A Geospatial Decision Support Tool for Seismic Risk Management: Florence (Italy) Case Study

Luca Matassoni[1], Sonia Giovinazzi[2(✉)], Maurizio Pollino[3], Andrea Fiaschi[1], Luigi La Porta[3], and Vittorio Rosato[3]

[1] Fondazione Parsec (Former Prato Ricerche), Prato, PO, Italy
{l.matassoni,a.fiaschi}@pratoricerche.it
[2] University of Canterbury, Christchurch, New Zealand
sonia.giovinazzi@canterbury.ac.nz
[3] ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development, DTE-SEN-APIC Lab, Casaccia Research Centre, Rome, Italy
{maurizio.pollino,luigi.laporta, vittorio.rosato}@enea.it

Abstract. Seismic risk assessment, which attempts to predict earthquake-induced physical impacts on structures and infrastructures, casualties and losses can be a powerful tool to support emergency response planning as well as the development of effective mitigation strategies. The Civil Protection (CP) Department of Florence Municipality commissioned this study as historical earthquakes showed an appreciable seismic risk for the city that needed careful civil protection planning. A Decision Support System DSS (*CIPCast-ES*) developed by ENEA, APIC Lab, in the framework of the EU-funded project CIPRNet, was used to simulate the seismic and impact scenarios for two major historical earthquakes felt in Florence, to assess the earthquake-induced damage at single building level, and the relative expected consequences on population. The possibility to account for the seismic microzonation (i.e. the possible amplification of the seismic hazard and therefore of the expected impacts due to soil conditions) was also included within DSS. The results of the scenario analysis, presented in the paper in tabular format, were provided to the CP of Florence Municipality as queryable, interactive and end-user friendly web-version maps.

Keywords: Seismic scenario · Civil Protection · Macroseismic vulnerability · Decision Support System

1 Introduction

The estimation of possible impacts induced by seismic events, including damages to the built environment, consequences for the population, direct and indirect losses, is a critical aspect for planning and preparing mitigation actions pre-event and for managing the emergency post-disaster.

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In Italy the Civil Protection (CP) Department is responsible for promoting and enhancing the community resilience to earthquake disasters, at different levels, including national, regional and municipal levels. As far as the municipal level is concerned the Mayor has the primary responsibility for the protection of the territory under his jurisdiction. Aiming to conduct an informed planning for post-earthquake emergency management, the CP Office of Florence Municipality commissioned this study to get an estimation of the possible earthquake-induced impacts in the City. In recent years significant progresses have been made in developing software platforms for seismic risk assessment to provide decision-makers with tools to assess, at regional or local level, and almost in real time, earthquake-induced impact and damage scenarios. The most well-known and internationally used ones include, among others: [1–8].

This study is based on a web-based Decision Support System DSS [9, 10], developed in the framework of a EU-funded project *CIPRNet, Critical Infrastructures Preparedness and Resilience Research Network* (https://www.ciprnet.eu/), and named *CIPCast* (https://www.ciprnet.eu/ads.html) [11], by the *APIC Lab*, of *ENEA*. The initial version of the *CIPCast* DSS (named DSS 1.0) was conceived as a combination of free/open source software environments [12, 13] including GIS features. These peculiar features of DSS 1.0 made it is particularly suitable for the final aim of this study, that was to provide the CP of Florence Municipality with queryable, interactive and end-user friendly web-version maps of selected earthquake scenarios, that they could use to plan for and test alternative emergency management strategies and resource allocations. In the context of this implementation DSS 1.0, has been upgraded to become a specific *Earthquake Simulator* module of the *CIPCast* DSS (hereafter named *CIPCast-ES*) [11]. It was customised to assess the earthquake-induced damage at single building level, and the relative expected consequences on the residents in term of casualties and displaced population. The possibility to account for the seismic microzonation (i.e. the possible amplification of the seismic hazard and therefore of the expected impacts due to soil conditions) was also included within *CIPCast-ES*, and used in this implementation thanks to the availably of a seismic microzonation study providing the relative amplification factors for Florence Municipality. Furthermore, a WebGIS application has been developed, as the natural geographical interface of the *CIPCast-ES*: basic information, maps and scenarios can be visualized and queried via web, by means of standard Internet browsers and, consequently, the main results can be easily accessible to the users and exploitable for further analyses [11].

