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# LOSS ESTIMATION SOFTWARE: DEVELOPMENTS, LIMITATIONS AND FUTURE NEEDS

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**ABSTRACT**

Hazard assessment and loss estimation analysis, benefit at the time being from a broad variety of modeling platforms and software tools helping to model the complex system and interactions between structure, infrastructure and multi-hazards. Those platforms are offered as open sources, semi-open or fully closed tools. The modules and associated analysis functions included in the platforms are typically related to hazard, fragility and loss assessment, as well as to visualization and reporting of the results. They are undeniably a great helping tool for engineers, decision makers and planners. Indeed, assessment of losses (physical or/and socio-economic) might considerably help to i) identify likely failures and performance of structural and infrastructure systems, thus allows taking adequate measures to enhance their performance; ii) prepare recovery plans for disaster events. Many tools are limited to seismic loss estimation and others offer a wider range of hazard applications. Some are user friendly, while others are more complicated for the user depending on the information technology platform used and the type of analysis they perform. In this paper, a review and comparison of on-market available tools are proposed, and then developments, limitations and future needs are discussed.

*Keywords: Loss Estimation; Software; Natural hazard; Vulnerability; Risk*

## 1. INTRODUCTION

In the last decades, a great interest was given to seismic loss mitigation of the built and populated environment at macro-level with different scales presented in an increasing order: districts, city, region, and country. The aim is to propose a management strategy, where the loss estimation is done in a proactive way by modeling a pre-earthquake scenario, or/and a recovery plan where the pre-earthquake scenario is updated in a reactive way by modeling the post-earthquake fixed scenario.

The considerable progress and scientific achievements over the past years in structural and geotechnical engineering and in seismology as well as the lessons learnt from numerous destructive earthquakes all over the world that resulted to valuable data and experiences have contributed to the development of advanced loss estimation methods and tools. In the other hand, the significant progress made over the last quarter of the twentieth century in the fields of informatics technologies and computer sciences has facilitated the development and implementation of various powerful tools to evaluate loss estimations (such as HAZUS, SELENA, Ergo, CAPRA, ELER, etc). Moreover, the real geographical localization of data related to structures and infrastructures using geographical information system (GIS) and remote sensing technologies have helped to create comprehensive databases and systems for data visualization, analysis, and damage evaluation.

Many countries have developed their own versions and tools, with different levels of sophistication, such as HAZUS, HAZTURK, EQviz, HAZ-TAIWAN, RiskScape, etc. The aim of those tools is to reduce seismic risk worldwide by promoting international cooperation of practitioners and researchers, knowing that «*Earthquake science is a global science, indifferent to political or physical boundaries,*

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*as evidenced by the Great Indian Ocean Earthquake and Tsunami of 2004, which caused life loss and destruction in a dozen nations*», as was noted in Gulkan and Reitherman (2012).

Moreover, resilience-thinking which surfaced in the last decade, encouraging cross-disciplines dialogues and promoting the importance of the societal factor in the risk management along with the structure and infrastructure component, makes loss estimation software a key tool to enhance community resilience. Therefore encouraging the establishment of disaster mitigation plans at national and local levels, focusing on prevention and preparedness, rather than post-disaster response and recovery. The software is often customized to the demands of the insurance industry to perform the computation of economic losses in a portfolio of insured assets, such as buildings and contents as well as business interruption. Most of the loss estimation software was initially developed for seismic hazard, however software algorithms are frequently expanded to include other hazards (e.g. tsunami, hurricanes, floods etc). In the following, a list of the available software is presented, while the most frequently used ones are briefly described, discussed and compared. Then the paper concludes and presents future needs.

## 2. LOSS ESTIMATION SOFTWARE

The loss estimation procedures are mainly based on four main modules: hazard, inventory/typology, vulnerability, and damage and loss analysis.

**Hazards**: might be scenario-based or probabilistic assessment. The scenario-based approach provides deterministic hazard maps generated for given hazard scenarios (e.g. given magnitude and location in case of earthquake hazard). The probabilistic approach considers all possible events, for example by means of probabilistic seismic hazard analysis (PSHA) in case of earthquake hazards. Based on Jayaram and Baker (2009) and Malargia et al. (2017), both methods preferably need to be considered.
**Inventory/typology**: includes the topology and main characteristics of the elements at risk, which are required for the definition of the elements' typology as well as their vulnerability and risk assessment.
**Vulnerability:** adequate fragility curve dataset and a fragility mapping dataset are selected and/or ingested for each typology of elements at risk.
**Damage and loss estimations:** damage analysis is achieved by creating and running several scenarios, based on the chosen inputs of ingested data. Damage is assessed by means of fragility functions that make use of the inventories and typologies. Damage is correlated to direct and indirect losses (e.g. casualties, repair costs, restoration time, functionality loss etc). The loss estimations are presented through maps, tables, and graphs.

