR platform is also provided. The actual cost would need to be estimated based on a bespoke technical implementation plan, which considers the capital investments related to implementing new assets, upgrading existing assets and their operations over the asset life cycle. The TURNkey FWCR platform offers a range of benefits as described in Deliverable 2.8. Whist CBA can be used to assess the tangible benefits offered by the platform (such as damage to assets and causalities), it is difficult to use CBA principles to evaluate the soft benefits offered by the TURNkey FWCR platform.

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14 Appendix H – Final End-User Use Cases

14.1 Use cases for Civil Protection (CP) and First Responder (FR) and Municipality (M) end-users

14.1.1 UC1: TURNkey to support understanding of impact to help plan a better targeted response

Goal	To understand the potential scale and sites of impact and enable the planning of a more accurate response
Use Case Instance	To achieve this goal TURNkey will provide the following: • Clearly defined uncertainty parameters. Animated maps to highlight areas more likely to be strongly affected, with impact on key assets • A manipulation of mapped info to allow comparison of zones before and after the forecasted earthquake • The facility to customise scenarios along different criteria so that the end user can calibrate the response accordingly
Primary End User	CP
Secondary End User	FR
Success guarantee	Incoming OEFs allow the end user to understand the likely scale of impact in terms of: • areas and key assets impacted • relative severity and priority for intervention • number of citizens displaced/wounded • likely resources needed
Preconditions	Both end users have a fully updated TURNkey platform highlighting the following, clearly labelled assets, for their area: • High impact assets e.g. bridges and key road networks • High vulnerability assets e.g. retirement homes, schools • High danger assets e.g. nuclear or chemical plants
Success scenario	1) OEF received 2) TURNkey platform rapidly 'populates' with information on how the various asset types are likely to be impacted 3) End user (CP): • Plans safe routes for SAR and specialist teams • Identifies safe areas for displaced citizens, tent cities and incoming first response organisations 4) End user (FR): • Gives advance warning to operating rooms and rescue teams ensuring that this are adequately staffed • Checks conditions of infrastructure and likelihood of collapse

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14.1.2 UC2: EEWs to enable a more rapid and accurate response

Goal:	To support a rapid and precise allocation of SAR teams to the most badly hit areas
Use Case Instance:	To achieve this goal TURNkey will provide the following: • Shakemaps – to identify priority areas for intervention • Shakemaps highlighting priority areas for intervention according to the asset classification identified in UC1 • Shakemaps monitoring the health of strategic infrastructure e.g. hospitals and response co-ordination centres • EEW alerts that may be forwarded to chemical/nuclear plants and similar High Danger assets • EEW alerts to FRs in case of aftershocks • EEW alerts from wider geographical area, to give visibility of seismic activity in the region that may affect the end user's area
Primary End User	FR
Secondary End User	SAR teams on site (for receipt of aftershock EEWs via the TURNkey app)
Success guarantee	• End users (FR) are able to get rescue units out of the station faster with clear intervention destinations • EEW aftershock alerts that enable FR to act to safeguard their safety and that of citizens in the area
Preconditions:	TURNkey sensors pick up seismic activity and signs of an imminent earthquake
Success scenario:	1) EEW received 2) End user (FR) operations centre uses shakemaps to identify priority intervention zones 3) SAR teams sent out to accurately identified priority intervention zones 4) TURNkey information is integrated with field verifications from the SAR teams for a more comprehensive assessment of the overall situation 5) Aftershock alerts sent directly to FRs on site via the TURNkey app 6) Aftershock alerts forwarded to key selected parties e.g. townhalls, business, chemical plants etc. (if appropriate)

14.1.3 UC3: RRE to support prioritisation, resource allocation and co-ordination

Goal:	To increase SAR effectiveness
Use Case Instance:	To achieve this goal TURNkey will provide the following: • Status of vulnerable buildings and critical areas, with evolution over time • Impacted areas by: number of victims, deaths and type of medical assistance needed • SAR protocols in place and players involved • Equipment being used • Intervention plans in place, with current status and key decisions taken • Visibility of all first response operations in the area • An 'I'm safe' button on the TURNkey app to be used by rescue teams on site • TURNkey remains active, providing updates beyond the first 72 hours
Primary End Users	CP and FR
Secondary End User	M (*limited usage*)
Success guarantee	End users receive continuous and comprehensive updates on areas of damage and compromised buildings, integrating SAR team verifications
Preconditions	In the immediate aftermath of an earthquake, TURNkey provides continuously updated information on the impact and rescue effort in the relevant areas
Success scenario:	1) RRE information and ongoing evolution of the situation is centralised and visible on the TURNkey 'dashboard' 2) End user (CP, FR) identifies buildings and areas needing intervention and/or evacuation and mobilises intervention teams 3) End user identifies (CP) safe zones and buildings to move citizens and set up medical hubs 4) End user (CP) communicates with citizens on where to go if displaced or in a dangerous zone 5) End user (CP) uses information to co-ordinate the rescue effort across multiple organisations 6) End user (CP) uses TURNkey to send out messages to selected rescue organisations, key infrastructure etc. 7) End user (CP) uses information provided beyond the first 72 hours to assess recovery timelines 8) End user (M) uses TURNkey data in compiling damage reports

