



IRMA platform for the calculation of damages and risks of Italian residential buildings

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Abstract

Italian Risk M^Aps (IRMA) is an innovative IT platform developed by European centre for training and research in earthquake engineering (Eucentre) with funds of the Italian Civil Protection Department, and addressed to the scientific community. IRMA allows data sharing, methods and models aimed to evaluate the seismic risk of Italian residential buildings, in order to comply with the requirements of the “Sendai Framework for Disaster Risk Reduction 2015–2030” (Sendai Framework). IRMA uses OpenQuake, a calculation engine developed as part of the Global Earthquake Model, to evaluate earthquake loss estimation. The user can create and upload different exposure/vulnerability databases as well as different sets of fragility curves on the platform. The hazard used in the platform is the MPS04 hazard model, developed by National Institute of Geophysics and Volcanology that is actually the reference hazard map for the Italian code regulation. IRMA is extremely flexible: by combining the different exposure databases with all the possible sets of fragility curves, the user can produce maps of conditional damage (i.e. the return period is selected) or unconditional damage (i.e. an observation time window is selected). Damage scenarios can also be performed by using shakemaps of seismic events as input. The shakemaps, preloaded in the platform, are those referred to the recent seismic events in Italy. The article describes the context in which IRMA was developed, its features and architecture. IRMA was used in 2018 by DPC to produce the National Risk Assessment, in agreement with EU decision 1313/2013.

Keywords Residential buildings · Earthquake · Damage risk assessment · Damage scenario assessment · Map

1 Introduction

Italian Risk M^Aps (IRMA) is a web platform of the Italian Civil Protection Department (DPC), developed by Eucentre, addressed to the scientific community and aimed to share data, methods and models for evaluating the seismic risk of the Italian territory (Borzi

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et al. 2018; Dolce et al. 2019a; Faravelli et al. 2019). It provides a common tool that can be used by the scientific community to produce seismic risk maps to be adopted in the “Sendai Framework for Disaster Risk Reduction 2015–2030” (Sendai Framework) (UNISDR 2015) in agreement with the Civil Protection Code (D.Lgs. n.1/2018).

Italy is one of the Nations that takes part in the “Sendai Framework for Disaster Risk Reduction 2015–2030”, whose main purpose is to provide guidelines for the management of multi-hazard risk. The goal of the framework is preventing risks due to future catastrophic events, reducing existing disaster risks to substantially decrease the losses of human lives and livelihoods, as well as of economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries. According to the Sendai Framework, the first of the four priority actions identified, is understanding disaster risk in all its dimensions: “vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment”. This knowledge is preparatory to any subsequent action in terms of prevention, mitigation, preparedness and response. The Sendai Framework also suggests “to develop, periodically update and disseminate, as appropriate, location-based disaster risk information, including risk maps, to decision makers, the general public and communities at risk of exposure to disaster in an appropriate format by using, as applicable, geospatial information technology;” (article 24c). In order to pursue this objective, at the end of 2018 the DPC produced a document of evaluation of natural risks (Italian Civil Protection Department 2018) with the fundamental support of the scientific community. The scientific community used the IRMA platform to produce seismic risk maps included in the document. In 2018, Italy published the new Civil Protection Code that includes the knowledge of risk scenarios among the non-structural prevention actions. Article no. 19 of the Civil Protection Code acknowledges a fundamental role to the scientific community, which participates in the prevention activities of the National Civil Protection Service, integrating knowledge and research findings. The need of the Sendai Framework to having a new risk assessment by the end of 2018, updated and compared to the previous one produced in 2015, was an important objective to be achieved. Finally, an important requirement in risk assessment is not only its scientific basis, but also its consent by the scientific community. Giving a common calculation tool to all researchers allows to easily verify the quality of incoming data results and a really fluid result sharing and comparing. This article will show how IRMA has met all these needs. The platform features, the required data, the user interface and the informatics infrastructure will be described.

2 Tools for estimation of seismic risk

In these years, several research groups around the world have developed tools for seismic risk assessment in order to estimate earthquake damages and losses. In Crowley et al. (2010) a number of existing risk software applications were reviewed. SEismic Loss Estimation using a logic tree Approach (SELENA) (Molina et al. 2010) is a software tool for seismic risk and loss assessment based on the HAZUS methodology (National Institute of Building Sciences 1999; FEMA 2003). The software is open-source and was developed by the International Centre for Geohazards ICG through NORSAR (Norway) and the University of Alicante (Spain). Another open-source tool to estimate earthquake hazard and risk is Earthquake Risk Model (EQRM) (Robinson et al. 2005). It is produced by Geoscience Australia, an Australian Government Agency, and for this reason, Australia is the current geographical area of application. Earthquake Loss Estimation Routine (ELER) (Hancilar

et al. 2010) is instead a standalone application that provides rapid estimation of earthquake shaking and losses in the Euro-Mediterranean region. Two tools with source code provided upon request are CEDIM (CEDIM Risk Estimation Tool) (Köhler et al. 2006) and Central America Probabilistic Risk Analysis (CAPRA) (Gill et al. 2009). The CEDIM software was developed by the Center for Disaster Management and Risk Reduction Technology in Potsdam, Germany, but it was used for damage and risk analysis on other earthquake prone areas of the world. CAPRA is a multi-hazards software to estimate losses. It is a World Bank's initiative that aims to strengthen the institutional capacity of assessing, understanding and communicating disaster risk, with the ultimate goal of integrating disaster risk information into development policies and programs. CANRISK (Ploeger et al. 2016) is a tool to assess the seismic vulnerability of buildings in Canada. The model implements fuzzy synthetic evaluation to quantify seismic risk, combines HAZUS methodology with its own methodology to estimate number of injuries, and uses a decision matrix to generate the injury profiles. The model is designed to include the ability to test the benefits of mitigation strategies such as the retrofit of operational and functional components and the implementation of earthquake safety campaigns. In the ongoing European project Pocrisc, Action 3 "Seismic crisis preparedness" (<https://pocrisc.eu/fr/page/action-3-preparatio-n-crise-sismique>), led by Institut Cartogràfic i Geològic de Catalunya (ICGC) and Bureau de Recherches Géologiques et Minières (BRGM), aims to develop and share tools dedicated to improving seismic crisis management, established in line with existing national strategies. These tools work in order to estimate at the municipality level the material and human assessments that will help guide and enable an appropriate response to the relief effort. Finally, Mesgar and Jalilvand (2017) had developed a scenario-based seismic loss estimation model for residential buildings in Iran, focusing on the city of Sari as a case study. Building related features were extracted from remotely sensed images and integrated with the statistical information in order to generate spatially distributed dataset.

Over several years, with funds of the Italian Civil Protection Department and coherently with the strategy of the new civil protection code, Eucentre, has also been developing tools, implemented in WebGIS platforms, for seismic risk and damage scenario assessment. These platforms consider residential buildings (Faravelli et al. 2017, 2018), school buildings (Borzi et al. 2013; Faravelli et al. 2017, 2018), transportation network infrastructures (Di Meo et al. 2018; Faravelli et al. 2018) and dams (Bozzoni et al. 2015; Bozzoni and Lai 2017) as vulnerable elements. Recently, also hospitals have been taken into account, as being critical buildings for civil protection purposes.