The implementation of *CIPCast-ES* to Florence case-study allowed the estimation of the expected physical damage to the built environment (limited to the analysis of residential buildings) for two major historical earthquakes felt in Florence in 1895 and 1919, along with the estimation of the consequences to the population in terms of homeless and expected casualties (injured and dead people).

After giving a brief overview on general and peculiar aspects of platforms for seismic risk analysis (a more comprehensive overview is out of the scope of this paper and can be found elsewhere: [5, 14, 15]) the paper presents in Sect. 3 the specific method implemented within ENEA *CIPCast-ES* for the analysed case study. Section 4 of the paper presents and discusses the obtained results. Potentialities and limitations of the study, along with the necessary steps to advance and support the dissemination of the use of DSS for CP purposes are discussed in the conclusions of the paper (Sect. 5).

2 A Short Overview on the Steps

Generally, essential components of platforms for seismic risk assessment include:

(a) *Hazard Component*: for the assessment and representation of the seismic hazard;
(b) *Exposure Component*: for the inventory and characterisation of the exposed assets (e.g. building, infrastructures) and communities;
(c) *Fragility/Vulnerability and Damage assessment component*: for the assessment of the physical assets vulnerability and the propensity to sustain damage when subjected to earthquakes;
(d) *Impacts/Loss assessment component*: for the estimation of the expected direct and indirect impacts and losses due to the earthquake-induced physical damage to structures and infrastructures.

Hazard component should provide, using either deterministic or probabilistic approaches, an estimation of the expected ground-motion considering the specific characteristics of the local/regional seismicity. Deterministic approaches estimate, for the city/area under analysis the expected ground motion, and related consequences, for one selected seismic event deterministic earthquake (e.g. the maximum historical event from a pertinent seismogenic source, or the maximum earthquake compatible with the known tectonic framework); probabilistic approaches estimates the probability of occurrence of a certain ground motion, and relative consequences, in a certain time frame, due to all the possible seismogenic sources that might generate an earthquake in the area under analysis. The selection of one of the two approaches should consider the goal of the study [16–18]. For both deterministic and probabilistic approaches *attenuation relationship* are used to describe how the ground motion attenuates as the distance away from the fault rupture increase. The earthquake ground motion, can be described in term of either qualitative parameters. Examples of quantitative/engineering parameters include, among others, the peak ground acceleration (PGA), elastic spectral quantities (S_a) that have been observed to be more efficient predictors of the structural performance than PGA. Macroseismic Intensity I is a qualitative description of the effects of the earthquake at a particular location, as evidenced by observed damage on the natural and built environment, and by the human and animal reactions at that location. Thanks to its qualitative nature it is the oldest measure of the earthquake Macroseismic Intensity scales have been extensively used when adopting empirical-based model for assessing the building stock seismic vulnerability and for estimating the possible earthquake-induce damage to it (see below).

To account for geological and geophysical characteristics of the sites that might modify the seismic ground motion, or might generate earthquake-induced geotechnical secondary hazards (e.g. potential liquefaction susceptibility, landslide and rock fall hazard, as well as earthquake-related flooding), seismic microzonation should be considered. Empirical observation or analytical simulation (for example, site response analysis) [19] can be used for estimating how the predicted ground motion at from either deterministic or probabilistic approaches should be modified to account for the local seismic microzonation.

Exposure Component: Should provide an accurate classification of the exposed assets, including structures and infrastructures. As far as buildings are concerned, the final aim would be to classify the building into groupings that are expected to behave similarly, sustaining a comparable level of damage, following an earthquake. To this aim, relevant data and information on the building stock should be collected. Preparation of a building stock inventory is a critical part of a seismic risk analysis study and can be both time and resourcing consuming. A compromise needs to be sought between the time and cost required for higher quality data on the building stock and the uncertainties arising from low quality data. For example, in the event of insufficient for a direct classification of the building in terms of the construction types inferences might be established between larger groups of buildings (referred later as categories), recognized on the basis of more general information and building types. Inferences may take the form of "for masonry buildings built before 1919, 40% belong to rubble stone typologies and 60% are old brick masonry buildings".