14.2 Use cases for Critical Infrastructure (CI) and Business Organisations (B)

14.2.1 UC1: Disaster and risk management planning at the individual site or building level before an earthquake event

Goal	To understand the potential scale and impact of different earthquake scenarios on built assets to better inform disaster management and business continuity planning
Use Case Instance	To achieve this goal TURNkey will provide the following: • assessments of building damage states against the EMS damage grades for a range of earthquake intensity and location scenarios (with a minimum most like and most sever scenario) • estimates of physical, human and economic losses based on typical building typologies or bespoke data provided by the end-user • shake maps, PGA and structural damage states as input into 3rd party assessments of functional loss for key built assets.
Primary End User	CI, B
Secondary End User	CP (as authorising agent[3])
Success guarantee	OEF simulations allow the end user to understand the likely scale of impact in terms of: • damage state assessments of their individual built assets which in turn will allow them to develop disaster and risk management mitigation plans • shakemap, PGA and damage state assessments as input to inform an assessment of impact on functional performance (note: the TURNkey FWCR platform will not provide information on damage to non-structural elements, fixtures or fittings)
Preconditions	End users have full access (in terms of bespoke data input and outputs) to the TURNkey FWCR platform: • to enter bespoke details of their built assets or bespoke fragility curves (which will need to be generated by 3rd parties outside of the TURNkey FWCR platform) • the 3rd party fragility curves are sufficiently detailed to allow reliable building level damage and loss assessments to be generated
Success scenario	Simulations provide a credible range of impact scenarios that allow the end-user to: • develop effective disaster management and business continuity plans

[3] It is unlikely the critical infrastructure or business organisations will have direct access to the TURNkey FWCR system during the current development. As such access will be through the regional or national disaster management and response organisation. Direct access could be provided through further TURNkey development after the current project.

	• test their plans through training exercises and evaluate the practical application of their long-term service/business delivery location and supply chain partnerships (through application of TURNkey to assess the resilience of their key downstream and upstream partnerships) • evaluate the necessity of disaster insurance for property/content damage and business disruption

14.2.2 UC2: Disaster and risk management planning at the critical infrastructure sector level before an earthquake event

Goal	To understand the potential scale and impact of different earthquake scenarios on a critical infrastructure sector's (regional) built assets to better inform disaster management and business continuity planning
Use Case Instance	To achieve this goal TURNkey will provide the following: • assessments of building damage states against the EMS damage grades for a range of earthquake intensity and location scenarios (with a minimum most like and most sever scenario) for all critical assets at the sector/regional level • estimates of physical, human and economic losses based on typical building typologies generated from generic data provided by the end-user • shake maps, PGA and structural damage states to allow strategic level assessments of functional loss for key built assets (strategic level functional assessments would have to be developed by 3rd party applications)
Primary End User	CI, B
Secondary End User	CP (as authorising agent)
Success guarantee	Simulations allow the end user to understand the likely scale of impact in terms of: • damage state assessments of their built assets across the sector which in turn will allow them to develop disaster and risk management mitigation plans, including redirecting service delivery to alternative locations that were less severely affected • use the shakemap, PGA and damage state assessments as input to inform an assessment of impact on functional performance (note: the TURNkey FWCR platform will not provide information on damage to non-structural elements, fixtures or fittings)
Preconditions	End users have full access (in terms of data input and outputs) to the TURNkey FWCR platform: • to enter generic details of their built assets and loss ratios

	• the critical infrastructure organisations critical built assets are located in a wider regional context that will allow an assessment of the functionality and performance of other factors (e.g., transportation networks) that could affect disaster management and mitigation plans
Success scenario	Simulations provide a credible range of impact scenarios that allow the end-user to: • develop effective disaster management and business continuity plans • test their plans through training exercises and evaluate the practical application of their long-term service/business delivery location and supply chain partnerships (through application of TURNkey to assess the resilience of their key downstream and upstream partnerships) • evaluate the necessity of disaster insurance for property/content damage and business disruption