Eucentre has also developed further platforms for assessing seismic risk for some European-funded projects. Within SASPARM2.0 project (Support Action for Strengthening PAlestinian capabilities for seismic Risk Mitigation), a WebGIS platform for Nablus city, in Palestine, has been developed (Di Meo et al. 2017). Another WebGIS platform has been developed by Eucentre in the NERA project (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation) for the assessment of the damage scenario taking into account the progressive damage (Bianchi et al. 2014). Finally, a WebGIS platform for the definition of damage scenario and losses related to transport infrastructures in three selected testbeds (Campania district, North Macedonia and Israel) has been developed in IFRA-NAT project (InfraNAT). In all projects mentioned, WebGIS platforms have been produced using Open Source code.

The platforms developed for the DPC take into account several assets (e.g. bridges, port facilities, tunnels, schools, hospitals, dams) but do not allow the users to upload their own data and models (i.e. fragility and exposure models). In fact, they are designed to use pre-defined data and models. However, none of the solutions mentioned above met the needs

of the DPC. The DPC needed an extremely flexible platform that would allow different users of the scientific community to load their fragility and exposure models, then run the risk calculation and, finally, combine the results in order to obtain a final map that can be considered acknowledged by the whole scientific community. From this perspective DPC asked Eucentre to develop a new ad hoc tool. In this framework IRMA has been conceived.

3 IRMA platform features

The IRMA platform is addressed to the scientific community that can use it to produce damage/risk maps and damage/risk scenarios for the Italian territory at municipality scale. In IRMA “Damage” is defined as:

- The number of buildings/dwellings that reach a damage level or
- The percentage of buildings/dwellings that reach a damage level with respect of total of buildings/dwelling in a municipality or
- The number of people that lives in the buildings that have reached a damage level or
- The total dwellings surface of the buildings that have reached a damage level.

In IRMA the damage levels (from D1 to D5) of the European Macroseismic Scale (EMS) (Grünthal 1998) are adopted:

- D1: negligible to slight damage (no structural damage, slight non-structural damage)
- D2: moderate damage (slight structural damage, moderate non-structural damage);
- D3: substantial to heavy damage (moderate structural damage, heavy non-structural damage);
- D4: very heavy damage (heavy structural damage, very heavy non-structural damage);
- D5: destruction (very heavy structural damage).

The user can also obtain the analysis result in terms of risk, defined as:

- Human losses (number of wounded and number of fatalities);
- Economic losses (cost of repair or replacement);
- Impact (usable or unusable buildings in the short and long time span, collapsed buildings).

The risk is a combination of damage using an appropriate matrix. IRMA has pre-loaded damage-to-risk matrices: the user can use them or upload his own. Figure 1 shows the calculation scheme of IRMA: the user uploads two excel sheets, one describing the building types (Exposure/Vulnerability file) and the second contains the parameters that define the fragility curves for the identified vulnerability classes (Fragility curves file). The IRMA platform uses the MPS04 hazard map (Stucchi et al. 2004, 2011), which represents the reference for the Italian code regulation, as seismic input at municipality centroid coordinates. This data cannot be customized by the user.

As shown in Fig. 2, IRMA combines data collected from the user with data stored in internal databases in order to build input file for OpenQuake-engine (OQ) (Pagani et al. 2014), which is adopted by IRMA as calculation engine. The OpenQuake-engine is an open source application that allows users to compute seismic hazard and seismic

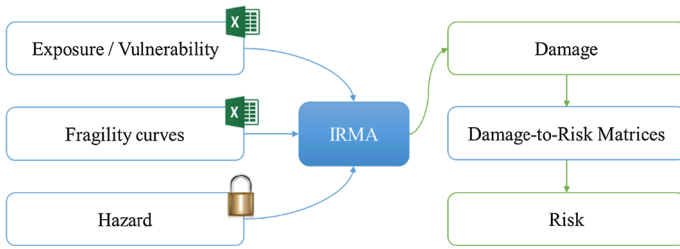


Fig. 1 Schema of main calculation steps

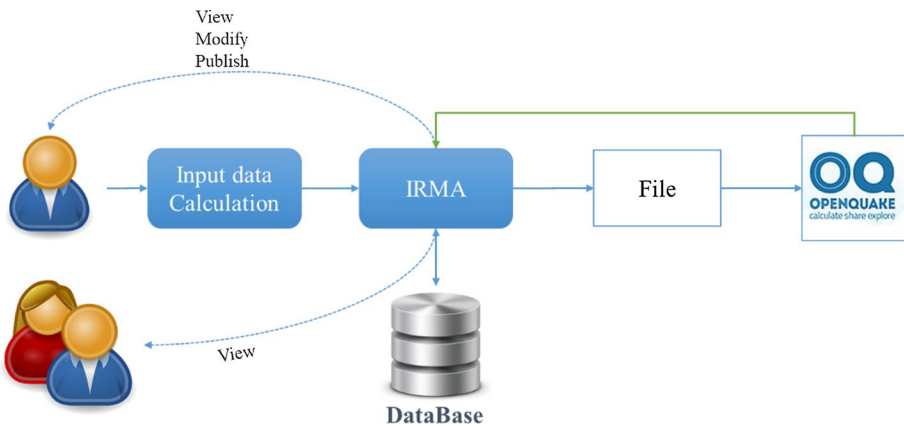


Fig. 2 Schema of iteration between users, IRMA and OpenQuake

risk of earthquakes on a global scale. It is an effort promoted and actively developed by the Global Earthquake Model (GEM) Foundation, a public–private partnership initiated by the Global Science Forum of the Organization for Economic Co-operation and Development.

Some of the data saved in the database are preloaded (see chapter 4 and chapter 5) while other are provided by the user (see chapter 6) or are the result of calculations (see chapter 7 and 8).

IRMA has the possibility to run three main calculations:

- *Unconditional damage/risk* is related to a specific observation time window (T_o), e.g. T_o :10 years. In IRMA the enabled observation time windows are: 1, 10, 50;
- *Conditional damage/risk* is related to an event with a certain return period (T_r), e.g. T_r :475 years. In IRMA the enabled return periods are consistent with the adopted hazard map: 30, 50, 72, 100, 140, 200, 475, 1000, 2500 years;

The “unconditional damage” can be described as the unconditional probability of failure (P_f) for a system with resistance R , under a seismic load S , using the following equation (Cornell and Krawinkler 2000):

$$P_f = \int_0^{+\infty} f_s(S)F_R(S) dS$$

where f_s is the probability density function of the ground-motion parameter (which can be obtained through the derivation of the seismic hazard curve) and $F_R(S)$ is the probability that the resistance R is less than a given level of severity, S (often termed the vulnerability or fragility curve). Hence, the annual probability of collapse, for example, can be obtained by combining the probability of exceeding the resistance of the building to collapse for a given level of ground motion [$F_R(S)$], with the annual probability of obtaining that level of ground motion (f_s), and summing this product over all possible levels of ground motion. This would allow to estimate the mean annual probability of collapse for a given typology of buildings; this calculation would need to be repeated for each typology present in the inventory of buildings (the exposure model) and then the results would be combined considering the proportion of each building typology.

Instead, in the “conditional damage” the condition is the occurrence of an earthquake with a selected return period.

IRMA platform includes a tool for scenario calculation starting from shekemap of real events (see chapter 4). This allows the user to test fragility and exposure models on a real case.

