SEISMIC RISK ASSESSMENT AS A BASIC TOOL FOR EMERGENCY PLANNING: "PACES" EU PROJECT

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ABSTRACT

The main steps of the seismic risk assessment as essential tool of the risk management process are presented, highlighting the need of its standardization for the development of emergency plans by the civil protection authorities. Some of the available seismic risk assessment methods and outcomes are illustrated and demonstrated through a seismic scenario application for Heraklion city, capital of Crete in Greece. The scenario application is part of the European Project "PACES" (Preparedness for Appropriate Accommodation in Emergency Shelters), funded by DG-ECHO, which aims to improve preparedness for accommodation of evacuees after an earthquake in emergency shelters, based on realistic seismic scenarios. Different earthquake scenarios have been simulated based on local seismic hazard, reference to one of which is made herein. Semi-empirical methodology for the assessment of the structural vulnerability of the exposed assets has been applied, as well as published loss models for the evaluation of monetary and human losses. The risk maps will enable updating of existing earthquake emergency plans, and allow the mapping of possible locations for shelters and engraving of evacuation routes, as illustrated by the pilot study of Heraklion city. Moreover, possible areas for mass evacuation can be identified, and health-care, as well as the response capacities of other local and governmental agencies, will be assessed accordingly. Finally, future challenges for the evolution of the preparedness policy by means of the risk assessment are discussed.

Keywords: risk management, seismic risk assessment, earthquake loss, emergency planning, structural vulnerability, risk scenarios, preparedness, emergency shelters, evacuees, casualties.

1 INTRODUCTION

Emergency planning, as an essential part of risk management, should reflect the social and state's need for the protection of life and property from disasters, and especially from the non-predictive earthquake hazard. Risk assessment is admitted, by both the scientific community and decision-making authorities, to be the key tool, for assessing the capacity of a community against seismic events, allowing for targeted decisions towards resilience enhancement. The latter involves the response and recovery of an active community against natural and man-made hazards. Hence, although the earthquake hazard cannot be predicted, the consequences from the seismic event can be mitigated by strengthening the preparedness level and increasing the resilience of the affected community.

The process of emergency planning through risk assessment requires the coordination of multiple working groups, from scientists to decision makers and first responders, healthcare services, from responsible authorities at all management levels to NGOs and the private sector. "PACES" (Preparedness for Appropriate Accommodation in Emergency Shelters) EU project involves the cooperation of all different partners, aiming to fostering preparedness at municipality, national and EU level and providing a common understanding of seismic risk. The need for updating of the existing contingency plans to reflect the most possible affected areas as a result of realistic loss estimates is revealed, highlighting the importance and utility of risk assessment. Moreover, these estimates are the basis for planning realistic based scenarios: table-top and small field exercises with all the benefits of testing the response

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capacities, highlighting the needs and shortfalls, and improving the seismic risk awareness of population, civil protection professionals and volunteers. The following sections include data and results obtained as outcome of the "PACES" EU Project.

2 SEISMIC RISK ASSESSMENT PROCESS

Risk assessment and risk mapping contribute to ensure that policy decisions are prioritised in ways to address the most severe risks with the most appropriate prevention and preparedness measures [1]. Moreover, "Risk management – Risk assessment Techniques" [2] (Fig. 1(a)) incorporates the overall process of risk assessment into risk management process by following: a) the *identification of the risk* by hazard and exposure recognition, b) the *risk analysis* as potential consequences composed by the assessment of the hazard impact level in quantitative terms, and c) the *risk evaluation*, which allows the classification of risk according to criteria. In other words, the risk management is based on scientifically supported risk assessment which leads to the needs identification for the *risk treatment* with measures in both the pre- and during-disaster phase.

2.1 Risk identification

The first step of the risk assessment process is the recognition of the risk. This includes the identification of the potential hazard, the definition of the extent of the area that will be studied, the establishment of the exposure model and the risk metric per type of impact. At