14.2.3 UC3: Business case for mitigation action to reduce the impact on critical service/business function

Goal	To understand the potential costs and benefits of mitigation actions to reduce the impact of different earthquake scenarios on the delivery of critical service/business function
Use Case Instance	To achieve this goal TURNkey will provide the following: • assessments of building damage states against the EMS damage grades for a range of earthquake intensity and location scenarios and different built asset mitigation interventions • estimates of physical, human and economic losses based on typical building typologies or bespoke data provided by the end-user • shake maps, PGA and structural damage states to allow third-party assessments of functional loss for key built assets and services
Primary End User	CI, B
Secondary End User	CP (as authorising agent)
Success guarantee	Simulations allow the end user to evaluate the cost/benefit of different built assets and facilities management mitigation actions: • change in damage profile and functional performance of individual buildings before and after physical mitigation (e.g., retrofit) interventions • change in functional performance of individual buildings before and after operational mitigation (e.g., change in use or service delivery models) interventions • evaluate costs and benefits for a range of mitigation actions and discuss scenarios/thresholds at which they would be implemented.
Preconditions	End users have full access (in terms of bespoke data input and outputs) to the TURNkey FWCR platform: • provides a comprehensive library of fragility functions, and/or allows the end user to enter bespoke details of their built assets and loss ratios to recalculate reduced damage levels related to a range of mitigation actions • the data provided by the TURNkey FWCR platform is sufficiently reliable to allow the losses of different mitigation scenarios to be evaluated (note: the costs of mitigation actions would be provided by 3rd parties)
Success scenario	OEF simulations provide reliable loss assessments that allow the end-user to:

	• develop cost benefit analyses against a range of potential mitigation action suitable for inclusion in business (built asset and facilities management) models

14.2.4 UC4: Early activation of disaster management and business continuity plans

Goal	To trigger early activation of disaster management and business continuity plans during a period of heightened seismic activity before an earthquake event
Use Case Instance	To achieve this goal TURNkey will provide the following: • daily assessments of the probability of ground shaking exceeding preset threshold levels
Primary End User	CI, B
Secondary End User	CP (as authorising agent)
Success guarantee	OEF alerts allow the end user to: • check health and safety procedures are fully operational • place key personnel on alert • adjust work patterns in anticipation of an earthquake event • protect critical systems • trigger logistic supply chains (e.g. deployment of portable generators and key recovery teams) • backup critical data • implement low cost and/or temporary mitigation actions identified during the scenario planning
Preconditions	**This use case will only be applicable to specific locations** where local conditions are suitable for reliable probability gains to be identified at a level of certainty that would avoid too many false-positives End users have full access (in terms of bespoke data input and outputs) to the TURNkey FWCR platform: • to enter bespoke details of their built assets and loss ratios • the data provided by the TURNkey FWCR platform is sufficiently reliable to allow the losses of different mitigation scenarios to be evaluated (note: the costs of mitigation actions would be provided by 3rd parties)
Success scenario	Daily probability gain assessments allow the end-user to confidently trigger disaster management and business continuity plans

14.2.5 UC5: EEW to improve personal safety of employees and other members of the public

Goal	To improve the safety of people on site (or transport system) through the triggering of an early warning of ground shaking following an earthquake
Use Case Instance	To achieve this goal TURNkey will provide the following: • an alert warning of imminent ground shaking exceeding preset threshold is at individual locations would be sent to the organisations control room (this would most likely be a security centre, either located on site or at a remote third-party facility depending upon the organisations security arrangements)
Primary End User	CI, B
Secondary End User	CP (as authorising agent)
Success guarantee	An EEW alert would allow the end user to: • manually initiate an audible alert across the potentially affected buildings/transport system advising people to mentally (and if appropriate physically - e.g. stop or pause activities, ensure safety lines are secure, evacuate dangerous locations etc.) prepare for ground shaking and to drop, cover, hold • manually initiate a 'go to safe mode' instruction for hazardous processes and employee/public transportation systems
Preconditions	EEWs are received from the authorising agent without significant delay (too long a delay between the CP receiving the alert and it been passed down to the CI/B will negate this use case). End users have full access (in terms of bespoke data input and outputs) to the TURNkey FWCR platform to enter alert activation thresholds for their built assets and critical systems
Success scenario	EEW alerts received in a timely manner and building occupants understand what to do if an alarm sounds. Although it is technically possible to link the issuing of an EEW alert directly to automated control systems, this is not currently part of the TURNkey project