IRMA allows access to users with one of three different roles, with different capabilities:

- *Researcher* The users with this role have access to most of the functionalities of the platform. The user’s settings and results are initially private and later each user can decide to share them with the community registered to the platform. This is possible only under the approval of his Supervisor;
- *Supervisor* A supervisor user gives the permission to the researchers linked with to share settings and results. Afterward, these data become available for the rest of the users;
- *DPC user* The DPC user is a third kind of role which, as other users, can visualize all the shared settings and results and, in addition, has the capability to combine different maps by assigning them a weight (see chapter 9).

4 Seismic input

In order to perform all the calculations, IRMA needs different types of inputs, some are set by the users and other are pre-defined in the platform like the seismic input that is given in two formats:

- Hazard model;
- Shakemaps.

The hazard model is based on the Italian Seismic Hazard map (MPS04) developed by Istituto Nazionale di Geofisica e Vulcanologia (INGV) and adopted at national level with a Civil Protection Ordinance (OPCM 3519/2006). It is the official Italian hazard model (Stucchi et al. 2004, 2011) and gives the seismic action (elastic response spectrum) for each point of a mesh (5×5 km) covering all the Italian territory.

Because the exposition is at municipality scale, starting from MPS04 the hazard is evaluated at the centroid of each municipality in order to have one single value. The formula to get the hazard value for a point different than the points of the mesh is coded in OPCM 3519/2006 (in principle a distance-weighted average). For example, Fig. 3 reports the peak ground acceleration (PGA) estimate value for the municipality of Pontassieve. The blue crosses are the point of MPS04 mesh. The numbers represent the PGA values for $T_r=475$ years.

The MPS04 and the interpolated values are given at bedrock. In IRMA it is possible to consider the soil amplification, but due to the lack of a reliable soil amplification maps at municipality level, the type of soil (and the soil amplification) is assumed uniform for the whole selected area.

The second type of seismic input is the shakemap. The user has to select the corresponding shakemap, in order to evaluate a seismic scenario for an event. Each shakemap provides the ground motion at the surface (i.e. including soil amplification) for the main Italian earthquakes that hit the country in the last decades (chapter 8 reports an example). The source for the shakemap is INGV (if available) or USGS (see Table 1 for detailed information). The shaking intensity is given in PGA.

An example of a shakemap is shown in Fig. 4; the shakemap is related to the seismic event of L'Aquila 2009 elaborated from INGV.

5 Exposure model

Italian National Institute of Statistics (ISTAT) is the main authority for compiling official statistics in Italy. Every 10 year ISTAT releases a census of the Italian population that includes data on the number of private civil buildings, number of dwellings, total dwellings surface for each municipality. Starting from 2018, census data are updated on a continuous base. These censuses include also more specific data like the number of floor and the type of construction. In IRMA the data of the 2001 census (ISTAT 2001) are pre-loaded. At the time of this research, those were the most updated census data

Fig. 3 PGA for $T_r=475$ years for the municipality of Pontassieve

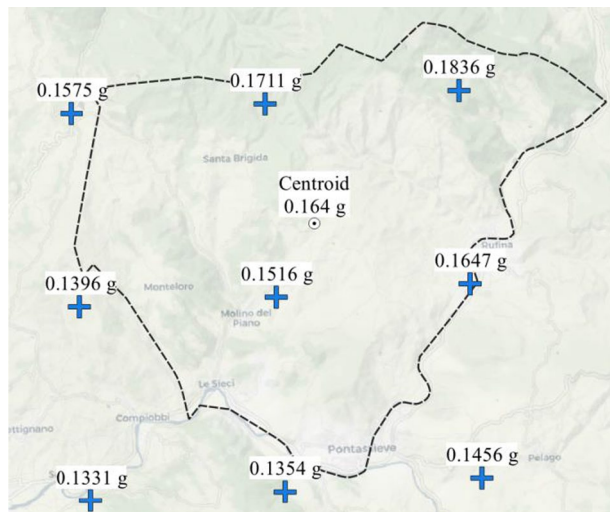
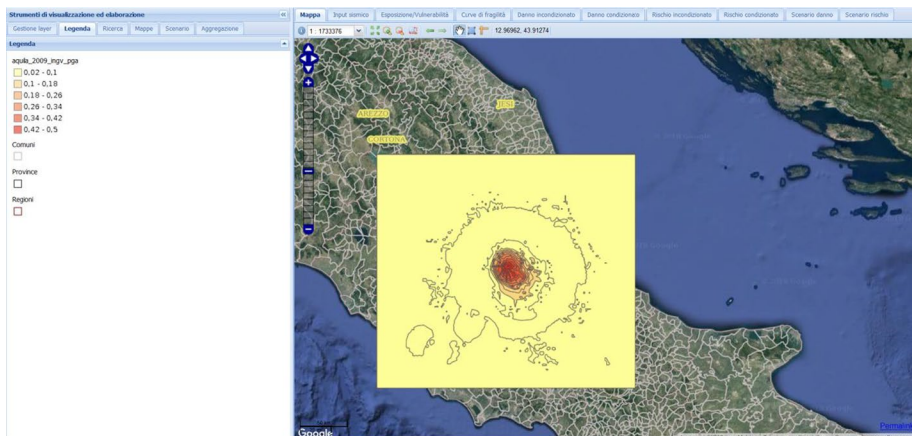


Table 1 List of shakemaps preloaded in the platform

Name	Date	Longitude WGS 84	Latitude WGS 84	Mw	Source
Friuli 1976	6th May 1976	13.119	46.241	6.45	USGS
Irpinia 1980	23rd November 1980	15.283	40.842	6.81	USGS
Irpinia 1980	23rd November 1980	15.283	40.842	6.81	Michelini et al. (2008)
Abruzzo 1984	7th May 1984	14.057	41.667	5.86	USGS
Marche 1997	26th September 1997	12.853	43.014	5.97	USGS
Pollino 1998	9th September 1998	15.949	40.060	5.53	USGS
Molise-Puglia 2002	31st October 2002	14.893	41.716	5.74	USGS
Emilia 2003	14th September 2003	11.380	44.255	5.24	USGS
L'Aquila 2009	6th April 2009	13.510	42.309	6.29	INGV
Emilia 2012	20th May 2012	11.263	44.895	6.09	INGV
Pollino 2012	26th October 2012	16.02	39.88	5.17	INGV
Garfagnana-Lunigiana 2013	21st June 2013	10.14	44.15	5.3	INGV
Amatrice 2016	24th August 2016	13.23	42.70	6	INGV

**Fig. 4** Shakemap related to the seismic event of L'Aquila 2009

that ISTAT has been processed. It should be mentioned that the ISTAT 2011 database was just recently added so that the maps published on the National Risk Assessment document (Italian Civil Protection Department 2018) were produced using the ISTAT 2001 database. The data about buildings and dwellings are limited to few information such as structure, number of storeys and construction age. These data are very important for joining the vulnerability models produced by the scientific community to the exposure of each municipality, as outlined in another paper within this same special issue (Dolce et al. 2020).