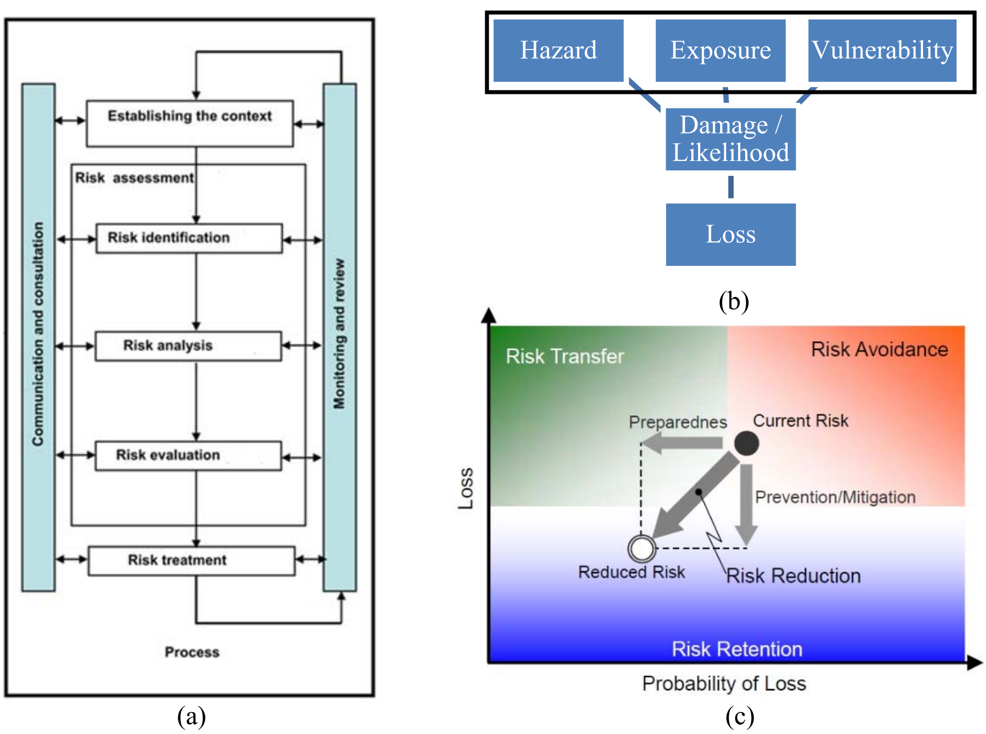


Figure 1: (a) Risk management process [2]; (b) Risk analysis input and output; (c) Concept of disaster risk treatment [3].

this stage, the risk scenarios that will be studied will be listed, according to the available hazard and exposure data, delineating the basic layer of the preparedness map.

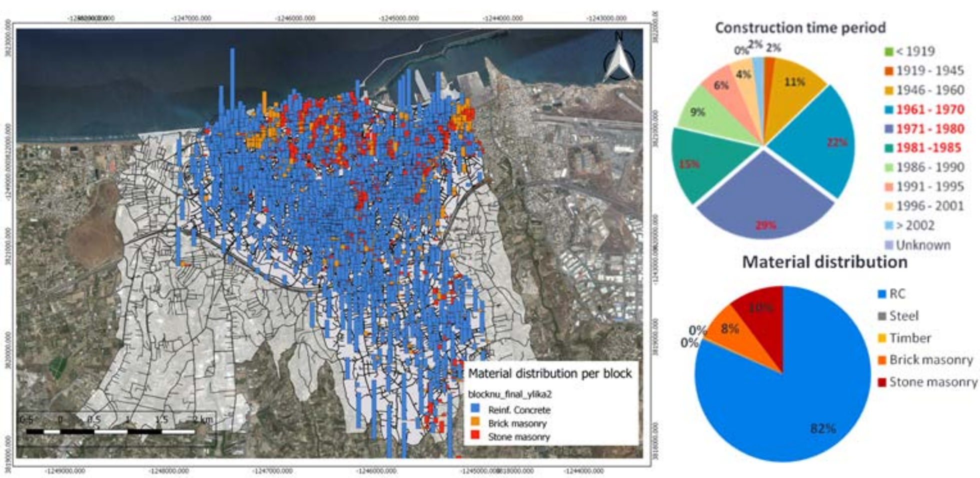
2.1.1 Elements at risk

Exposure refers to “people, property, systems, or other elements present in hazard zones that are subject to potential losses” [4]. Regarding the building stock, the data collection of the study area refers to the history of its development, construction details, urban settlement, maintenance level, etc. This can be performed remotely, on site or both. The types of data needed to build the exposure model are the following: a) building footprints from spatial data of the study city/area (digitized actual urban plan, georeferenced satellite, radar data, drone captured images etc.), b) building descriptive data provided by the census of structural wealth, which is often performed in parallel to the population census, and c) population and socio/economic spatially distributed data.

For the structural vulnerability classification and physical risk estimation, the main characteristics are: the construction material and structural resisting system, the number of storeys, the construction time period with respect to the seismic design code provisions, the building’s use, the interaction with the adjacent building in aggregates and the state of preservation, but also regularity of the building both in plan and elevation. It is often the case that, for privacy reasons, the correlation of the data of the general building census with the spatial footprints may be achieved only at a larger census tract level, which, however, is compatible with the urban risk studies principles. The spatial distribution of the buildings’ characteristics shown in Figure 2 for Heraklion city, allows for the recognition and study of the area at risk and supports risk management decisions.