In this paper, a list of at least 50 software for earthquake loss estimation was gathered. The main characteristics of the software are presented in Table 1. Those characteristics are: Name, Open source, Region, Ownership, Hazard type/ Peril (earthquake, flood, hurricane, tsunami, storm, wind, surge, wave), Exposure (district, city, regional, country, and multiple-levels), Programming language, GIS-based, Institution, Location, Hazard modeling (deterministic predicted, deterministic observed, probabilistic), Vulnerability (empirical, analytical). The list is mainly based on Daniell (2011) and World Bank (2014) reports. The following terms were used: Hazard type: E= Earthquake; F= Flood; H= Hurricane; T= Tsunami; St= Storm; Wi= Wind; Su= Surge; Wa= Wave. Exposure: d= District; Ci= City; R= Regional; Co= County; ML= Multiple-Level. Hazard modeling: DP= Deterministic Predicted; DO= Deterministic Observed; P= Probabilistic. Vulnerability: E= Empirical; A= Analytical. Opensource: OS = opensource, CS = Closed source, SA = standard application (upon request), SC = source code (upon request). Other software is available such as ESCENARIS, KOERILOSS, NHEMATIS, QUAKELOSS, HEC-RAS/HEC-HMS/HEC-FDA/HEC-FIA HEC Suite, but are not presented in Table 1.

Finally, 15 tools were selected for further discussion. The first 10 were chosen based on Daniell (2011), who classified software using the multicriteria analysis (MCA) of Stafford et al. (2007): MAEviz (now named Ergo), DBELA, SP-BELA, ELER, SELENA, StrucLoss, EQRM, HAZUS, EQSIM, CAPRA. In addition, the following software is debated: HAZTURK, HAZ-TAIWAN, GEM tools, OOFIMS (SYNER-G), QLARM. Finally, some newly available tools are also presented.

### *2.1 Ergo (ex-MAEviz, ex-mHARP) and (HAZTURK, EQvis, SYNER-G)*

Ergo ranked top-1 based on the MCA presented in Daniell (2011) and Stafford et al. (2007), and was one of the best ranked by the World Bank report (2014). A Hazus-based application, the ex-mHARP, ex-MAEviz (Mid-America Earthquakes Visualization) was developed by Mid-America Earthquake Center (MAE) and National Center for Supercomputing Applications (NCSA) at the University of Illinois. The initial purpose was to perform seismic risk assessment in the Middle States of USA. Aiming to allow users to add their own hazard data, it uses a combination of Sakai (an open source web portal), SAM (Scientific Annotation Middleware), and NEESgrid (a framework of tools to allow researchers to collaborate).

The software is completely open source, has a Windows-based format, is a visually driven system, it features inbuilt GIS, and it is deemed to be among the most efficient software for scenario risk assessment and decision support (mitigation, benefit-cost). It has a large array of modules and infrastructure types for analysis (at least 48) allowing the estimation of hazard impact on lifelines, social or economic systems. It is improved continuously by a developer community through the Ergo Consortium. The software is user-friendly and easily extendable. It contains detailed hazard, vulnerability, and risk management modeling. It has already been integrated into HAZturk (Turkey Platform) (Karaman et al. 2008), EQvis (European platform), and has been used in the SYNER-G platform, a European Union (EU) project (Pitilakis et al. 2014), which has added a large fragility function manager to it, in addition to other tools. Moreover, it was expanded to consider datasets from Turkey and worldwide in recent versions. Ergo is open source software.

### *2.2 HAZUS*

HAZUS (Hazards U.S.) was proposed by FEMA during the '90s, to calculate the earthquake damage to buildings, infrastructure and populations over a census tract, county, or state in the United States. Earthquake hazard includes ground shaking and ground failure due to liquefaction, fault rupture and landslide (Kircher et al. 1997). It was developed progressively to become a multi-hazard tool, to estimate potential losses from earthquakes, floods, hurricanes, and tsunami. The methodology includes classification, fragility and restoration models for all the elements at risk. It allows for the calculation of losses to buildings, infrastructure, and lifelines, as well as social loss (such as casualties, injures, homelessness and disruption) and economic loss. HAZUS is heavily calibrated to U.S. conditions, and it operates only with the commercial software ArcGIS. It is GUI (Graphical User Interface) and allows ShakeMap input. Hazus, is a semi-open source software, and it is mainly applicable for the USA since data is implemented for this area; the code itself is not open.