A brief comparison between ISTAT 2001 and ISTAT 2011, reported in Fig. 5, shows that from 2001 to 2011 the number of buildings and the population have considerably

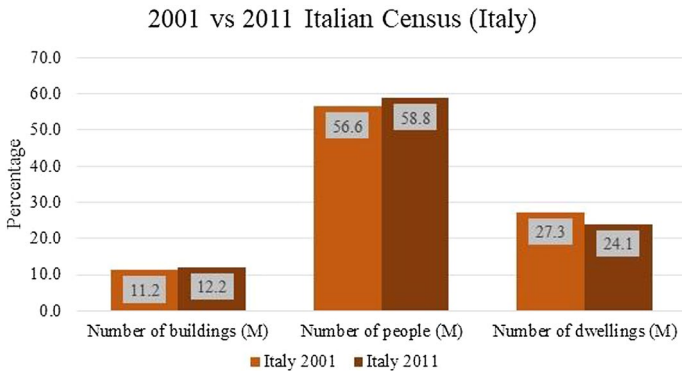


Fig. 5 Comparison between ISTAT 2001 and ISTAT 2011 for all buildings, people and dwellings in Italy

increased (+ 8.6% for buildings and + 4.0% for population) while the number of dwellings has decreased (− 11.8%). Analyzing the data for macro areas (Northern, Center, Southern Italy and main islands) the same trend is observed (Fig. 6). A difference in the data collection concerns the storey number, while the 2001 database provides the distribution for each storey from 1 to 8, the database puts together the 2011 storey numbers greater than 4, with consequent loss of detail.

6 Vulnerability model

In order to collect input data from the scientific community, as required by DPC, in IRMA researchers can classify the exposure data (ISTAT 2001 or ISTAT 2011), described through building types, into vulnerability classes and associate one or more fragility curves for each building type, according to the criterion described in Dolce et al. (2020). Note that in total, by crossing the ISTAT information, 56 building types for masonry and 56 for reinforced concrete buildings/dwellings are pre-recorded in IRMA. The number of vulnerability classes, according to which each building type could be

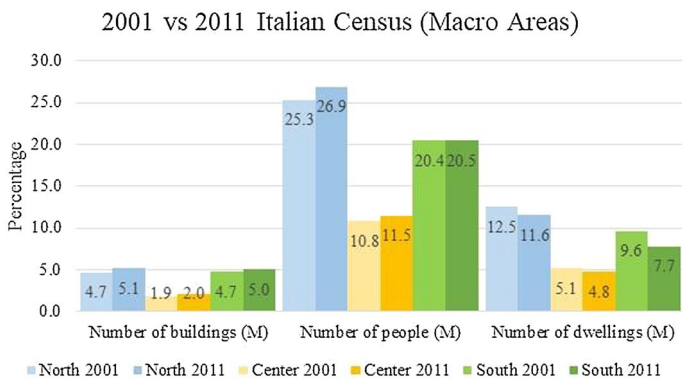


Fig. 6 Comparison between ISTAT 2001 and ISTAT 2011 for all buildings, people and dwellings subdivided in Northern Italy, Central Italy, Southern Italy and main islands (Sicily and Sardinia)

	A	B	C	D	E	F	G	H
1	Type of Building	Year	Number of storeys	% A	% B	% C1	% C2	% D
2	masonry	< 1919		80	20	0	0	0
3	masonry	< 1919		75	25	0	0	0
4	masonry	< 1919						

Fig. 7 Example of vulnerability classes settings, the user compiles the highlighted cells

	A	B	C	D	E	F	G	H	I	J
1			D1		D2		D3		D4	
2	Taxonomy	Number of storeys	Mean [g]	Std Dev [g]	Mean [g]	Std Dev [g]	Mean [g]	Std Dev [g]	Mean [g]	Std Dev [g]
3	A	1								
4	A	2								
5	A	3								

Fig. 8 Example of fragility curve settings, the user compiles the highlighted cells

described, varies from one to five and are named, for convenience, as A, B, C1, C2, D as in the EMS scale (Grünthal 1998) but the definition is left completely to the user in his vulnerability model (Dolce et al. 2020). Figure 7 reports a section of the template file named “Exposure/Vulnerability” (see Fig. 1) that the user is required to compile to set the building types.

The user chooses which percentage of the building type (i.e. type of building, construction time period, number of storeys) falls in a vulnerability class. For example, in Fig. 7 the user has set that 80% of the one-storey buildings in masonry, built before 1919 are of type “A” and the remaining 20% are of type “B”. This procedure has to be completed for all the existing combinations; however, IRMA checks that all the combinations have been considered. Note that the vulnerability classes are valid for all municipalities that falls into the area selected for the calculation, so there is no need for the user to explicitly define any geographical data.

The number of combination varies depending on some user selection:

- *Building type* the user can choose to focus on masonry or reinforced concrete buildings only—or on both. There’s also an option to manage the type “other” buildings (i.e. material type neither masonry nor R.C.);
- *Number of storeys* the user can choose to group buildings into low (L), medium (M) and high (H)—or to keep the number of storeys separate;
- *Seismic classification* the user can decide to subdivide the buildings into non-seismically designed and seismically designed buildings. The classification default algorithm implemented in IRMA assigns vulnerability classes (C2 or D) to the R.C./masonry buildings comparing the date of construction and the year of seismic classification of the municipality to which they belong. This approach is coherent with the criterion defined by Di Pasquale and Orsini (1997), dividing the class C in two sub classes C1 and C2. Regardless of the year of seismic classification of the municipality, buildings built before 1982 are considered non-seismically designed. In fact, a vast work of seismic reclassification of the Italian territory was done after the Irpinia earthquake of 1980. As a result, since the early 1980 s the new seismic regulations have been widely applied.

The second step for the definition of the vulnerability model is the fragility curve settings. Figure 8 reports the excel file named “Fragility curves” (see Fig. 1) that the user compiles to define the parameters of the fragility curves.

For each vulnerability class (A, B, C1, C2, D), for each number of storeys (or L, M, H) and for each damage level (D1, D2, D3, D4, D5) the user sets the fragility curve through two values: the mean and the standard deviation of the lognormal distribution, this being the cumulative distribution adopted to represent mathematically the fragility curve. As before, all the combinations are mandatory and IRMA checks the validity of the set.

The user has to download the template excel files from the platform, which list all the needed combinations. He fills in these files offline and then uploads the vulnerability models to the platform as two separate excel files.

7 Damage and risk tool

The combination of the hazard model with the exposure and the fragility model gives the damage/risk assessment. For running the calculation of a damage map, the user can choose (see Fig. 9): the exposure/vulnerability database, the set of fragility curves, the region of Italy for which performing the calculation (or all Italy), the type of analysis (conditional or unconditional) and the type of soil. The user can limit the calculation to a specific demographic class, for example only municipalities with less than 3000 inhabitants. This filter has been implemented to enable the user to account for the different vulnerability model that can be representative of a big city and a small municipality.

The outputs of this choice will consist of damage and consequences distribution limited to the territorial extents chosen. Moreover, if the fragility curves are applicable to just a fraction of existing heritage (masonry or reinforced concrete buildings), the resulting map will be relevant to this asset only. Using these indications, the platform creates the OQ input files, processes them through the calculation engine and post-processes the output, making it available to the user. The user can view the result on a map, download the map as a shapefile or view the results for a selected area (municipality or administration over the municipality up to the whole country) in tables. The user can change the number and the range of the map intervals in IRMA map. Figure 10 shows an example of a conditional damage map with “equal count intervals”. This method classifies results to be plotted into a certain number of ranges with an equal number of elements in each range.