2.2 Risk analysis

Following the flowchart of the risk assessment process (Fig. 1), the risk analysis is its most fundamental step. It includes the elaboration of all the data collected in the risk identification



(a) (b)

Figure 2: (a) Spatial distribution of building stock of Heraklion city per construction material; (b) Total building distribution per construction time period and material.

step and the final determination of risk. The risk can be defined as "the combination of the consequences of an event or hazard and the associated likelihood of its occurrence" [2].

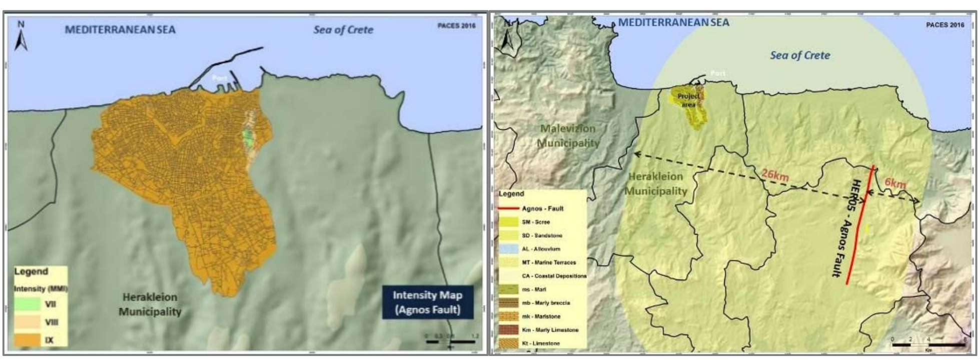
The risk analysis may be *qualitative*, where risk is described as high, medium, or low, or *quantitative*, where risk is described with a defined risk metric (e.g. number of casualties, displaced population, sum of direct, and indirect cost). The former can be expressed by a *risk matrix* which includes the following information: a) hazard (relative likelihood for qualitative assessment), b) impact (intensity of consequences), and c) risk criteria for scoring (high, medium, low risk). The quantitative assessment, further described below, despite the high detailed data demand for all risk modules, leads to quantifiable results which enable comparisons and may better reflect risk mitigation actions.

2.2.1 Seismic hazard analysis

Seismic Hazard is defined as the probability that an earthquake will occur at a given area, within a given window of time, and with ground motion intensity exceeding a given threshold. The seismic hazard assessment may follow two main approaches, the *probabilistic* (PSHA) and the *deterministic* (DSHA) approach. Moreover, when the hazard assessment is expressed in *qualitative terms*, historical mapped events and expert judgment might be used for characterization of hazard zones.

The *probabilistic assessment* involves identification and characterization of all hazardous sources for the target site, description of seismicity, determination of the motion intensity at each source and probabilistic calculations towards the recurrence period of the resulted maximum magnitude earthquake and ground motion exceedance. Worldwide, the probabilistic approach, highly refined and developed by seismic experts, is mostly applied at national/regional level studies and is commonly used in insurance related applications.

Due to the complexity of the probabilistic method, which stems from the need of deep knowledge of the historical seismicity of the study area as well as its seismotectonic and geotechnical environment, the *deterministic approach* is often favored for the establishment of preparedness maps and risk societal awareness. The latter involves the selection of specific earthquake scenario(s), which consist(s) of the potential activation of specific earthquake source(s) leading to the plausible description of "how the future may develop" [1]. DSHA provide a straightforward framework for a) the worst-case scenarios, e.g. the largest



(a) (b)

Figure 3: (a) Intensity distribution for DSHA assessment as result of the MCE selected scenario for Heraklion city; and (b) Probable affected area at the same scenario.

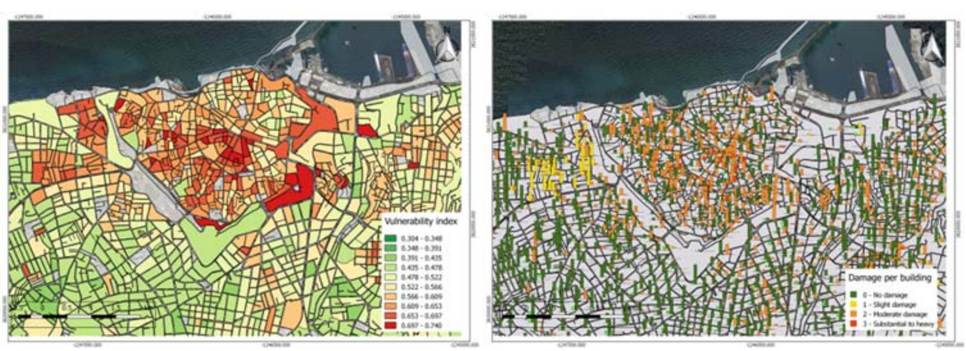
magnitude at the closest distance, defined as the Maximum Credible Earthquake (MCE), which is the case applied at Heraklion (Fig. 3); b) the most likely scenarios, using earthquake catalogues and scientific models, and c) the simulation of a past event of special interest based on available data. The prioritization of hazards, with regards to their severity and impact, leads to the final selection of the hazard scenario. For risk management procedures, this should be considered an illustrative realistic example of hazard and consequently risk representation, yet not the unique for which measures should be taken.