Fragility/Vulnerability and Damage assessment component: The damage that might affect a building stock, when subjected to a seismic event, can be predicted via different approaches, including: (a) actual damage observation (b) expert judgment, (c) simplified-mechanical and analytical models; or a combination of the three aforementioned approaches. Methods based on actual damage observations are derived statistically processing the damage data from different earthquakes and summarising the outcomes in term damage of: (a) damage probability matrices, DPM (e.g. [20, 21]); (b) vulnerability curves (e.g. Eq. 5); or fragility curves (e.g. [22]).

Impacts/Loss assessment component: Earthquake-induced structural and non-structural damage to building is the root cause for several losses and impacts [23]. Consequences to buildings and their contents, direct economic losses (e.g. cost of repair/reconstruction of building structural or non-structural elements, or replacement of machinery and content), consequences to inhabitants and building occupants can be estimated once the physical damage sustained by the buildings has been assessed. Different empirical correlations, translating structural and non-structural damage into percentage of losses are proposed by different authors and in the framework of different seismic risk analysis methods. These correlations apparently different can be, actually, represented according to a common formulation (Eq. 6).

3 Case Study Description

Florence, the capital of the Tuscany Region, in Italy, is a city, which bustles with industry and craft, commerce and culture, art and science. The population of Florence municipality is about 400,000 inhabitants spread over a territory of just over 100 km^2. The territory pertains mainly to the plain of fluvial-lacustrine basin of Florence-Prato-Pistoia hosting a conurbation of about 1,000,000 inhabitants (Fig. 1). Population growth was impressive especially in the last two centuries, reaching the maximum in the seventies of the last century.

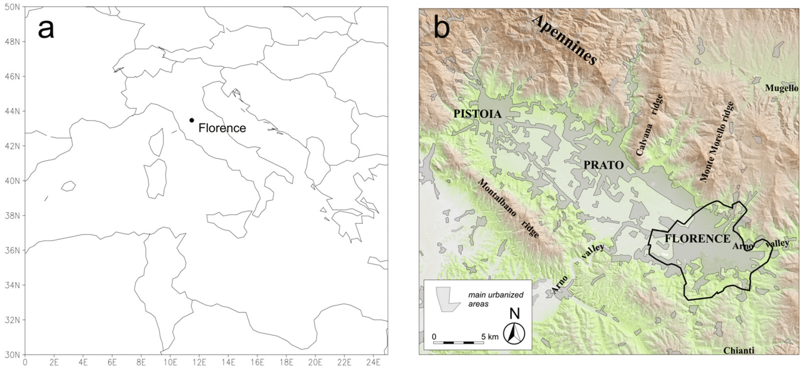

Fig. 1. Florence (Northern Tuscany, central Italy): localization (a) and morphological setting of the area and boundary of the Municipality (b)

3.1 Historical Seismicity and Selection of the Earthquake Event for the Scenarios

Despite the low-moderate historical seismicity presents in the area, the seismic risk in Florence should be regarded as a serious issue nowadays, considering the increased urbanisation and related population and the fact that mostly of the buildings were not designed according to seismic criteria. The national rules recognized Florence as affected by seismic hazard only starting from 1981, currently identifying a low seismic hazard (class 3 to 4 with 1 as higher hazard) with acceleration peak values spanning the 0,125 g–0,150 g range with a return period of 475 years (10% probability of exceedance in 50 years [24]).

Historically, 229 earthquakes were felt in the territory of Florence [25]. Out of these, 20 had intensity larger or equal than the damage threshold i.e. $I_{MCS} = 5-6$. The largest felt historical earthquake, among those known, occurred on May 18, 1895 with an estimated magnitude M = 5.5, intensity at epicentre $I_{0MCS} = 8$ located near Florence, in an area without known seismogenic sources [26]. The felt intensity in Florence was $I_{MCS} = 7$ causing minor to moderate damages to several buildings [27].

The closest seismogenic source is "*Mugello east*" (about 25 km far from Florence) that originated the June 29, 1919 earthquake with an estimated M = 6.3, and $I_{0MCS} = 10$ [26]. The felt intensity in Florence was $I_{MCS} = 6$ causing minor damages to the building stock. Further seismogenic sources include "*Mugello west*", which is linked to the 1542 event M = 5.9 and "*Poppi*" in Casentino, for which there is only one record of a strong historical earthquake (i.e. 1504, M = 5.1). All the aforementioned individual areas (i.e. *Mugello east, Mugello weast* and *Poppi*) belong to a same composite seismogenic source, referred to as "*Mugello-Città di Castello– Leonessa*" running for 200 km along the Apennines from the latitude of Pistoia about (north-west) to the upper valley of the Nera River in Umbria (south-east). The Prato-Fiesole fault system is a further seismogenic source that is closer to the city, but is a debated one since strong earthquake have not been reported/measured for that (see Fig. 2 [27]).

