ANALYSIS OF ORDINARY BUILDINGS ON THE ISLAND OF ISCHIA (ITALY) FOR A SEISMIC IMPACT ASSESSMENT

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ABSTRACT

Ischia is a quiescent volcanic complex, characterized by several periods of activity, also of explosive typology. Each year, seismic stations detect few low-energy events, although in the past severe earthquakes occurred, causing extensive damage. The last significant seismic event, with a magnitude of 3.91, occurred on 21st August 2017, again in the municipality of Casamicciola.

The hazard constituted by seismic phenomena is compounded by a high exposed value, in terms of population and buildings. From 1861 to today, the resident population has increased considerably, from 23,511 to 62,831 units, to which are added 4 million tourists a year.

The high risk of the Ischia territory highlights the need to bring the sustainable planning at the centre of the debate, considering the vulnerability of the area. In this perspective, an application aimed at assessing the seismic impact scenario induced by a single seismic event is illustrated below. The aim is to show a methodological approach able to quantify the resources necessary for emergency planning and organization of operational intervention.

KEYWORDS

Seismic Risk, Seismic Impact, Buildings Vulnerability

1. INTRODUCTION

Ischia is a quiescent volcanic complex, which has had several periods of activity, also characterized by large explosive eruptions. The last eruption occurred in February 1302, when a crater opened in the Fiaiano area, emitting lava for more than two months. Since then, the island's volcanic system has continued to manifest its activity through widespread fumarolic and hydrothermal activity and recurrent seismicity.

Every year, seismic stations detect few low-energy events, although strong earthquakes have occurred on the island in the past, causing extensive damage. In particular, the March 4, 1881 event caused severe damage in Casamicciola and Lacco Ameno. The

July 28, 1883 earthquake, on the other hand, was the most catastrophic event to occur on the island in recent centuries. In total, the earthquake caused 2313 deaths and 762 injuries, as well as 9500 homeless people, who were housed in shacks. The last significant seismic event, with a magnitude of 3.91, occurred on August 21, 2017, also in the municipality of Casamicciola.

In addition to the hazard from seismic phenomena, there is a high exposed value in terms of population and built-up area. From 1861 to the present, in fact, the resident population has increased significantly, from 23,511 to 62,831. To this is added about 4 million tourists a year. The increase in population has produced, in parallel, an increase in the number of buildings, often constructed in derogation of building regulations with shoddy materials and/or on fragile soils and, for this reason, particularly vulnerable to geophysical hazards. The high risk of the Ischian territory places special emphasis on the need for sustainable planning that considers the vulnerability of the area.

The high seismicity of the area has always drawn attention in the National Risk Assessment (NRA) in the perspective of Disaster Risk Management (DRM). The event of 21 August 2017 has been, in fact, studied by several researchers with the aim of determining, through computer tools and modeling, the seismic impact of the analyzed area in terms of building damage and damage mitigation [1,2,3]

With a view to estimating losses (of buildings, lives and economic), the Civil Protection Department has made available the possibility of assessing the impact on the island of Ischia through the IRMA platform [4]. This platform provides a library of past seismic events, including the one that occurred in Ischa on August 21, 2017, and allows accredited researchers to define a vulnerability model of the investigated area and obtain an estimate of the expected damage.

With this in perspective, an activity of analysis of the ordinary Ischian built-up area is illustrated in the following, which gives the possibility to know the constructive peculiarities of the area and to estimate a possible response of the built-up area towards seismic phenomena. To this purpose, the PLINIVS Study Center (PSC) carried out a field data collection activity aimed at typological characterization of the island's urbanized built-up area. The investigation has been carried out at two scales: the first was developed at the scale of homogeneous sectors through the CARTIS form, the second is a building-by-building data collection activity conducted through the CARTIS BUILDING form and the PLINIVS form.

In a second step, the data collected has been used within a scenario assessment model of seismic impact in Ischia induced by the seismic event of 21 August 2017. This model shows the approach to be followed for assessments aimed at quantifying the resources needed for emergency planning and the organization of operational intervention. A seismic impact assessment goes through the estimation of three variables: hazard, vulnerability and exposure [5]. Hazard is the probability of occurrence of the single event, of a certain severity, in the specific area and in a specific time period. Vulnerability is the sensitivity of an exposed element to the seismic event. It can be assessed as the probability that the exposed element will experience a certain level of damage or changes in state, with reference to an appropriate scale, because of an event of assigned intensity. Exposure is the geographic distribution in quantitative and qualitative terms of the different elements at risk that characterize the area under consideration (buildings and occupants), whose condition and/or functioning may be damaged, altered or destroyed due to the occurrence of the seismic event. The outcome of the model is represented by the probable buildings distribution on appropriately chosen damage scale.