2.2.2 Physical and social vulnerability

Sendai Framework [5] quotes vulnerability as "the conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of a community to the impact of hazards", associating the vulnerability with both the physical environment and the human dimension of disaster.

The physical (structural) vulnerability is the first element taken into account for the creation of emergency plans, given that it directly reflects the response of the built environment on which the risk assessment, mapping and planning will be primarily based. This is defined as the degree of damage the elements at risk (exposed assets) are likely to experience. It is generally an intrinsic parameter of the studied structural system; it mainly depends on its structural, mechanical and geometrical characteristics, although the soil conditions are often responsible for modifying its structural behaviour. Mainly, methods of vulnerability analysis are divided into two main categories, with different possibilities and limitations based on the available level of information and resources and on the extent of the area under examination.

Empirical or *Macroseismic* methods are based on statistical observations of recorded damage data by strong past earthquakes and account for the fact that buildings with similar structural characteristics will experience common extent and type of damage. This is the concept of Damage Probability Matrix (DPM), first introduced by ATC-13 [6] and further adopted for the European data [7], [8]. Giovinazzi and Lagomarsino [9] proposed damage different risk metrics. In function to the hazard intensity, the conditional probability of being in or exceeding a particular damage state is defined by means of semi-empirical vulnerability functions (for empirical methods) or fragility curves (for analytical methods). Four or five



(a) (b)

Figure 4: (a) Mean vulnerability index per building block (vulnerability increases with ascending index); (b) Cumulative distribution of damage to buildings per block for analysed seismic scenario in Heraklion city.

probability functions based on the EMS-98 macroseismic scale [10], succeeding to quantify the qualitative DPMs. The “Vulnerability Index Method” [11] correlates the seismic action with the building response through an index established by damage survey data. In Figure 4a, the mean vulnerability index per building block for Heraklion building stock has been mapped using the Giovinazzi and Lagomarsino [9] macroseismic proposed methodology, being considered as scientifically accurate enough for European cities.

Analytical methods employ the fragility curves, i.e. continuous relationships expressing the conditional probability that different damage states will be exceeded at specified ground motion levels. These are developed through detailed analytical or simplified seismic assessment parametric study of building models, which account for all possible variations due to differences in geometric and material properties of buildings and all credible failure modes included in modern seismic design codes [12]. This approach is computationally intensive and time consuming therefore curves, scientifically generated, are often standardized per building typology for future similar applications [13], [14].

2.2.3 Impact

The evaluation of the direct *physical damage* of structural and non-structural components of the buildings stock is the first essential step that will lead to the evaluation of impact in damage states, in addition to the “No damage” state, depending on the selected methodology, describe the damage expected per building category. In Figure 4(b), the most probable damage assessed per building is cumulatively illustrated per building block. Regarding the case study examined herein, it is evident that the highest damage is concentrated in the most vulnerable (Fig. 4(a)) city centre.

The final *economic loss* for the built environment for a given seismic event (hazard scenario) or seismic intensity with return period (probabilistic method), is obtained by combination of the probability of occurrence per damage state and the respective assumed loss ratio per building typology. This is the ratio between the cost to repair a structure with respect to the cost of replacing with a new construction, in a discrete scale per damage state. The economic loss impact is the most comprehensive outcome for assessing and mapping the spatial distribution of the most affected zones considering the assessed damage with actual