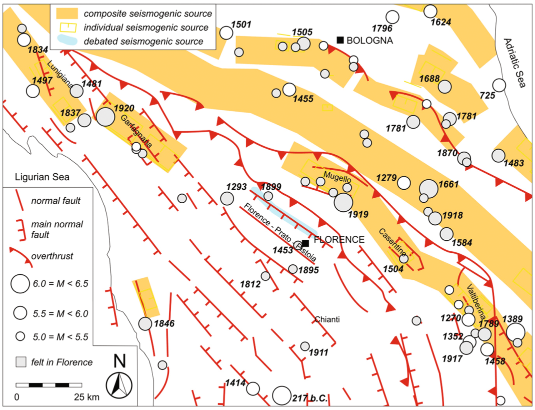

Fig. 2. Tectonics features (adapted from [28]), main seismicity (from [21]), and seismogenic sources (from [26])

The historical seismic events with significant felt macroseismic intensity in Florence, i.e. $I_{\text{MCS}} \geq 6$, were collected and collated [25], to identify the maximum credible earthquake: it is possible to notice the occurrence of four events with felt intensity $I_{\text{MCS}} = 7$ in Florence (years 1414, 1453, 1895), with epicentre location either in Florence or its surrounding areas (i.e. 1414 epicentre Wester Tuscany). These events were characterized by epicentral intensity $6 \geq I_{0\text{MCS}} \geq 8$, estimated magnitude $5.1 \geq M_w \geq 5.7$; their seismogenic sources is unfortunately unknown. The events where the epicentre was attributable to a seismogenic source (i.e. 1542, 1729, 1919) were characterized by a lower felt intensity in Florence, i.e. $I_{\text{MCS}} = 6$ despite the higher magnitude at the epicentre, (i.e. $M_w = 5.95$ and $M_w = 6.29$ for the earthquake generated by the Mugello seismogenic source in 1542 and 1919 respectively). Due to the aforementioned gaps of knowledge in the historical seismicity, it seemed unfeasible to establish a maximum credible earthquake for Florence area. Therefore, the decision was made, for the sake of this study, to analyse the damage scenarios generated by two historical events with epicentre location one in the Florentine area and the other in the Mugello area, respectively: (i) 18 May 1895, estimated magnitude $M_w = 5.50$ (epicentre located only few km outside the municipal boundaries); 29 June 1919, estimated magnitude $M_w = 6.38$.

The epicentral locations of the selected events were assumed (in WGS84 from [21]) as: 43.7 N − 11.267 E for the 1895 Florentine event; 43.95 N − 11.483 E for the 1919 Mugello event. The appropriateness of the selected events is supported by [29] showing that the higher percentage contribution (25–30%) to the probabilistic seismic hazard in Florence, by disaggregation, is related to a $M_w = 4.5$–5 earthquake occurring within 10 km from the city boundary; while a Mw = 6–6.5 earthquake occurring between 20 and 30 km, is contributing by less than 5%. Moreover the selected scenario events were preferred to others causing comparable levels of impacts on the build environment, being more recent and therefore supported by a greater number of information on the observed effects for different locations. The 1919 Mugello event associated to the *Mugello east* seismogenic area has an estimated minimum return period of 450 years [26].

3.2 Available Data

For the sake of this study the Municipality of Florence provided three detailed databases in GIS format, namely: Registry of Buildings (RB); Registry of Population (RP); Map of the Amplification Factor of the seismic wave (MAF). The RB database (version of April 2015) provided for each building the following information: (i) function (i.e. residential, commercial, offices, production, services, tourism or other); (ii) building material (masonry, reinforced concrete, reinforced concrete with pilotis, other); (iii) state of preservation (very bad, bad, good, very bad); (iv) height (meter above ground)/number of stories[1] (underground and above ground); (v) period of construction (<1918; 1918–1945; 1946–1960; >1960). The RP database provided the distribution of residents within the city (377,139 inhabitants at 31 December 2014), in term of number of people localized at point level at their residence address.