### *2.3 DBELA and SP-BELA*

DBELA (Displacement Based Earthquake Loss Assessment) and SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment, Borzi et al. 2008) were developed at the EUCENTRE in Pavia, Italy. They provide vulnerability assessments for reinforced concrete and masonry structures based on the displacement capacity and simplified pushover methods respectively. They are considered as probabilistic approaches, using statistical exposure data, and Monte Carlo simulation to produce the building database for the vulnerability analysis. Damage distribution is obtained for three limit states, while uncertainties are taken into account. The methodology used in DBELA was described in Crowley et al. (2004), Calvi et al. (2006), Bal et al. (2008) and has been extended by Silva et al. (2013). Daniell et al. (2009) used DBELA for Istanbul datasets and found that it offers, for some of the datasets, more accurate results than HAZUS; nevertheless, it is more time-consuming. SP-BELA has a different code built structure representing the structure and thus the shear capacity. It is not easily adaptable to different building types outside the European-Mediterranean region. Currently, SP-BELA is not in software form and was not applied to a large dataset. The methodology can be used easily in SELENA, EQRM or OSRE and can be used to update some vulnerability approaches used in HAZUS.

DBELA is open source, while SP-BELA is semi-open.

### *2.4 ELER*

ELER (Earthquake Loss Estimation Routine) has been developed within the EC FP6 project NERIES (NEtwork of Research Infrastructures for European Seismology) by Bogazici University of Istanbul, together with researchers from Imperial College, NORSAR, and EMSC (Stafford et al. 2007, Erdik 2007). It is a multi-level methodology comprising five steps: detailed ground motion prediction uncertainty and regional variability analysis and source parameters, estimation of ground motion using geological and geotechnical information, incorporation of strong motion data in the form of a ShakeMap. Thus by means of the exposure and vulnerability methodology, it is able to produce a Loss Map with the regional losses (Erdik et al. 2008). The code has two modules of analysis, which are EHA (Earthquake Hazard Assessment) and ELA (Earthquake Loss Assessment). The ELA module has three levels; Level-0 estimates casualties based on the magnitude and intensity information; Level - 1 estimates casualties and building damages based on intensity information; Level-2 estimates casualties and building damages based on ground motion and spectral parameters. The latest version includes pipeline damage estimation and economic loss estimation tools, and allows the user to input hazard maps, and to define easily new building types and their associated vulnerability values. The outputs are in the form of a shape file, the software is tailored to scenario based analyses as well as for quasi-real time rapid earthquake loss assessment, while a default building inventory corresponding to an approximated European database is available. The platform allows calculations that are conditional on the hazard with a given return period, which makes it difficult to perform a fully probabilistic risk assessment. Recently has been used to a “proof of concept” study for seismic risk assessment at pan-European level using open datasets available across the EU (Corbane et al. 2017). ELER is open source software.

### *2.5 SELENA*

SELENA (Seismic Loss EstimatioN using a logic tree Approach) is proposed by NORSAR with support from the International Centre for Geohazards in Norway. It is mainly based on the HAZUS methodology and uses a logic tree approach for the weighting of the input parameters in order to consider epistemic uncertainty (Molina and Lindholm, 2005, 2007). The hazard analysis is probabilistic, real-time, or deterministic. The physical damage to the building stock is computed by applying Capacity Spectrum-based methods.  Damage and loss estimates are provided on the level of geographical units.

The software benefits from a GUI. It allows all types of disaggregation and logic trees in order to calculate loss. It uses Octave (or stand-alone Matlab format. It is fully open source as long as the user has Matlab). Moreover, RISe (Risk Illustrator for SElena) was created (associated with GIS viewer) to allow easy viewing of the results from the SELENA analysis (Lang et al. 2008). However, as it was noted in the World Bank report (2014), outputs are difficult to manipulate, while the number of input text files makes it complicated to run without errors. Meanwhile, each year, SELENA undergoes constant developments to incorporate the latest state-of-the-art as well as requests from users and many versions were released. SELENA is open source.