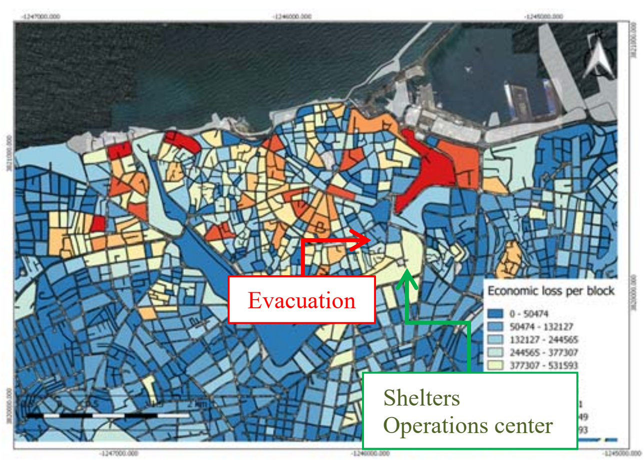


Figure 5: Economic loss map for analysed seismic scenario in Heraklion city used for emergency planning

building's value. The non-structural elements can be also included into the total economic loss when relevant information is available. The spatial distribution of loss for Heraklion is illustrated in Fig. 5, making use of the damage functions for reinforced concrete buildings developed by Kappos and Dimitrakopoulos [15] representative of local construction and design practice. With regard to masonry structures, the loss ratios proposed by Dolce et al. [16] are regarded as representative to the local masonry buildings and are used herein.

Human impact can be estimated in terms of casualties, as well as affected population in need of displacement and sheltering. The households in need of housing are distinguished in those seeking for *short-term shelter* and the *long-term displaced* ones, due to loss of habitability of their homes. The number of people seeking short-term public shelter is of great concern for the emergency response mechanism, while the longer-term impacts on the housing stock influence local governments' politics. The number of casualties is of high importance for the preparedness of the health-care local and regional system's performance.

Casualties are obtained as the number of deaths and injured by combining building occupancy and occupancy rate (to account for different temporal scenarios), building typology, expected damage and casualty ratios per damage state. The most common casualty models are those of Coburn and Spence [17], FEMA [13] and JRC [18] which focus on physical damage, neglecting potential aggravating factors linked to social vulnerability (e.g. healthcare access). Casualty ratios are specific to the particular building typologies, building practices, emergency response performance and other local conditions and thus, they should be ideally developed, or adapted according to engineering judgment and local (or at least national) historical evidences. They refer to the probability of one experiencing different levels of severity of injury, or even, fatality according to the damage the building suffers. The spatial representation of the casualties is suggested to be applied at a larger urban entity (and not at parish/building block level) since the models themselves incorporate high level of inaccuracy which may generate alarming results at small population groups. By all means, the generation of risk maps in terms of casualties, at a prevention or early warning stage, is very important for both the preparedness of the healthcare system (e.g. availability of the necessary number and typology of ambulances) and the immediate targeted intervention, respectively.

The expected casualties for the MCE scenario analysed in this study, for Heraklion city are summarized in Table 1, making use of Coburn and Spence [17] model for fatalities, as suggested by Kappos and Dimitrakopoulos [15] and FEMA [13] guidelines for the estimation of injuries. Severity 1 corresponds to injuries requiring basic medical aid, whereas Severities 2/3, merged together, include injuries requiring a greater degree of medical care even posing life threatening condition. It is important to highlight that the absolute values should not be considered but, instead, their order of magnitude should be used for guaranteeing post-earthquake adequate response (e.g. hospital beds, doctors).

Most of the models for the estimation of the affected population to be evacuated are based on the FEMA [13] methodology which calculates long-term displaced and immediate shelter-seeking populations as a function of probability of the considered structural damage to buildings and the registered population. More specifically, it is assumed that people from

Table 1: Casualties per severity for two temporal scenarios applied in Heraklion city.

	Day-time	Night-time
Fatalities	32	40
Severity 1	337	421
Severities 2/3	90	113

damage states 3, 4 and 5 (substantial, to heavy, very heavy and destruction) will be in need of short-term sheltering (Fig. 6a), while the population of buildings being in the last two states will urge long-term accommodation (Fig. 6b). Evidently, the latter corresponds to a lower number of persons; evacuees of the "red-tagged" ("dangerous for use") buildings. FEMA [13], and subsequently other researchers [19], [20], introduce reduction coefficients with respect to the total number of inhabitants based on social and demographic weight factors (ethnic, income, ownership, age) that may influence the decision for home evacuation. The decision upon the number and typology of shelters based on the risk assessment results will be further discussed in Section 3.