14.2.6 UC6: EEW to reduced damage to critical systems allowing faster recovery after an earthquake

Goal	To reduced damage to systems that are highly vulnerable to shaking
Use Case Instance	To achieve this goal TURNkey will provide the following: • an alert warning of imminent ground shaking exceeding preset threshold at individual locations would be sent to the organisations control room (this would most likely be a security centre, either located on site or at a remote third-party facility depending upon the organisations security arrangements)
Primary End User	CI, B

Secondary End User	CP (as authorising agent)
Success guarantee	An EEW alert would allow the end user to: • manually initiate 'shut-down or go to park mode' instructions to operators of critical equipment (note critical equipment would have to have been identified during the OEF simulation stage. TURNkey would not contain information about which equipment needs to be shut-down) • open automatic doors (subject to security considerations) to allow egress from damaged buildings once ground shaking stops • issue automated recall for key disaster response personnel to activate their personal disaster response protocols (e.g., to initiate the disaster response command and control committee, initiate their health and safety checks etc.)
Preconditions	EEWs are received from the authorising agent without significant delay (too long a delay between the CP receiving the alert and it been passed down to the CI/B will negate this use case). End users have full access (in terms of bespoke data input and outputs) to the TURNkey FWCR platform to enter alert activation thresholds for their built assets and critical systems
Success scenario	EEW alerts received in a timely manner and critical systems are set to 'safe-mode'. Although it is technically possible to link the issuing of an EEW alert directly to automated control systems, this is not currently part of the TURNkey project

14.2.7 UC7: EEW/RRE to initiate early activation of disaster management plans

Goal	To improve the safety of people on site through early activation of disaster management plans
Use Case Instance	To achieve this goal TURNkey will provide the following: • early assessments (within 30 minutes of ground shaking) of earthquake intensity and estimated damage states for critical built assets • regular updates of shake maps, damage and loss estimates • **if TURNkey sensors are fitted within a building**, bespoke estimates of acceleration and inter-storey drift at the building level • automated email and messaging system (including social media) for key employees and other stakeholders
Primary End User	CI, B
Secondary End User	CP (as authorising agent)
Success guarantee	An early estimates of ground shaking and damage state would allow the end user to:

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	• dispatch security and inspection teams to provide a real-time observational assessment of the actual damage state and functional capacity of the buildings with the most predicted damage state • information received from real-time observation would allow disaster management plans to be modified to reflect the actual situation on the ground The automated email and messaging system would allow the end-user to: • convene their disaster management committee and activate standard response protocols • inform key external stakeholders (including where appropriate members of the general public) of potential issues as part of stakeholder relationship management
Preconditions	The end-user has direct access to the TURNkey FWCR platform through the authorising agent to allow operational decisions to be actioned and recorded in real-time • communication systems, email and social media channels must be robust and operational after an earthquake
Success scenario	EEW alerts and early RRE damage and loss assessments are received in a timely manner and initial real-time assessments of damage states and functional performance are gathered (see UC10 for further details) that can directly inform local earthquake response and recovery actions, including early advice to external stakeholders (e.g. customers, regional/national disaster response agencies etc.) on service level functionality and estimated time of recovery

14.2.8 UC8: RRE to monitor the progress of response and recovery activities, including employee safety

Goal	To monitor the progress of recovery activities, including safety of those undertaking the activities
Use Case Instance	To achieve this goal TURNkey will provide the following: • a mobile app to each authorised employee engaged in the response and recovery process that will allow real-time reporting of actual damage state (including photographs) and functional performance of individual buildings to the TURNkey FWCR platform • early warning of potential ground shaking and an 'I'm safe' function to monitor the status of employees • regular updates and progress reports (via the TURNkey dashboard) of predefined disaster response protocols developed during the simulations
Primary End User	CI, B

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Secondary End User	CP (as authorising agent)
Success guarantee	Real-time reporting and updating of damage state would allow the end user to: • modify standard disaster management and response protocols and dispatch appropriate teams to address the real needs on the ground • issue advance warning of potential ground shaking requiring teams on the ground to move away from confirmed (through real-time assessments against EMS damage grades) damaged buildings • monitor the progress of recovery operations on a single dashboard • use of the 'I'm safe' function of the mobile app will allow central control room to monitor the safety of individual employees if ground shaking occurs
Preconditions	The end-user has direct access to the TURNkey FWCR platform through the authorising agent to allow operational decisions to be actioned and recorded in real-time • communication systems must be robust and operational after an earthquake; both between the end-user and their employees/external stakeholders and between the authorising agent and the TURNkey FWCR platform
Success scenario	RRE dashboard provides a single source for command and control of the response and recovery process resulting in more efficient actions; better customer/external stakeholder relationship management; and a more rapid recovery leading to reduced long-term critical infrastructure/business losses