Run a new calculation	
Select an exposure set	Select...
Select a fragility set	Select...
Select a region	Select...
Select soil type	Select...
Select calculation type	Select...
Select municipality demography	Select...

Fig. 9 View of the options to launch a new damage evaluation

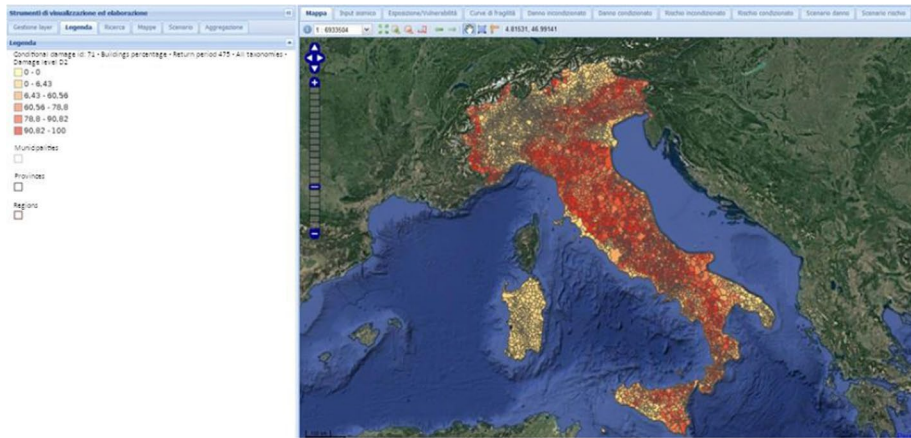


Fig. 10 Example of map: conditional damage for return period $T_r=475$ and damage level D2

Since IRMA allows a researcher to use a set of fragility curves valid for a specific asset such as building type (e.g. masonry) or for a specific region (e.g. Lombardia), thanks to the possibility of combining results from different researchers, for example an analysis on R.C. buildings, the final map could cover the whole country inventory.

For each EMS damage level from D1 to D5, damage maps provide the total number of buildings (or dwellings) affected, the percentage of buildings (or dwellings) calculated on the total number of buildings of each municipality, the dwellings surface and the population living in buildings reaching each of the five damage levels.

Risk maps combine, according to specific formulations defined in Dolce et al. (2020), the results of the damage maps so as to turn them into impact and losses indicators. In particular, the impact gives the number of buildings that are usable, not usable in the short and long time span and collapsed. The losses are expressed in terms of fatalities, injuries and economic losses.

The damage-to-risk matrices provide the rules to turn damage levels into risk indicators. Each matrix gives for each damage level the percentage that contributes to an impact/loss. Figure 11 illustrates the steps for risk evaluation: Matrix 1 gives the percentage of damaged buildings that corresponds to the selected impact (i.e. usable,

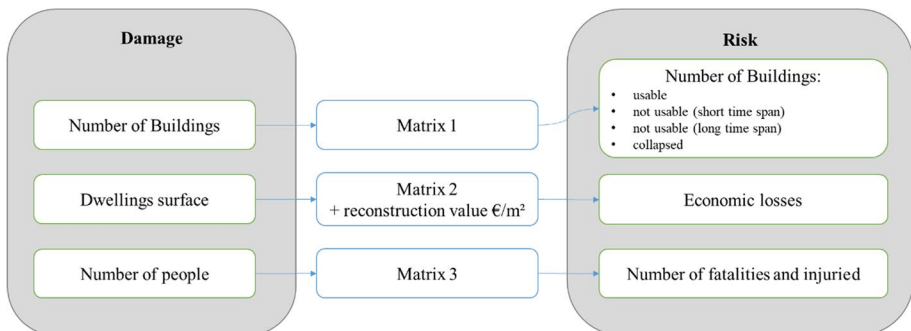


Fig. 11 Scheme of risk evaluation

Table 2 Matrix 1 default values—buildings impact

Damage level	Usable (%)	Not usable (short time span) (%)	Not usable (long time span) (%)	Collapsed (%)
D1	100	0	0	0
D2	60	40	0	0
D3	0	40	60	0
D4	0	0	100	0
D5	0	0	0	100

unusable and collapsed), Matrix 2 and 3 give the values to evaluate the economic and human losses, respectively.

The user can choose whether to input the coefficients of each damage-to-risk matrix or to use the default values pre-loaded in the platform. Table 2 reports the default coefficients related to building impact. The values involve, for example, that 60% of the buildings with D3 damage and all buildings with D4 damage have to be considered not usable in a long time span, coherently with formulation of Dolce et al. (2020). In Table 3 the percentages of the repair or replacement cost as a function of building damage is shown. For instance, in order to repair a building that has reached damage level D2 (moderate damage), the cost would be 10% of the whole reconstruction cost. In IRMA the default reconstruction cost is 135,000 €/m², but the user can however change this value. The default cost parameters proposed in IRMA are calibrated on the actual repair costs that were monitored in the reconstruction process following the Italian earthquake of L'Aquila 2009 (Di Ludovico et al. 2017a, b). In Table 4 the default coefficients related to fatalities and injuries are shown. As described in Dolce et al. (2019a), there are several references for assessing expected casualties after earthquakes. The original idea from Coburn and Spence (1992) was further developed and updated by various authors based on local context and considering observed data after significant earthquakes worldwide (Spence 2011). An example for Italy may be found in Zuccaro and Cacace (2011). In any case, the high uncertainty in these estimates is emphasized in all the works, due to

Table 3 Matrix 2 default values—percentages used for computation of economic losses

Damage level	Cost of repair or replacement (%)
D1	2
D2	10
D3	30
D4	60
D5	100

Table 4 Matrix 3 default values—relationship among damage level, fatalities and injuries

Damage level	Fatalities	Injuries (%)
D1	0	0
D2	0	0
D3	0	0
D4	1	5
D5	10	30

several factors that can affect the real impact (presence of occupants in the different day hours and year seasons, damage and partial or total collapse mechanisms of the buildings, effectiveness of rescue operations, etc.). The probability of injury or death of the building's occupants is generally evaluated depending on the damage level of the building. It is assumed that the ratio of injured and dead respect to occupants provided by the population census is significant only for damage levels D4 and D5, the most severe ones. The default values proposed by the platform have been calibrated on an expert basis by the working group from the aforementioned literature references. We assumed that the number of fatalities is equal to the one percent of the people living in buildings which reached the damage level D4 (very heavy damage) plus the ten percent of the people living in buildings which reached the damage level D5 (collapse). The calculation for the injured follows a similar method.

8 Damage and risk tool for scenario events

The user can test the uploaded fragility and vulnerability models comparing the results of scenario events with observed damage data and losses. In the tab “Scenario” the user can run the calculation of the damage scenario corresponding to the shakemaps available in the platform. The user chooses the exposure/vulnerability database, the set of fragility curves, the region of interest and the damage-to-risk matrix and then runs the analysis for scenario events. The results for the entire area concerning the calculation for masonry buildings are shown on the map (Fig. 12). Figure 13 shows the number of masonry and R.C. buildings for each damage level for the L'Aquila scenario. The results can be computed in terms of damage or risk. Results of numerically calculated damage scenario can be compared with observed damage data made available in another Web-GIS platform called DaDO (Database di Danno Osservato). DaDO was developed in the framework of an agreement between the DPC and Eucentre and encompassing building damage data relevant to past Italian major earthquakes (Dolce et al. 2017, 2019b).