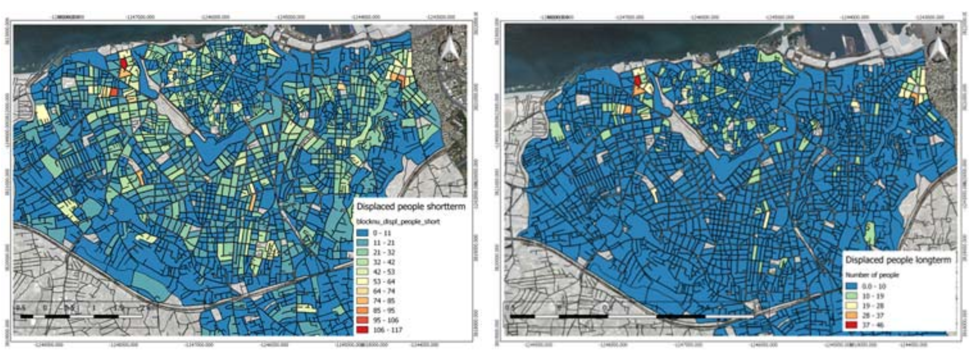
In the framework of the most modern *integrated* (or holistic) risk assessment approach [21], [22], the social vulnerability can be also modeled and convoluted with the outcome of the physical risk. Social vulnerability may be assessed through composite indicators constructed as a combination of social and economic indicators, such as demographic variables and economic status of the population, access to infrastructures and education, governance actions for treatment and mitigation of risk [23]. Mapping the integrated risk outcome makes clearer the influence of all contributors (hazard, built environment, socio/economic tissue) and provides additional tools to stakeholders for establishing up-to-date, customized to the real needs, plans.

2.3 Risk evaluation

Risk evaluation is the final stage of the risk assessment process and includes the comparison of the results of the risk analysis with risk criteria so as "to determine whether the risk and/or its magnitude is acceptable, tolerable or should be treated" [2]. The risk criteria are imposed through European and/or national regulations, guidelines and standards and include associated costs and benefits, impacts on quality of human life or even environmental factors. It should be noted that this step, although conceptually being the last one, it takes place throughout the entire risk evaluation procedure [24].

3 EMERGENCY PLANNING BASED ON SEISMIC RISK

Risk maps, being the outcome of the risk assessment process, are important tools for support



(a) (b)

Figure 6: (a) Spatial distribution of population in need of short-term shelter for analysed seismic scenario in Heraklion city; (b) Spatial distribution of population in need of long-term housing.

of the risk management strategy. Maps with the physical damage distribution provide to the authorities a first comprehensible picture of the most affected areas, based on the structural performance of the built environment. This may be done *qualitatively*, with colour tagging of the city by means of an average evaluation of the damage state per building block, or *quantitatively*, with maps illustrating the cumulative building number lying within a damage state. As discussed, the economic loss map, accounting also for the actual building cost, is the most comprehensive outcome of risk assessment. The map of Figure 5 presents a distribution of the structural losses of Heraklion with scaling in financial terms. Considering that the replacement cost is constant for all building typologies, it may be concluded that the map clearly highlights the most and less affected areas based on their vulnerability. Hence, in collaboration with the Civil Protection Authorities, with consultation of the urban plan and input regarding the configuration of road axes, the evacuation and response routes are engraved. Maps of affected population (displacement needs, casualties) (Fig. 6) are, additionally, taken into account in order to foresee potential needs of evacuation or rescue operations.

After an earthquake, as it is advised, people have to evacuate affected buildings (with small or heavy damages) at least for the whole aftershock period and the post-damage assessment of the buildings to be completed. Thus, the refuge areas after an earthquake can be distinguished in the *emergency assembly meeting points* (for a few hours), the *emergency shelters or sites* (for days to weeks) and the *temporary settlement areas* (for weeks to years). Essential part of the contingency planning against earthquake emergency is the identification of the most appropriate location for *emergency shelters* and *temporary settlement areas*. The former are open-space sites that satisfy safety criteria for short-term permanence. A sufficient number of, properly designated and evidenced to the public, sites should be distributed throughout the city. As regards the temporary settlement areas, these correspond to settlements required for long-term housing for evacuees from houses with extended repair or reconstruction needs. Both sites should have the appropriate facilities, size and conditions to accommodate affected population in respect to their needs. They should be located close to highly affected areas but not within them, taking into account that evacuees wish to stay in the proximity to their homes. Existing plans and land-use cadastre will be used, in combination with the risk maps and the absolute estimated figures, for the identification of the most appropriate and available locations either for emergency shelter sites or for temporary settlement areas. International guidelines on shelters and camp management should be followed [25]–[27]. As marked on Figure 5, the loss map is used for the identification of the “safest” areas for potential establishment of shelters and the most affected areas where evacuation may be deemed necessary.

Additionally, past and global experience may be used for the evaluation of the actual needs based on the risk assessment outcome (e.g. provision in tents, mobile homes). The experience of Italian civil protection in Regione Emilia Romagna [28] and CEDIM [29] is summarized, together with the input of FEMA [13] and the aforementioned guidelines. It is mentioned that not all displaced population will seek public shelter and, apart from demographic and cultural characteristics, this strongly depends on weather conditions, aftershock activity, proximity to the affected neighbourhoods, risk and damage perception and the proportion of the affected population. It has been observed that a large amount of the people fleeing their home are temporarily hosted by neighbouring households, when these are safe, and/or in cars and private tents when the weather allows it. More specifically, during 2012 Northern Italy earthquakes, only 40% of residents of uninhabitable dwellings were temporarily housed in the camps and 19% of the evacuees were in need of long-term housing.