For the sake of this study, RB and RP databases had to be spatially joined to assign the population to the residential buildings. People of each street number were assigned to the closest residential building (characterized by a minimum area of 25 m^2 to exclude many smaller accessory building). The automatic GIS operation for integrating the two databases introduced some uncertainties. For 4.100 buildings (14% of the total) it was not possible to associate some resident: some were actually vacant; but for others that were far from the related street number point (e.g. building without direct access to the main street) the inhabitants were assigned to other closer building, This error might affect the results related to the assessment of the impacts on the population, in particular when conducted at single building level.

Finally, the MAF database provided values of the local seismic amplification factor AF. The University of Florence, Department of Earth Sciences [30] elaborated MAF database on the basis of the available geological and geophysical data (1,220 borehole and down-hole tests overall) using the 1-D software Shake-91 [31] for the numerical analysis and the Kriging method for the spatial interpolations of the results. The maximum value obtained for the local seismic amplification factor resulted AF = 2.4; values AF < 1.2 were regarded as negligible.

4 Method

4.1 Deterministic Seismic Hazard and Site Effects Analysis

In this study, the deterministic approach was preferred to the probabilistic one since the main focus was on planning the emergency management and the response for a single event [18]. For the assessment of deterministic hazard scenarios, DSS 1.0 [10]

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[1] When the information on the number of stories above the ground was not available it was estimated as the height divided by 3, being 3 m the standard inter-story height for residential building in Italy.

implemented by default the Sabetta and Pugliese attenuation law [32] that calculates the attenuation of the ground shaking, a function of the distance, in terms of PGA for a given earthquake defined in term of epicentral location and estimated magnitude M at the epicentre. In the present study, the DSS 1.0 was modified, aiming to evaluate the deterministic hazard in terms of macroseismic intensity, I instead of PGA. Macroseismic intensity provides a qualitative description of the seismicity in relation to the damage observed on the built environment. In this respect it can be easily communicated and understood by the end-users and easily handled for managing post-disaster emergencies. Moreover, since DSS 1.0 implemented the macroseismic method for the vulnerability assessment, *CIPCast-ES* [11] is able to provide a hazard scenario directly represented in terms of I avoided the introduction of large uncertainties when converting instrumental measures e.g. PGA, into I [33].

Three attenuation laws were selected for implementation within *CIPCast-ES*, from a review available for the Italian territory [34, 35], namely: Eq. (1), by Faccioli and Cauzzi [36]; Eq. (2), by Pasolini et al. [37]; Eq. (3), by Allen et al. [38].

$$I_{MMI} = 1.0157 + 1.2566M_w - 0,6547 \ln \sqrt{R^2 + 4} \tag{1}$$

$$\begin{aligned} I_{MCS} = 5.862 + 2.460M_w - 0.0086\left(\sqrt{R^2 + 3.91^2} - 3.91\right) \\ - 1.037\left(\ln \sqrt{R^2 + 3.91^2} - \ln 3.91\right) \end{aligned} \tag{2}$$

$$I_{MMI} = 2.085 + 1.428M_w - 1.402 \ln \sqrt{R^2 + h^2 + \left(2.042e^{(M_w-5)} - 0.209\right)^2} + S \tag{3}$$

where M_w is the moment magnitude of the earthquake, R (km) is the epicentral distance, h (km) is the hypocentral depth (set as 3.91 km in Eq. (2)), S in Eq. (3) is a site topographic factor (not considered here because absent in the other equations). Equation (1) is validated for $M_W < 5.5$ (otherwise R in the equation is not the epicentral distance but the shortest distance from site to surface projection of the ruptured fault), Eq. (3) is validated for hypocentral distance (R^2 + h^2) less or equal to 50 km (otherwise see [38]). Macroseimic intensity I was given referring to Mercalli-Cancani-Sieberg, MCS, scale (I_{MCS}) or Modified Mercalli (I_{MMI}) scale.