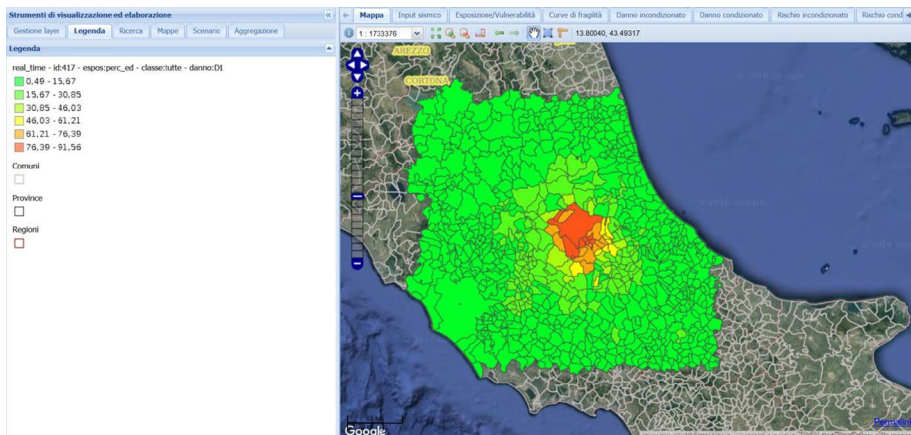


Fig. 12 Damage scenario for the seismic event of L'Aquila 2009: % of masonry buildings in D1 (light damage)

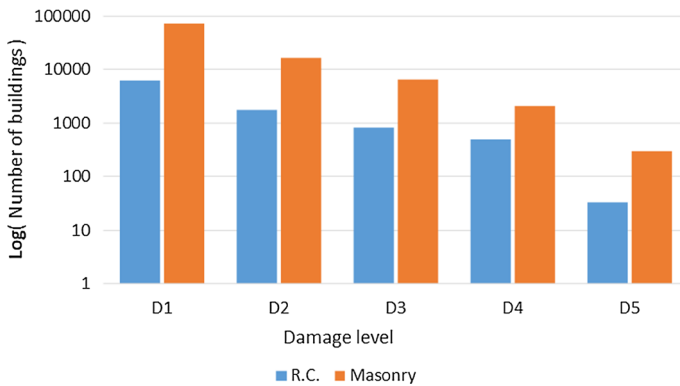


Fig. 13 Number of buildings per damage level for the damage scenario for the seismic event of L'Aquila

9 Interface

The IRMA platform integrates an authentication of the users with different roles. Three types of roles have been implemented:

- *Researcher* He uses most of the functionalities of the platform from the definition of vulnerability model to the damage risk settings. Every time the researcher uploads a new vulnerability model or makes a new calculation the files and result are saved in the platform in private mode and no other users can see them. Then, the researcher can share his databases and analysis results under the approval of his Supervisor.
- *Supervisor* He can decide to allow the researchers, who are linked with him, to share their database and analyses results. Afterward, these data become public and available for the rest of the community.
- *DPC user* The DPC user can view all the shared database and analyses results processed by the researchers and approved by their corresponding supervisors. DPC user can also combine different maps by assigning them a weight. This feature enables DPC user to obtain average maps which include contributions from the whole scientific community.

In order to clarify the workflow a possible use case is here described: six researchers were producing a map (e.g. unconditional damage, time window 1 year) for the whole Italian territory and the entire residential building stock. Four researchers have developed the fragility curves for masonry building and the other two for R.C. buildings. Figure 12 Damage scenario for the seismic event of L'Aquila 2009: % of masonry buildings in D1 (light damage)

Figure 14 presents the four maps derived from the four masonry fragility sets, in Fig. 15 are shown the two maps obtained from the two R.C. fragility curve sets. When those six maps are published in IRMA the DPC user can combine the results. In Fig. 16a is shown the result of the combination of the four masonry maps using a weight of 0.25 for each map, in Fig. 16b the combination is for the two R.C. maps with a weight of 0.5. The last operation is the aggregation between the final masonry map and the final R.C. map. The result of the aggregation is shown in Fig. 17 and a schematic flowchart of these operations is reported in Fig. 18.

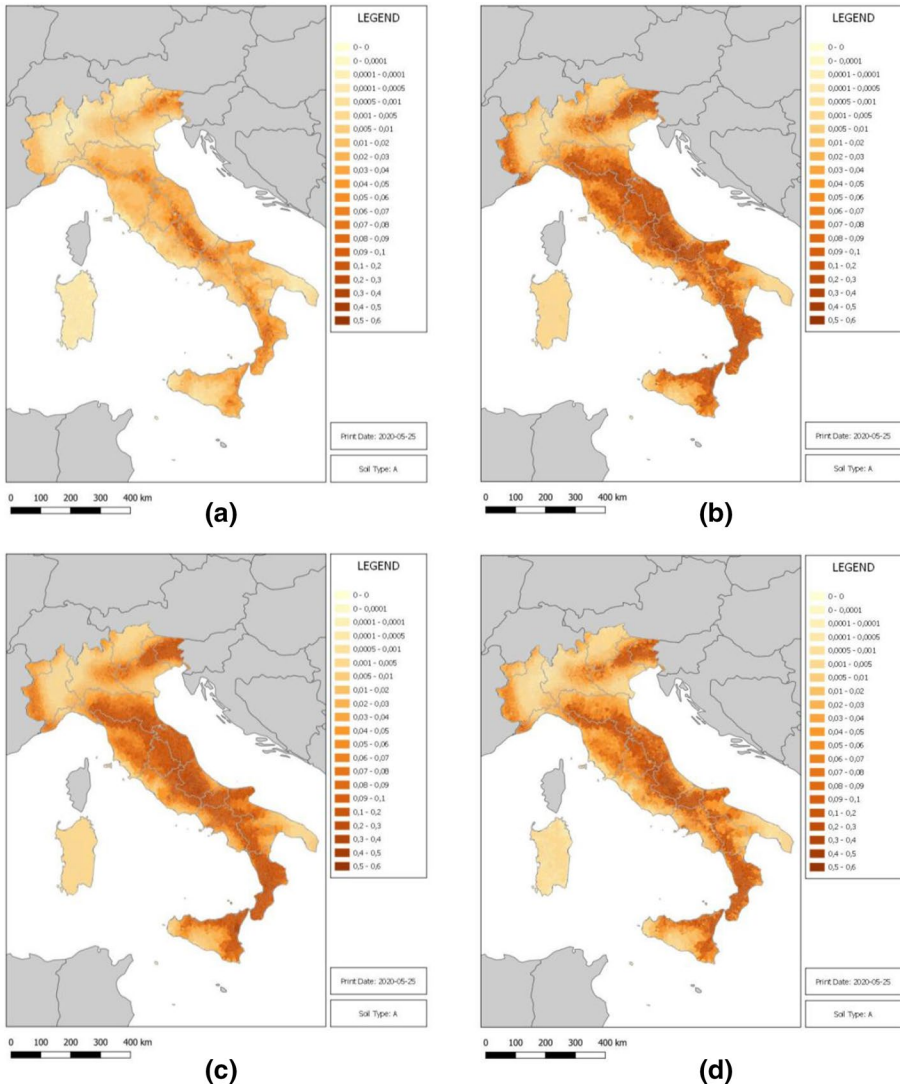


Fig. 14 Seismic damage in terms of percentage of masonry buildings affected by D4 in a time window of 1 year. Each map from **a** to **d** is derived from a different set of fragility curves

The Homepage of the platform is organized in the two sections reported in Fig. 19. The first section is defined “Display and processing tools” and consists of different tabs that are “Layer management”, “Legend”, “Search”, “Maps”, “Scenario” and “Aggregation”. The second section includes the tab “Map” that allows visualizing all the operations performed in the platform.