The impact has been assessed through the E.A.S.E. model [6,7], a procedure developed by the PSC that discretizes the area under consideration through a square-mesh grid of size 250x250m. For each cell are defined: hazard data, in terms of PGA; exposure data, in terms of number of buildings for each structural vulnerability class. Combining these data with seismic vulnerability, the model provides, cell by cell, the number of collapsed buildings, the number of not available buildings. The hazard value per cell was derived from macro-seismic intensity data produced by [8] and grid-fitted. The exposure model is built based on the BINC method [9], which defines a probable quantitative and qualitative distribution of buildings on cells. The method makes use of both data collected in the field through filing and, where accurate information is not present, statistical correlations between data collected in the field and aggregate data on buildings by census units in the 2011 ISTAT database (Italian National Statistics Institute).

The paper is organized in two sections. The first one is focused on the analysis of the ordinary buildings and contains the description of the used forms for the survey activities, the criteria adopted for the built of the geo-database and the seismic characterization of the buildings for each municipality of the Ischia Island. The second section describes the impact model E.A.S.E., the characterization of the three factors with respect to the August 21, 2017 event on the grid and the outcomes in terms of damaged buildings.

2. ANALYSIS OF ORDINARY BUILDINGS

2.1 The cognitive investigations

To be able to assess the risk related to an eruption of the Ischia volcano, an extensive and detailed cognitive campaign of seismic (with reference to pre-eruptive seismic events) and volcanic vulnerability of the ordinary Ischia built-up area was conducted, through the compilation of:

- the CARTIS form [10] relating to the six Ischian municipalities;
- the CARTIS BUILDING form for 2,000 buildings appropriately chosen within the compartments identified in the CARTIS forms mentioned in the previous point;
- the PLINIVS form for 3,000 buildings (about 10% of the island's building aggregates).

The surveyed data has been used to update the distribution of vulnerability classes of the Island's built environment, correcting the distributions obtained on an ISTAT basis.

2.2 The CARTIS and the CARTIS BUILDING form

The CARTIS form (1st Level Form for Typological-Structural Characterization) is aimed at surveying the prevailing ordinary building types within municipal or sub-municipal areas (referred to as "sectors"), characterized by homogeneity of the building fabric in terms of age of first establishment and/or construction and structural techniques.

The form refers to ordinary buildings only, mainly for housing and/or services. These are, for the most part, multi-story buildings, characterized by masonry or reinforced concrete framed or baffled structure, and with inter-story heights and spacing between vertical structural elements contained. Therefore, typologies attributable to monumental assets (religious buildings, historic buildings, etc.), special structures, (industrial warehouses, shopping centers, etc.) or strategic structures (hospitals, schools, barracks, prefectures, civil defense headquarters, etc.), whose characteristics do not fall within those of ordinary buildings, are excluded from the characterization.

The form is organized in 4 sections (from 0 to 3):

Section 0 has two parts. The first one (Part A) contains the general characteristics of the Municipality (number of residents and number of buildings) and the identity details of the interviewees. The second one (Part B) contains the list of the homogeneous sectors identified within the municipality, and for each of them the number of buildings and the percentage distribution of them on the different vertical macro-types is given. Four macro-types of "masonry" and four macro-types of "reinforced concrete" can be indicated in this section; the detailed characteristics of the vertical types will then be specified in subsequent sections.

Section 1 identifies the typology in the Sector. There are also the identification code in the Sector, the position in the urban context, together with a picture and sketches of the typology in plan and section.

Section 2 contains the general features referred to at least the 80% of the buildings with the examined vertical typology. The collected information regards the geometry as well as to some metric information (number of floors; average floor height; ground floor average height; underground floors; average floor area) together with age of construction and main use, described by different possible ranges. For the construction period and the number of floors it is possible to provide two boxes representative of the most recurrent values on the investigated typology.

Section 3 characterizes the structural elements of the typology. There are three parts in the Section: 3.1A, 3.1B and 3.2. The Sections 3.1A and 3.1B are alternatives to each other and characterizes the vertical typology, while Section 3.2 contains info on the other typological characteristics.

The CARTIS BUILDING form characterizes the typology of an individual structural unit. The structure of the sheet coincides with that of CARTIS one, except for Section 0, absent in the CARTIS BUILDING, which refers to subdivisions.