According to Margottini et al. [39], Eq. (1) assumed MCS intensity equal to Medvedev-Sponheuer-Karnik (MSK) intensity for strong earthquakes [36] while Eq. (2) considered only the MCS intensity [37] and Eq. (3) the MMI [38]. MMI and MSK macroseismic scale have a direct correspondence [40] with the European Macroseismic Scale, EMS-98 [41], universally recognized in Europe as the standard macroseismic intensity scale and implemented in the Macroseismic vulnerability method. Grades of MCS macroseismic scale tend to be higher than those assigned using other scales, the relationship between the two scales it is often solved setting EMS intensity a degree level lower than the MCS intensity, but in realty more complex than this; as such there is not a clear correspondence between MCS and EMS-98 [42, 43]. *CIPCast-ES* was customised to allow the end-users to select one of the three aforementioned attenuation law and to set the parameters defining the selected scenario earthquake (e.g. for Eq. 3: epicentre coordinates; magnitude; and hypocentral depth).

CIPCast-ES was able to calculate, after that, at each building level, R [km], as the distance between the epicentre of the earthquake scenario and the centroid of each building footprint, and therefore the macroseismic intensity, for each one of the three equations, assumed to be equivalent to $I_{EMS\text{-}98}$.

The DSS 1.0 could not account for the effects of amplification due to soil conditions. *CIPCast-ES* was modified so that, the $I_{EMS\text{-}98}$ values assessed at the bedrock according to Eqs. (1) or (2) or (3) could be locally increased taking into account the local amplification factor AF, available from microzonation studies. The increase in the macroseismic intensity to account for soil condition (ΔI_{soil}) was calculated, according to the macroseismic method [44], as:

$$\Delta I_{soil} = \frac{\ln(AF)}{\ln 1.6} \tag{4}$$

For individual building, the related amplification factor was evaluated as the average between the maximum and minimum AF range identified within the boundaries of each building.

4.2 Building Vulnerability and Damage Assessment

For the assessment of the seismic vulnerability of the building stock at census tract-level DSS 1.0 implemented a method referred to as Macroseismic vulnerability method [40, 45] that uses a vulnerability index V and a ductility index Q to characterize the vulnerability of a single building or group of buildings, accounting for the building type, constructive and geometrical features. DSS 1.0 assessed the building stock vulnerability, as a function of the building typology and height, by sourcing the data on the building stock from the 2001 national census of population and houses [10].

In this implementation *CIPCast-ES* was customised to allow for the vulnerability assessment at single building level, as a function of the following information: construction material (e.g. masonry or reinforce concrete, RC); period of construction; number of stories; and state of maintenance. The estimation of V, at the individual building, was carried out implementing the procedure described in [45]. Table 1 shows the basic vulnerability index V*, and the vulnerability modifiers ΔV (i.e. increment or decrement to V*), assigned to each building or group of buildings as a function, respectively, of: (i) building material and period of construction; (ii) state of maintenance, number of stories, possible aggregation with adjacent buildings, presence of weak plan (referred to as pilotis) for RC buildings.

Reference was made to the information included in the RB database to calculate the ΔV values by assuming:

- for the maintenance - good and very good as *good*; bad and very bad as *bad*;
- for the number of stories - 1 to 2 floors as *low;* 3 to 5 as *medium*, >5 as high;
- aggregation status and presence of pilotis.

For buildings where information about the period and/or material of building and/or state of preservation were vacant, the worst case scenario (i.e. higher value of V^* and/or

Table 1. Assumed V* values by period and building material, and ΔV values by state of preservation, number of stories, aggregation status and presence of pilotis

Category	Building period Masonry	*V**	State of maintenance		Number of storeys			Aggregate building		Pilotis
			good	*bad*	*low*	*med.*	*high*	*no*	*yes*	
I	< 1919	0.79	0	0.08	−0.08	0	0.08	−0.04	0.04	-
II	1919 - 1945	0.73	0	0.06	−0.08	0	0.08	−0.04	0.04	-
III	1945-1971	0.69	0	0.04	−0.08	0	0.08	−0.04	0.04	-
IV	> 1971	0.65	0	0.04	−0.08	0	0.08	−0.04	0.04	-
	RC		good	bad	low	med.	high	no	yes	
V	< 1971	0.59	0	0.04	−0.03	0	0.03	0	0.04	0.12
VI	1971–1981	0.55	0	0.04	−0.03	0	0.03	0	0.04	0.12
VII	> 1981	0.42	0	0.04	−0.03	0	0.03	0	0	0.06

ΔV was assumed). According to the Macroseismic method the correlation between the seismic input and the expected physical damage is expressed in terms of a curve of vulnerability, described by a closed analytic function:

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25V - 13.1}{Q}\right)\right] \quad (5)$$

where:

- μ_D is the mean damage expected for the individual building or group of buildings;
- I is the seismic hazard described as a continuous parameter, according to the EMS-98 [41], calculated as $I_{EMS\text{-}98} = I_{badrock} + \Delta I_{soil}$;
- V is the value of the vulnerability index calculated as $V = V^* + \Delta V$;
- Q is the index of ductility assumed equal to Q = 2.3 [46];

From the resulting mean damage μ_D *CIPCast-ES* allocated the level of damage to each building, according to the EMS-98 5 level damage scale [41], plus the absence of damage D_0 as clarified in Table 2.