### *2.6 StrucLoss*

StrucLoss 1.4, developed by the Earthquake and Structural Department of Gebze Institute of Technology in Istanbul – Turkey, is the updated version of KOERILoss 1.0 (Kandilli Observatory and Earthquake Research Institute Loss Estimation Software). It was produced as part of the EC FP6 LESSLOSS project for the case study of Istanbul. Damage estimation is done using both: macroseismic intensity methodology and HAZUS-like spectral displacement vulnerability methodology. It considers deterministic and probabilistic approaches for earthquakes. Direct economic, social losses, and vulnerability curves for various building types are derived from the damage classes as well as. StrucLoss is a semi-open source.

### *2.7 EQRM*

EQRM (Earthquake Risk Model) is a regional earthquake risk assessment tool developed by Geoscience Australia (GA) for Australian cities. It utilizes a Python or Matlab-based program created based on the HAZUS model. It is capable of earthquake scenario ground motion and scenario loss modeling as well as probabilistic seismic hazard (PSHA) and risk (PSRA) modeling. It includes a regional seismicity model, attenuation model, regolith site response model, elements at risk (social demographics, building inventory), building vulnerability model (capacity), casualty and injury models, and economic loss model.

The software provides a large number of visualization options for the hazard (uniform hazard spectra, hazard exceedance, and probabilistic seismic hazard analysis) and for the risk (AAL, PML, disaggregation), moreover, it includes a large number of building typologies. It was the first software to calculate event-based PSHA with a great level of detailed analysis, and it still has the lead for physical risk output options in terms of annual losses and risks. It is a completely open source and extendable (only in its Python version, the Matlab version is closed-source), but it is lacking the GIS integration (World Bank report 2014).

### *2.8 EQSIM*

EQSIM (EarthQuake damage SIMulation) tool has been developed by the University of Karlsruhe, is heavily based on HAZUS and includes the integrated Disaster Management tool (DMT). EQSIM uses up-to-date reconnaissance techniques such as damage detection by means of airborne laser scanning data and response tools for coordination; communication and information after an earthquake as part of the Disaster Management Tool (DMT). In the same way as EPEDAT, a detection support system is offered to analyze data after the earthquake and to combine it with pre-earthquake data. An "augmented reality" system is included; it enables individual buildings to be observed in terms of their structural weaknesses post-earthquake (Daniell 2011). It is not open source. The detailed method was presented by Markus et al. (2004), among other publications, which provide an insight into using tools and methodologies. An open source version will be available soon at www.eeqsim.com, under the name of eEQSIM.

### *2.9 CAPRA*

CAPRA (Comprehensive Approach to Probabilistic Risk Assessment) is a risk modelling platform released in 2008. It is an on-going initiative that has been developed in different phases with the financial support, in the beginning, of the World Bank, the Inter-American Development Bank and the UNISDR. Is a freely available software for disaster risk modelling, incorporating models for 8 different natural hazards into the same probabilistic risk assessment framework, including earthquakes, tsunami, landslides, volcanic eruptions, tropical cyclones, convective rainfall, floods, and droughts. The main core of CAPRA is composed of 14 software modules (Bernal and Cardona, 2018, Reinoso et al. 2018). SMA (Strong Motion Analyst) focuses on the processing of strong-motion signals and seismological data; SMS (Seismic Microzonation Studio) focuses on the dynamical soil response of 3D geological environments; CRISIS 2015 is the seismic hazard and tsunami module; TCHM (Tropical Cyclones Hazard Modeler) is a state-of-the-art hazard calculator for cyclonic wind and storm surge; FA (Flood Analyst) and SRM (Stochastic Rainfall Modeler) provide the tools for flooding modeling; LHM (Landslide Hazard Mapper) focuses on the calculation of landslide susceptibility and hazard; VHAST (Volcanic Hazard Analysis and Simulation Tool) incorporates probabilistic methodologies to account for volcanic hazard; Drought Pro provides cutting-edge tools for drought simulation; EE (Exposure Editor) focuses on the construction and management of geo-databases for exposed elements; VS (Vulnerability Studio) focuses on the computation and edition of vulnerability functions; CAPRA-GRM is the risk calculation engine; EvHo performs holistic evaluations of risk; and FileCAT provides data management capabilities to the overall set of programs.