For Heraklion city, based on local experience and taking into account lessons learned from other cases in Europe, it is assumed that 50% of the assessed affected population will be in the need of emergency public sheltering. It has been observed that people would opt first for individual solutions, such as accommodation in relatives' or friends' houses, in second houses, etc. To the final figures, the number of residents of non-damaged buildings are considered, due to fear, as well as the number of non-privileged social groups that may seek accommodation (e.g. case of Roma during 2014 Cephalonia earthquake). For the estimation of procurements in tents and other provisions, two facts should be taken into account. First, for Heraklion, as has been employed in other coastal cities in Greece, the use of ships is envisaged. Moreover, the human power available few hours after the shock is important in order to assess the maximum number of camps with tents that can be deployed in day 1. Seeking for the optimum time- and financially-wise solution, and considering that support in provisions will arrive within the first days from adjacent communities/regions, a realistic ratio of 25–30% of the affected short-term population may be assumed for the provisions and the planning in the pre-disaster phase.

With regard to long-term accommodation, it covers the needs of households for several months, even years. This may be provided with temporary solutions in public buildings, assessed and verified regarding their structural capacity, or by import of mobile homes. Similar to the previous approach, a ratio of no higher than 30% of the long-term displaced population may be finally in need of housing, taking also into account state's allowances for reduction in vacancy rates. Unfortunately, the housing recovery time can be hardly estimated as it depends on multi-variable parameters, such as household income, local market, state's subsidies, insurance claims, etc.

4 CONCLUSION/DISCUSSION

The establishment of an effective emergency planning as part of seismic risk management requires multi-jurisdictional effort, from different governmental authorities and agencies as well as cross-country experiences. The effective communication among them will enable the exchange of expertise, will reveal the needs and shortfalls and avoid duplication of efforts, which often lead to conflicting plans. In the framework of "PACES" EU project, the seismic risk assessment enables each partner to develop emergency plans according to the scientifically and empirically highlighted needs, following the concept of "avoiding highly affected zones for accommodation purposes while operate within them for evacuation".

The main steps of the risk management process were presented and demonstrated through a case study for Heraklion city in Greece. The results of the case study revealed several challenges and needs for the future of scientifically supported emergency management:

- Refined updated and interoperable geographical information data (remote sensing data, UAV imagery, GIS-data) and more accurate descriptive data.
- Update of micro zonation hazard maps, vulnerability and loss models for local characteristics.
- Regular review of emerging and evolving risks, methods and plans.
- Enrichment of maps with multi-hazard, multi-risk analysis results, taking also into account induced, secondary hazards, i.e. landslides, liquefaction, tsunamis, floods and fires.
- Integrated/holistic risk evaluation, taking into account social vulnerability metrics aggravating the final loss.
- Estimation of non-direct economic loss, such as business interruption and relocation cost, building content and inventory losses, loss of income, etc., to be provided to

stakeholders for consideration of risk transfer or retention measures (insurance, disaster fund).
- Standardization of all steps of seismic risk assessment procedure as an indispensable tool for planning by civil protection authorities. Harmonization of methodologies and data following experts experience on both scientific and managerial aspects.
- Implementation of risk communication strategy for several target groups, based on different risk perception levels and public needs, highlighting the importance of the final risk (loss) maps.