Table 2. Degrees of damage by the average damage μD value according to EMS-98 scale [41].

Damage degree	None	Slight	Moderate	Heavy	Very heavy	Destruction
	D_0	D_1	D_2	D_3	D_4	D_5
μ_D range values	<0.5	≥ 0.5; <1	≥ 1; <2	≥ 2; <3	≥ 3; <4	≥ 4; ≤ 5

4.3 Expected Consequences on Population and Buildings

The DSS 1.0 could not estimate the expected consequence on the population due to earthquake-induced physical damage to the buildings. This feature was included in *CIPCast-ES,* as for the approach proposed in [40] The occurrence probability of a certain consequence p_c was derived as a function of the likelihood of the building suffering the 5 different EMS-98 damage damages, p_{Dk} k from 0 to 5 as follow:

$$p_c = \sum_{k=0}^{5} w_{ck} p_{Dk} \tag{6}$$

The assessment of the weighting factors $w_{c,k}$ was obtained from empirical relationships derived from the statistical analysis of the damage and the consequences observed after past earthquakes [47, 48]. In particular, in this work reference was made to the correlations proposed by [49] calibrated on Italian earthquake events, recognizing however few limitations of the same, as far as the assessment of the consequences on the population are concerned, including the facts that it does not account for and distinguish night and day, seasonal and weather conditions, different behaviours for different class of residents (e.g. due to age, gender, particular physical conditions, etc.) [50]. Table 3 reports the weighting factors $w_{c,k}$ for the consequences on buildings.

Table 3. Weighting factors wc, k for assessing the expected consequences on buildings [49].

Damage degree		None	Slight	Moderate	Heavy	Very heavy	Destruction
		D_0	D_1	D_2	D_3	D_4	D_5
Collapsed buildings (CB)	w_{CB}	0	0	0	0	0	1
Unusable buildings (UB)	w_{UB}	0	0	0	0.4	1	1

The consequences on the population are assessed as follow: Casualties (CA), including serious injuries and deaths 30% of the residents living in collapsed buildings; Displaced People (DP) all the residents living in Unusable Buildings (UB) minus the number of casualties, estimated as above.

5 Results and Discussion: Scenarios for Selected Earthquakes

The simulations of the two selected earthquake scenarios run with *CIPCast-ES* provided, for different attenuation laws (Eq. from 1 to 3) and in the hypothesis of considering or neglecting site amplification (AF = none, AF = average respectively) the results summarised in Table 4, in terms of consequences on buildings, and people, including: collapsed buildings (CB); buildings with damage level D4 and D5; displaced population (DP); and casualties (CA).

As a general comments, it can be noted that the implementation of the different attenuation laws brought to fairly similar results (Eq. (2) was not used for the 1919 Mugello case study as the assumption of $I_{MCS} = I_{EMS\text{-}98}$ did not seem to be acceptable) and that the role of soil amplification can be very relevant and should not be therefore neglected when estimating earthquake-induced impacts. The analysis showed that strong earthquakes originated in the Mugello area (such as the 1919 Mugello earthquake) could cause in Florence an overall damage to the built environment similar to the one caused by weaker earthquakes with epicentre close to the City (such as the 1895 Florentine earthquake).

Table 4. Impacts on buildings and population resulting from *CIPCast-ES* for the two selected earthquake scenarios

	AF	Attenuation Eq.	Consequences on buildings		Consequences on people	
			CB	D4-D5	DP	CA
1895 Florentine	None	(1)	–	97	852	–
		(2)	–	120	1081	–
		(3)*	–	123	1091	–
	Mean	(1)	–	1681	17894	–
		(2)	–	2379	26308	–
		(3)*	–	2458	27139	–
1919 Mugello	None	(1)	–	140	1364	–
		(3)*	–	100	916	–
	Mean	(1)	–	3701	41788	–
		(3)*	–	1782	20007	–

*the hypocentral depth for Eq. (3) is assumed h = 3.91 km, as for Eq. (2).