CAPRA was developed entirely in Visual Basic.NET and is available at no cost. Variability and uncertainty are nicely handled. Inbuilt GIS related directly to the loss calculations is available, GIS is modular and extendable. Few fatality functions and economic functions are available. The source code of CAPRA is available. It was funded by World Bank, CEPREDENAC, UNISDR, SFLAC, DFAT-AG, and IDB and is developed by ERN Ingenieros Consultores S.C, INGENIAR: Risk Intelligence and CIMNE.

### *2.10 OpenQuake*

OpenQuake is a tool for earthquake loss estimation developed as part of the Global Earthquake Model (GEM). In particular, OpenQuake is a web-based risk assessment platform, which offers an integrated environment for modelling, viewing, exploring and managing earthquake risk (Silva et al. 2014). The platform includes the following types of analysis: scenario damage assessment, scenario risk assessment, classical probabilistic seismic damage analysis, classical probabilistic seismic risk analysis, stochastic event based probabilistic seismic risk analysis, retrofit benefit-cost ratio analysis. OpenQuake is widely used in seismic risk analysis studies (e.g. Silva 2015, Faravelli et al. 2018). It provides a consensus from some earthquake experts globally through a stakeholder process for some parts of the software. It is open-source software written in the Python programming language, available on a public repository.

### *2.11 OOFIMS*

OOFIMS (Object-Oriented Framework for Infrastructure Modeling and Simulation) has been developed (Franchin and Cavalieri, 2013) within EC FP7 SYNER-G project, as a computational tool to assess the vulnerability and risk to earthquakes of an urban area including buildings, lifelines, and critical facilities. The tool is coded in MATLAB language according to the object-oriented paradigm (OOP), allows to model and analyze the performance of interconnected/interdependent infrastructure systems (road, electric power, water supply, storm water, gas, hospitals) and sets of buildings, at the urban/regional scale, in ordinary or "disturbed" conditions (e.g. due to the impact of a natural or man-made hazard). It includes models for spatially distributed seismic action, in terms of ground shaking (peak ground motion parameters, spectral acceleration or velocity) and geotechnical intensity measures (permanent ground deformations). The input and output files are given in xml format, while GIS shape files, can also be used for input linked to the xml. The framework has been applied to assess the systemic vulnerability and risk of different infrastructure (Cavalieri et al. 2014, Esposito et al. 2014, Argyroudis et al. 2015, Cavalieri et al. 2016) and has been adapted for tsunami and volcanic hazards (Gehl et al. 2013). The source code and example files are freely provided.

### *2.12 QLARM, EPEDAT and PAGER (Rapid earthquake loss assessment after damaging earthquakes)*

QLARM provides loss estimates for earthquakes after the event. The post-earthquake alerts issued include the number of fatalities and injured and average damage to buildings in the affected areas. This service is carried out in partnership between WAPMERR (World Agency of Planetary Monitoring and Earthquake Risk Reduction) and the Swiss Seismological Service (SED-ETH, Zurich). QLARM is an outgrowth of the former QUAKELOSS software. The estimates include: (1) The expected percentage of buildings in each of five damage states in each settlement, (2) the mean damage state in each settlement, (3) the numbers of fatalities and injured, with error estimates, in each settlement. The loss estimates are provided in about 30 min after the earthquake (Erdik et al. 2014). The source code is available under request.

EPEDAT (Early Post-Earthquake Damage Assessment Tool) was developed by EQE International, Inc. for post-earthquake loss estimation in California (Eguchi et al. 1997). The output includes estimates for building and lifeline damage and for casualties based on county housing and demographic data. It is Windows-based and uses Modified Mercalli Intensity to quantify the hazard.

PAGER (Prompt Assessment of Global Earthquakes for Response) provides fatality and economic loss impact estimates following significant earthquakes worldwide. The estimates are generally available within 30 minutes and are updated as more information becomes available. Rapid estimates include the number of people and names of cities exposed to each shaking intensity level as well as the likely ranges of fatalities and economic losses. PAGER does not consider secondary effects such as landslides, liquefaction, and tsunami in loss estimates at this time.

It is noted that for rapid loss assessment after an earthquake the fast and reliable information on the source location and magnitude is essential. Moreover, the availability of adequate inventory data and fragility models for the affected area is critical. However, only limited number of countries and cities has well-developed building inventories. Several efforts such as PAGER and Global Earthquake Model (www.globalquakemodel.org) projects aim, to develop global building inventory databases and fragility models.