In IRMA the user can:

- Download the template of the excel files for defining the vulnerability model;
- Upload the compiled excel files that define his vulnerability model;

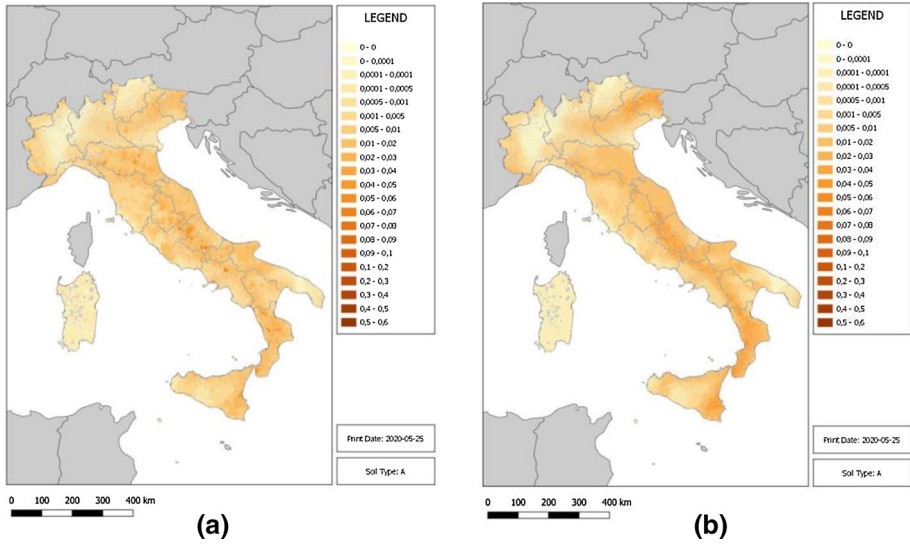


Fig. 15 Seismic damage in terms of percentage of R.C. buildings affected by D4 in a time window of 1 year. Map (a) and map (b) are derived from two different set of fragility curves

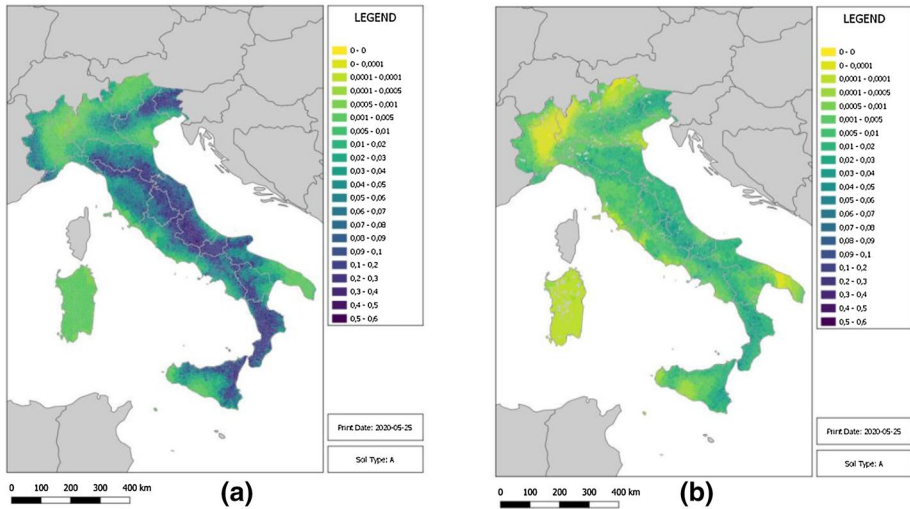


Fig. 16 Map (a) is the seismic damage obtained by the combination of the four maps in Fig. 14. Map (b) is the seismic damage obtained by the combination of the two maps in Fig. 15

- Run calculation as described before;
- Download the results as a shapefile;
- View the data: seismic input, exposure, fragility curves;
- View the result on a map or in tabular format;
- Manage the map visualization: show and hide, themed, zoom and query a layer.