Reading the result from a CP end-user perspective, Table 4 shows that: casualties should not be a major issue in the event of an earthquake in Florence; similarly complete collapse of buildings should not be probable. However the CP Department of Florence Municipality might have to deal with a number of displaced people that might range between 800 and 28,000 approximately. A number of buildings in the range of 100 to 3,700 approximately might suffer severe/moderate damage, potentially requiring the need for activating rescue operations and for cleaning rubbles from the urban road network.

In term of the possibility to validate the results on observations from historical events, for the first selected earthquake, i.e. 1895 Florentine, the results obtained seem

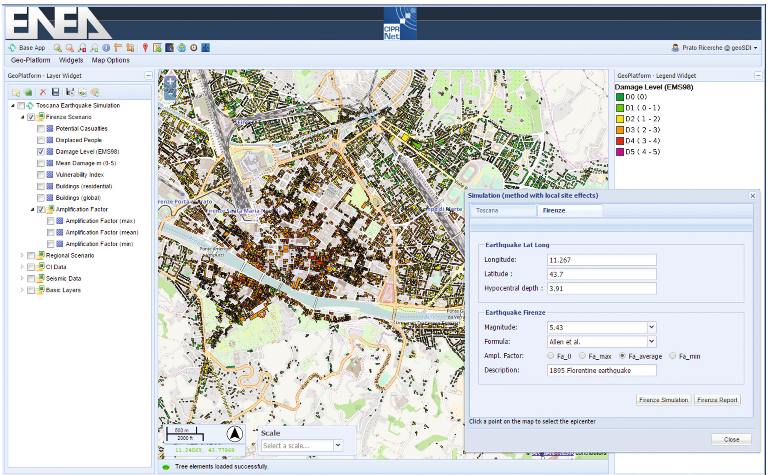

Fig. 3. *CIPCast-ES*. WebGIS interface: example of 1895 Florentine earthquake scenario

coherent with the few available historical information, although a direct comparison is not feasible. The 1895 Florentine earthquake, caused in Florence a minor to moderate widespread damage to the residential buildings (Fig. 3) and to all the monuments, including churches and historical buildings [27, 51, 52]. Four people died, while the number of injured is unknown [21, 52]. No casualties were estimated by the *CIPCast-ES* for the 1895 Florentine earthquake, however it is fair to say that the scenarios evaluated the consequences only on residential buildings, excluding monuments and strategic buildings, such as schools and hospitals.

6 Conclusion

The study presented in this paper provided a good opportunity for upgrading the DSS 1.0 tool to become the *CIPCast - Earthquake Simulator* and showed the effectiveness of the tool to bridge the gaps between scientists and end-users, providing a platform well understood and manageable by both the groups. As seen from this and similar implementations several uncertainties might affect the final results of a seismic risk analysis including: the completeness and reliability of the data available for characterising the exposed asset and population; the assumption made to estimate the hazard, the building vulnerability and expected damage along with the reliability of the adopted models; the several limitations when assessing the possible impacts on people due to the difficulties to account for population dynamics and several further variables that might be influential.

Despite that, and recognising all the aforementioned limitation, this implementation showed that it is very useful to provide to CP Authorities at least with a rough estimation, possibly supported by historical evidences, that could inform their planning and it is very useful to provide them with queryable, interactive and end-user friendly maps, as the ones generated with *CIPCast-ES*, of possible scenarios that could prompt "what-if" discussions; citing Dr. Gramme Edwards *"It's not the plan that's important, it's the planning"*. However, further development of *CIPCast-ES* and the desirable comparison and integration of potentialities with other platforms such as [5, 7], for example, will be promoted to enhance the tool and possibly reduce the uncertainties. Thanks to its modularity and capability, *CIPCast-ES* allows to perform analysis not only on buildings but also on distributed infrastructures, including roads, gas electric power, telecommunication, etc. Moreover, *CIPCast-ES* is not limited to earthquake hazard but could also simulate impacts from flooding and extreme weather conditions, allowing multi-hazard analysis and cascading hazard analysis (e.g. increased of flooding risk after earthquakes).

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