### *2.13 Newly available tools*

Some other tools for loss estimation have been recently developed: The Interdependent Networked Community Resilience Modeling Environment (IN-CORE), which is built upon the Ergo software, allows the modeling of the impact on interdependent infrastructure of earthquakes, windstorms, tornadoes, tsunamis, and wildland urban interface fires as well their recovery (Gardoni et al. 2018). The Cyber Physical System built on Ergo, for disaster response for high-rise complex facilities in Korea (Suh et al. 2018). Earl, an interactive toolbox that facilitates story-based building-specific earthquake-induced risk and loss assessment, providing loss vulnerability curves and expected annual losses (Elkady et al. 2018). SeisDaRo for the estimation of seismic damage in Romania, relying on the SELENA software and HAZUS methodology, and more recently on USGS's PAGER methodology, while is also functional in real-time (Toma-Danila et al. 2018). The Middle East and North Africa (MENA) Earthquake Model developed by Willis Re, capable of quantifying losses for a region which has historically not been covered comprehensively by catastrophe models (Schmid et al. 2018).

Table 1. Overview of existing loss estimation software.

| Name | Open source | Hazard type / Peril | | | | | | | | Exposure | | | | | Hazard modeling | | | Vulnerability | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | E | F | H | T | St | W | Su | W | D | Ci | R | Co | ML | DP | DO | P | E | A |
| **CAPRA** | OS | X | X | X | X | X | | | | | | | | X | X | X | X | X | X |
| **CATS** | OS | X | | | | | | | | | | | | X | X | X | | X | |
| **DBELA** | OS | X | | | | | | | | X | X | | | | X | X | X | | X |
| **ELER** | SA | X | | | | | | | | X | X | | | | X | X | X | X | X |
| **EmerGeo** | - | | | | | | | | | | | | | X | X | | | X | |
| **EPEDAT** | CS | X | | | | | | | | X | X | | | | X | X | | X | |
| **EQRM (Mathlab)** | CS | X | | | | | | | | X | X | | | | X | | X | X | X |
| **EQRM (Python)** | OS | X | | | | | | | | X | X | | | | X | | X | X | X |
| **EQSIM** | CS | X | | | | | | | | X | X | | | | X | X | | | X |
| **Extremum** | CS | X | | | | | | | | | X | X | X | | X | X | | X | |
| **HAZ-Taiwan** | CS | X | | | | | | | | | | | | X | X | X | X | | X |
| **Hazus-MH** | OS | X | X | X | X | | | | | | | | | X | X | X | X | | X |
| **InLET** | CS | X | | | | | | | | X | X | | | | X | X | | X | |
| **Insafe** | OS | X | X | | X | | | | | | | | | | | | | | |
| **LNECLOSS** | CS | X | | | | | | | | X | X | | | | X | | | | X |
| **PAGER 2010** | SA | | | | | | | | | | | | | X | | X | | X | X |
| **Ergo (MAEviz/ mHARP)** | OS | X | | | | | | | | D | | | | | X | X | X | X | X |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **OpenQuake** | OS | X | | | | | | | | | | | | | | | | | |
| **OPENRISK** | OS | X | | | | | | | | | | | | X | X | X | X | X | |
| **OSRE** | OS | X | | | | | | | | | | | | X | X | X | X | X | |
| **PAGER v1** | CS | X | | | | | | | | | X | X | X | | | X | | X | |
| **QLARM** | SC | X | | | | | | | | | X | X | X | | X | X | | X | |
| **QL2** | CS | | | | | | | | | | X | X | X | | X | X | | X | |
| **RADIUS** | OS | X | | | | | | | | | X | | | | X | | | X | |
| **REDARS** | CS | X | | | | | | | | X | X | X | | | X | X | X | X | |
| **RiskScape** | SA | X | X | | X | X | X | | | X | X | X | | | X | X | | X | |
| **ROVER-SAT** | SA | | | | | | | | | | | | | X | X | X | | X | |
| **SAFER** | OS | X | | | | | | | | X | X | | | | X | X | X | X | X |
| **SELENA** | OS | X | | | | | | | | X | X | | | | X | X | X | | X |
| **SES2002 & ESCENARIS** | CS | X | | | | | | | | | | | | X | X | X | | X | |
| **SIGE** | CS | X | | | | | | | | | | | | X | X | X | | X | |
| **SP-BELA** | CS | X | | | | | | | | X | | | | | X | X | X | | X |
| **StrucLoss** | CS | X | | | | | | | | X | X | | | | X | | X | X | X |
| **BASEMENT** | OS | | X | | | | | | | | | | | | | | | | |
| **Delft-3D-FLOW** | OS | | X | | X | X | | | | | | | | | | | | | |
| **Kalypso** | OS | | X | | | | | | | | | | | | | | | | |
| **NoFDP IDSS** | OS | | X | | | | | | | | | | | | | | | | |
| **Sobek Suite 1D/2D with HIS-SSM** | OS | | X | | | | | | | | | | | | | | | | |
| **TELEMAC-MASCARET** | OS | | X | | | | | | | | | | | | | | | | |
| **TCRM** | OS | | | X | | X | X | | | | | | | | | | | | |
| **SLOSH** | OS | | | | X | X | | X | X | | | | | | | | | | |
| **TOMAWAC Wave** | OS | | | | | | | | X | | | | | | | | | | |
| **TsuDAT using ANUGA** | OS | | | | X | X | | X | X | | | | | | | | | | |
| **HAZTURK** | CS | | | | | | | | | | | | | | | | | | |
| **OOFIMS (SYNERG)** | SC | X | | | | | | | | | | | | X | | | X | X | X |