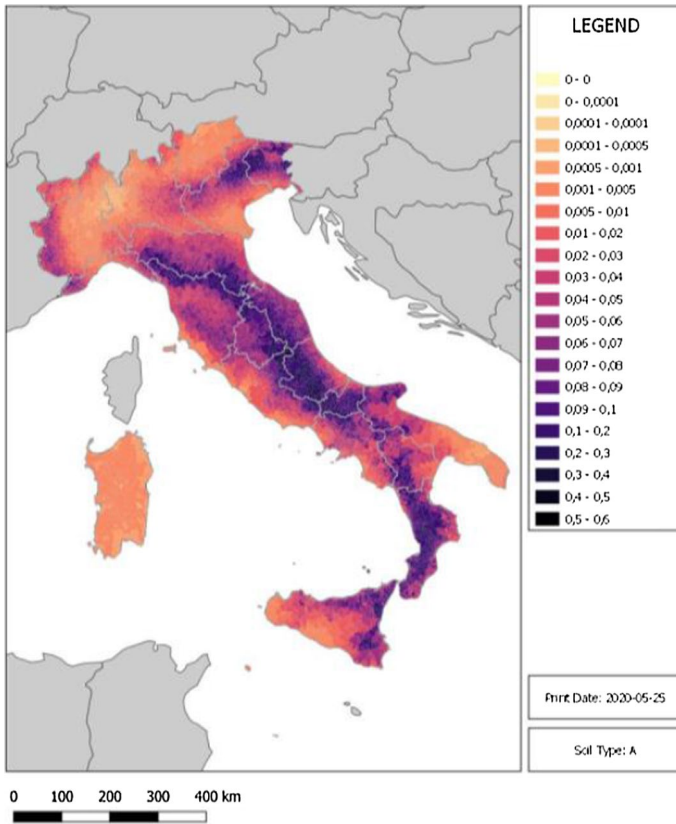


Fig. 17 Seismic damage obtained by the aggregation of the two maps in Fig. 16

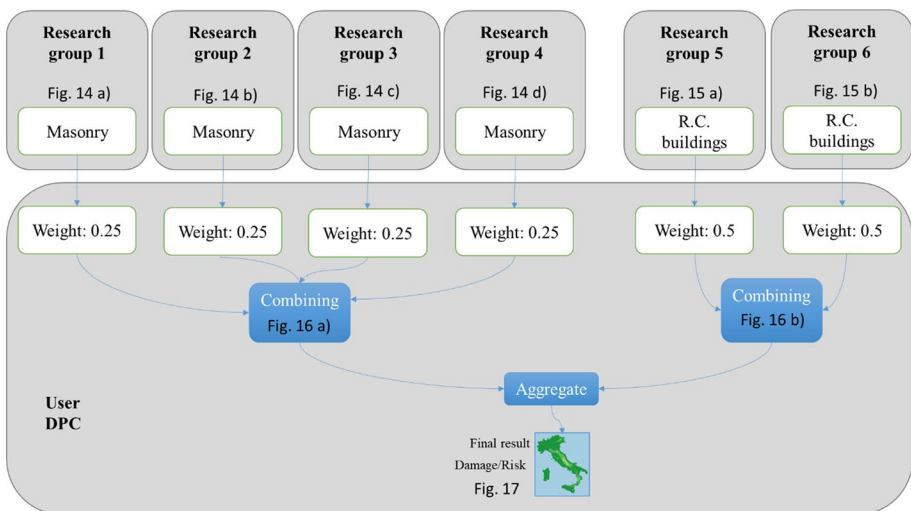


Fig. 18 Aggregation and combination scheme

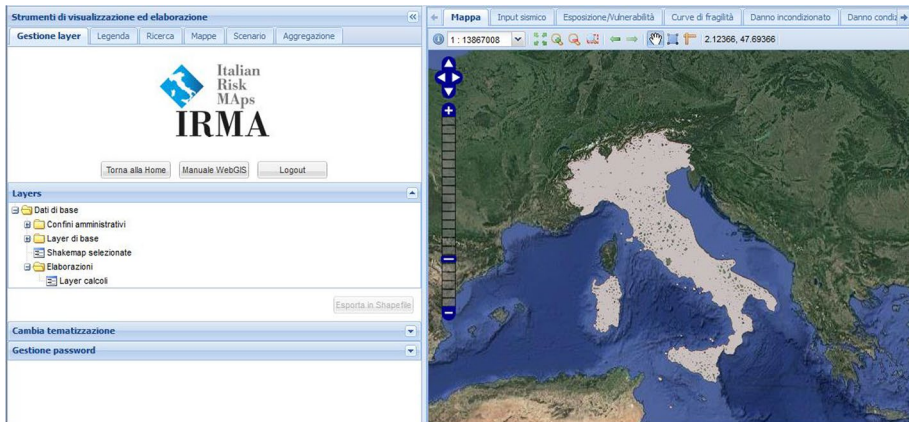


Fig. 19 IRMA homepage

All these operations are allowed both with private owned data and published shared data.

The “[Appendix](#)”, reported at the end of the article, summarizes the IT infrastructure and the software used for the development of the IRMA platform.

10 Conclusion

Italy is one of the Nations that takes part in the Sendai Framework for Disaster Risk Reduction 2015–2030, a non-binding agreement signed by the participating states in the Third United Nations World Conference held in March 2015 in Sendai, Japan. The purpose of the Sendai Framework is to provide the guidelines for the management of multi-hazard risk. The considered risks are both natural and anthropogenic. The goal to achieve is preventing the risks due to future catastrophic events and reducing existing disaster risks, in order to substantially decrease the losses. The Priority 1 of the Sendai Framework is “Understanding disaster risk”. To implement this Priority, in the framework of an agreement between the Italian Civil Protection Department and Eucentre, a centre of excellence of the department itself, a specific WebGIS platform called Italian Risk MAPs (IRMA) was developed. This platform is addressed to the scientific community that can use it to produce risk maps and damage scenarios for the Italian territory. The best feature of the platform is the flexibility: IRMA allows the user to insert his own database of exposure/vulnerability and the set of fragility curves. The only fixed element are the seismic input and the census data provided by ISTAT for residential buildings. If the seismic input is probabilistic, the MPS04 hazard map is assumed in the analysis. In case of deterministic input, the platform allows to consider some preloaded shakemaps. The platform is in constant evolution, in order to accommodate requirements from the scientific community. Future upgrades for soil amplification will be put into account as soon as microzonation studies, that the DPC is coordinating at national scale in the framework of the National Seismic Prevention Plan (Dolce et al. 2012) will be available.

The Irma platform is a tool for risk analysis and sharing of data and results. These features have been appreciated both by the DPC and by the scientific community, laying the

basis for further developments, for instance extending the platform to other structures and infrastructures than residential buildings. A version of IRMA for school buildings will be released shortly and IRMA for churches, hospitals and infrastructures are under construction by DPC with the support of Eucentre.

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Appendix

The IRMA platform was developed to show data of different format: maps, vector or raster files, numeric data, shown as interactive graphs or in thematic maps, and text documents. The data are both user input and results from elaborations. Figure 20 shows the IT infrastructure of the platform. Data and maps are stored in a spatial database. The database gives a high speed in reading and writing and all the functions that a database has: SQL queries, indexing, backup management, changes monitoring. The database is Postgres with the PostGis extension, which adds support for geographic objects allowing location queries to be run in SQL.

The main part of the IT infrastructure is the web server Apache Tomcat that has the capability of running Java Servlets (and several others Java specifications). A Java Servlet is a program that can interact with the “outside world” (i.e. web). In IRMA, the component that calculates the values of the graphs is a Java Servlet. Geoserver is a java-based software whose aim is to publish maps and geographic data linked with maps. Geoserver reads the geographic data from the database and has functions to transform this data into images or tables when the client asks for a map or a data table. The infrastructure is provided with specific Java Servlets that query the database and give back the result for when a client requests for the data stored in such database.

The client (i.e. the graphic interface that the final user sees in his/her web browser) is a web site with a collection of libraries written in Javascript. Some of the libraries are developed by third parties for general purposes and others are developed for the IRMA platform. The client libraries work together to manage the user interaction: map navigation, tabs consulting, graph interaction and so on. Table 5 shows that the programs and libraries that constitute the platform are Open Source or Free.

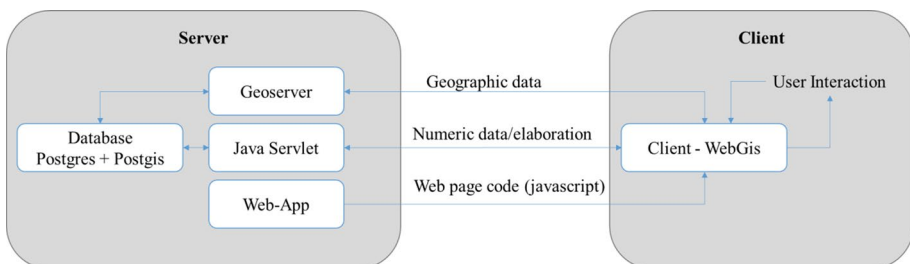


Fig. 20 IT basic infrastructure

Table 5 List of libraries and software used in the IRMA Platform

Program/library	Function	License	Cost	Reference web site
PostgreSQL	Database	BSD	Free	www.postgresql.org
Postgis	Spatial database extension	GPL	Free	www.postgis.org
Apache Tomcat	Web Server	Apache	Free	tomcat.apache.org
Java	Programming language	GNU	Free	www.oracle.com/java/index.html
Geoserver	Map Server	GPL	Free	geoserver.org
Open Layers 2	Javascript Library (maps)	BSD	Free	www.openlayers.org
Geo Ext 1.1	Javascript Library (maps)	BSD	Free	www.geoext.org
ExtJs 3.4.0	Javascript Library (forms)	GPLv3	Free	www.sencha.com/products/js
HighChart	Javascript Library (chart)	CC-non commercial	Free	www.highcharts.com

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