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REFERENCES

[1] SEC, Risk Assessment and Mapping Guidelines for Disaster Management. *Commission Staff Working Paper 1626*, Brussels, 2010.
[2] *Risk management – Risk assessment techniques,* International Organization for Standardization, p. 176, 2009. ISO31010.
[3] Asian Disaster Reduction Center (ADRC), *Total Disaster Risk Management – Good Practices*, pp. 11–17, 2005.
[4] United Nations International Strategy for Disaster Reduction (UNISDR), *Terminology on disaster risk reduction*, Geneva, Switzerland, 2009.
[5] United Nations, *Sendai Framework for Disaster Risk Reduction 2015-2030, 3rd UN World Conference*, 2015.
[6] Applied Technology Council (ATC), Earthquake Damage Evaluation Data for California, *Report ATC-13*, Redwood City, California, USA, 1985.
[7] Dolce, M., Masia, A., Marino, M. & Vona, M., *Earthquake Damage Scenarios of the Building Stock of Potenza (Southern Italy) Including Site Effects, Bulletin of Earthquake Engineering*, **1**(1), pp. 115–140, 2003.
[8] Eleftheriadou, A.K. & Karabinis, A.I., Development of damage probability matrices based on Greek earthquake damage data*, Earthquake Engineering and Engineering Vibration,* **10**(1), pp. 129–141, 2011.
[9] Giovinazzi, S. & Lagomarsino, S.A., Macroseismic Method for the Vulnerability Assessment of Buildings, *Proceedings of the 13th World Conference on Earthquake Engineering, Paper No. 896*, 2004.
[10] European Macroseismic Scale. *Cahiers du Centre Européen de Géodynamique et de Séismologie Vol. 15,* ed. G. Grünthal, European Center for Geodynamic and Seismology, Luxembourg, 1998.
[11] Applied Technology Council (ATC), *Rapid Visual Screening of Buildings for Potential Seismic Hazards, Report ATC-21*, Redwood City, California, USA, 1988.
[12] Kyriakides, N.C., Chrysostomou, C.Z., Tantele, E.A. & Votsis, R.A., Framework for the derivation of analytical fragility curves and life cycle cost analysis for non-seismically designed buildings, *Soil Dynamics and Earthquake Engineering*, **78**, 2015
[13] Federal Emergency Management Agency (FEMA), HAZUS-MH MR4. *Technical Manual – Multi-hazard Loss Estimation Methodology – Earthquake Model*, Washington D.C., 2003
[14] RISK-UE, *An advanced approach to earthquake risk scenarios, with applications to different European cities (2001–2004)*, 2004.

[15] Kappos, A. & Dimitrakopoulos, E., Feasibility of pre-earthquake strengthening of buildings based on cost-benefit and life-cycle cost analysis, with the aid of fragility curves, *Natural Hazards*, **45**, pp. 33–54, 2008.
[16] Dolce, M., Kappos, A., Masia, A., Penelis, G. & Vona, M., Vulnerability assessment and earthquake damage scenarios of the building stock of Potenza (southern Italy) using Italian and Greek methodologies. *Engineering Structures*, **28**, pp. 357–371, 2006.
[17] Coburn, A. & Spence, R., *Earthquake Protection*, John Wiley: Chichester, UK, 2002.
[18] Guidelines for the consideration of socio-economic impacts in seismic risk analysis. Joint Research Centre. *Institute for the Protection and Security of the Citizen. SYNER-G Reference Report 5*, pp. 178.
[19] Chang, S.E., Pasion, C., Yavari, S. & Elwood, K., Social Impacts of Lifeline Losses: Modelling Displaced Populations and Health Care Functionality. *Proceedings of Technical Council on Lifeline Earthquake Engineering (TCLEE) Conference*, pp. 563–572, 2009.
[20] Khazai, B., Braun, J. & Vangelsten, B.V., Definition of a group of output indicators representing socio-economic impact from displacement in emergency/temporary shelter. *Tech Report D4.1 of the SYNER-G project,* p. 70, 2011.
[21] Burton, C.G. & Silva, V., Assessing Integrated Earthquake Risk in OpenQuake with an Application to Mainland Portugal. *Earthquake Spectra*, **32**(3), pp. 1383–1403, 2016.
[22] Carreño, M.-L., Cardona, O. & Barbat, A., Urban Seismic Risk Evaluation: A Holistic Approach. *Natural Hazards*, **40**, pp. 137–172, 2007.
[23] Cutter, S.L., Boruff, B.J. & Shirley, W.L., Social vulnerability to environmental hazards. *Social Science Quarterly*, **84**, pp. 242–261, 2003.
[24] Papathoma-Köhle, M., Promper, C. & Glade, T.A., Common Methodology for Risk Assessment and Mapping of Climate Change Related Hazards—Implications for Climate Change Adaptation Policies. *Climate,* **4**(8), 2016. Doi:10.3390/cli4010008.
[25] Federal Emergency Management Agency (FEMA), *Guidance on Planning for Integration of Functional Needs Support Services in General Population Shelters*, Washington, D.C., 2010.
[26] The Sphere Project, *Humanitarian Charter and Minimum Standards in Humanitarian Response*, **3**, p. 206, 2011.
[27] European Commission (ECHO), Shelter and Settlements. *DG ECHO Thematic Policy Document*, 2017.
[28] Regione Emilia Romagna, I Danni del terremoto e le politiche messe in campo per affrontare l'emergenza e la ricostruzione, *Primo bilancio*, Bologna, 2012.
[29] CEDIM Forensic Earthquake Analysis Group, *Shelter report for the Oct.23 2011 Eastern Turkey Earthquake*, GFZ Potsdam, 2011.