| Name | Region | Ownership and/or Institution | GIS based | Programming language |
|---|---|---|---|---|
| **CAPRA** | Central America | EIRD / World Bank | No | Visual Basic.NET |
| **CATS** | North America | DTRI, FEMA / FEMA, ESRI | Yes | ESRI ArcView |
| **DBELA** | World | EUCENTRE | No | Matlab |
| **ELER** | Europe | NERIES / JRA-3, NORSAR, Imperial | No | Matlab |
| **EmerGeo** | World | EmerGeo | | |
| **EPEDAT** | North America | California OES / EQE International | No | Windows-based, Mapinfo |
| **EQRM (Mathlab)** | Australia | Geoscience Australia | No | Matlab |
| **EQRM (Python)** | Australia | Geoscience Australia | No | Python |
| **EQSIM** | Europe | CEDIM / KIT | No | C++, xmf |
| **Extremum** | World | Extreme Situations Research Center Ltd. | Yes | Windows-based, GIS |
| **HAZ-Taiwan** | Asia | National Science Council / NCREE | No | Microsoft Visual C++ and MapInfo |

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|---|---|---|---|---|
| **Hazus-MH** | North America | FEMA, NIBS / USGS | Yes | VB6, C++, ArcGIS |
| **InLET** | North America | ImageCat, Inc. | No | Js, Windows |
| **Insafe** | | AIFDR | No | Java, QGIS plugin |
| **LNECLOSS** | Europe | LNEC, Consortium | No | Fortran |
| **PAGER 2010** | World | USGS | | |
| **Ergo (MAEviz/ mHARP )** | World | University of Illinois at Urbana Champaign | Yes | EclipseRichClient, Geotools |
| **OpenQuake** | | GEM | No | Python, Java |
| **OPENRISK** | World | AGORA, USGS, OpenSHA / SpaRisk LLC | No | Object-oriented, Web, GUI |
| **OSRE** | World | AGORA / Kyoto University | No | Windows-based GUI, Java |
| **PAGER v1** | World | FEMA / USGS | No | Matlab, unknown |
| **QLARM** | World | ETHZ and WAPMERR | No | Internet-based, Java, PostgreSQL |
| **QL2** | World | M. Wyss | | |
| **RADIUS** | World | Geohazards Int., IDNDR / UNEP | No | Excel |
| **REDARS** | North America | FHWA / MCEER, ImageCatInc | No | GUI Windows, Basic |
| **RiskScape** | Australia | NIWA and GNS | No | Java—GIS not needed |
| **ROVER-SAT** | North America | University of Boulder | | |
| **SAFER** | World | 23 Worldwide Institutions/ Multiple EU | No | Matlab, C++ depending on version |
| **SELENA** | World | NORSAR | Yes | Matlab, C++ depending on version |
| **SES2002 & ESCENARIS** | Europe | Gen Dir. Of Civil Protection, Spain | No | Visual Basic, dll using MapObjects 2.1 |
| **SIGE** | Europe | OSSN, Italy | No | Visual Basic, dll using MapObjects 2.1 |
| **SP-BELA** | Europe | EUCENTER | n/a | n/a |
| **StrucLoss** | Europe | Gebze IT, Turkey / METU | No | MapBasic and MapInfo |
| **BASEMENT** | | ETH-Z | No | Python code in some parts, unknown for some |
| **Delft-3D-FLOW** | | Deltares | Yes | C++, GIS and other connecting languages |
| **Kalypso** | | Hamburg University of Technology and Bjoernsen Consulting Engineers | No | Java |
| **NoFDP IDSS** | | Darmstadt University | No | Eclipse, Java |
| **Sobek Suite 1D/2D with HIS-SSM** | | Deltares | Yes | C++, GIS and other connecting languages |
| **TELEMAC-MASCARET** | | Collaboration (Germany, UK, France) | No | Fortran |
| **TCRM** | | GA | No | Python and some C |
| **SLOSH** | | NOAA | No | Python and C vers 3.94 |
| **TOMAWAC Wave** | | Collaboration (Germany, UK, France) | No | Fortran |
| **TsuDAT using ANUGA** | | ANU and GA | No | Python |
| **HAZTURK** | Turkey | | | |
| **OOFIMS (SYNERG)** | World | SYNER-G EC FP7 / Univ. of Rome 'Sapienza' | No | Matlab |

## 3. CONCLUSIONS AND RECOMMENDATIONS

Hazard assessment and loss estimation analysis, benefit at the time being from a broad variety of modeling platforms and software tools helping to model the complex system and interactions between structure, infrastructure, and multi-hazards. In this paper, after concisely introducing the hazard assessment and loss estimation method, the list of all available software was gathered and investigated. Then, the most familiar and the performance platforms – including open sources, semi-open or fully closed tools – were briefly presented. The described software packages can benefit from each other. Some recommendations are offered for improvement and collaborations.

For Ergo, Daniell (2011) noted that it should be considered within GEM because it is fully user-oriented, specifically Ergo economic and social algorithms could offer great benefit to GEM. While in the World Bank report (2014), they noted that Ergo should be integrated within many other software (Deltares, etc.), but on the other hand Ergo could benefit from probabilistic modeling if combined with EQRM. Daniell (2011) noted that recommendation and improvements for Greater Utility HAZUS have already been adjusted and it has influenced EQRM, SELENA, MAEviz, HAZ-TAIWAN, etc. Hazus methods, as well as most of the functions, were published in Porter (2008), among others. Nevertheless, it can become open source and more global by including and adapting fragility functions to non – USA regions. On the other hand, some of its modeling options can be applied to most other software packages such as the liquefaction, fire-following-earthquake, and input-output models. SELENA, was recommended by the World Bank report (2014) that the GUI interface should be improved, that many shortcomings exist regarding the intensity measurement. On the other hand the logic tree component can be adapted by other software packages. The GIS viewers such as ArcView can be implemented to display losses (Daniell, 2011). For the EQRM, the socioeconomic indicators should be added, and there should be greater depth in GIS. There is no GUI, thus it is difficult to handle by basic users. The software simply needs to be combined with Ergo, was noted in the World Bank report (2014). The EQRM would also combine with CAPRA. Moreover, it could combine well with software from GA (TCRM, TsuDAT) and with Deltares' flood software, however rewriting would be necessary. CAPRA could benefit from the input of fragility/casualty/economic functions from other projects. Moreover, it could benefit from synergy with EQRM or Ergo to add more functionality. Considering the GEM / OpenQuake, the installation procedure needs to be improved, and a stand-alone GUI with data is required. Nevertheless, the software is still in the test-production phase, therefore those improvements might have been considered or scheduled to be considered. Moreover, it is difficult to propose possible synergies since the software is not released yet. «A *natural synergy between OpenQuake and GEM is possible, given that the Python-coded EQRM joins well with the Global Earthquake Model (GEM)*», as it was noted in the World Bank report (2014). OOFIMS is the only software that models and analyzes the performance of interconnected/interdependent infrastructure systems, also considering the spatial variability of ground motion intensity at regional scale as well as of cross-correlation of ground motion across different intensity measures. Other platforms can benefit from OOFIMS. Fragility curves provided in HAZUS are frequently used in other software. However, the methods and tools provided by other software (e.g. OpenQuake, DBELA, SP-BELA) can be used by other software to update or improve their fragility functions. Finally, in the context of the new EU civil protection mechanism, seismic risk assessment at a pan-European level is essential. A relevant proof of concept study has been recently performed using ELER software, however, similar studies are encouraged using other software (e.g. ERGO, OpenQuake), aiming to a common methodology and loss assessment platform with up-to-date building inventory and population data for Europe.

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