The cognitive survey of the island of Ischia has been carried out by filling out the CARTIS BUILDING form for randomly selected buildings in all the compartments, in proportion to the number of total buildings in each compartment. The on-site survey phase revealed some critical issues of the survey activity carried out based on the CARTIS form related to:

- a different percentage distribution of some types in the different compartments, as shown in Table 1.
- the need to correct the perimeter of some compartments in the municipalities of Ischia, Lacco Ameno and Casamicciola Terme.

Table 1.Percentage distribution of prevailing typologies in the subdivisions of the six municipalities on the island of Ischia through compilation of CARTIS (C) and CARTIS BUILDING (CB) form.

MUNICIPALITY OF ISCHIA			MAS01		MAS02		RCO01		RCO02		surveyed buildings [CB]	
			C	CB	C	CB	C	CB	C	CB		
			%								N°	
1	C001	castle	100	100							**10**	**555**
2	C002	historic centre	80	60	20	40					**160**	
3	C003	expansion area 1	30	15	50	65	20	20			**135**	
4	C004	expansion area 2	10	5	60	70	20	15	10	5	**180**	
5	C005	expansion area 3	10	80			90	20			**25**	
6	C006	expansion area 4					100	100			**45**	

MUNICIPALITY OF BARANO D'ISCHIA			MAS01		MAS02		RCO01		RCO02		surveyed buildings [CB]	
			C	CB	C	CB	C	CB	C	CB		
			%								N°	
7	C001	historic centre	100	100							**60**	**295**
8	C002	expansion area 1	100	100							**60**	
9	C003	expansion area 2	65	65			35	35			**95**	
10	C004	expansion area 3	30	65			70	35			**80**	

MUNICIPALITY OF CASAMICCIOLA TERME			MAS01		MAS02		RCO01		RCO02		surveyed buildings [CB]	
			C	CB	C	CB	C	CB	C	CB		
			%								N°	
11	C001	after earthquake	60	40	40	60					**95**	**203**
12	C002	expansion area 1	100	100							**8**	
13	C003	expansion area 2	50	50			60	50			**90**	
14	C004	expansion area 3					100	100			**10**	

MUNICIPALITY OF FORIO			MAS01		MAS02		RCO01		RCO02		surveyed buildings [CB]	
			C	CB	C	CB	C	CB	C	CB		
			%								N°	
15	C001	historic centre	32	45	65	45	3	10			**135**	**483**
16	C002	expansion area 1	30	38	30	37	25	25	15	0	**185**	
17	C003	expansion area 2	25	15			40	65	35	20	**173**	

MUNICIPALITY OF LACCO AMENO			MAS01		MAS02		RCO01		RCO02		surveyed buildings [CB]	
			C	CB	C	CB	C	CB	C	CB		
			%								N°	
18	C001	historic centre	100	100							**45**	**252**
19	C002	expansion area 1	100	100							**16**	
20	C003	expansion area 2	65	80			35	20			**101**	
21	C004	expansion area 3	50	80			50	20			**90**	

MUNICIPALITY OF SERRARA FONTANA			MAS01		MAS02		RCO01		RCO02		surveyed buildings [CB]	
			C	CB	C	CB	C	CB	C	CB		
			%								N°	
22	C001	historic centre	90	95			10	5			**145**	**180**
23	C002	expansion area 1	70	70			30	30			**35**	

2.3 The PLINIVS form

In addition to the analysis of building types through the compilation of the CARTIS BUILDING form for the six Ischia municipalities, an expeditious survey of an additional sample of 3,000 buildings has been carried out, identified based on specific characteristics of the subdivisions (size, diversity of types and building density).

The analysis of the buildings has been done through expeditious visual survey and compilation of the Level I form, called PLINIVS, for the collection of parameters affecting the seismic and volcanic vulnerability of buildings, which has been used extensively in previous research. The information contained in the PLINIVS form can be divided into two groups. The first contains the common parameters used for seismic vulnerability assessment, like as information on the main vertical and horizontal structures, regularity in plan and elevation, age and preservation of the building, and number of floors. The second group is specific to the behavior of the building with respect to a volcanic eruption, as it collects information on the elements of vulnerability with respect to fall deposits (roofs) and pyroclastic flows (openings and infills).

Specifically, the PLINIVS form is divided into the following eight sections:

Section 1: The IDENTIFICATION section locates the building with reference to the geographical parameters provided by the Campania region;

Section 2: The GENERAL INFORMATION section refers to the type (ordinary building, warehouse, electrical station, etc.), purpose (hospital, school, etc.), use (fully used, partially used, unused, and abandoned), and exposure (ordinary, strategic, exposed to special hazards) of the building;

Section 3: The CONDITION section refers to the age, the state of preservation of the structure (poor, mediocre, good, and excellent), and the type of finish (cheap, ordinary, luxury);

Section 4: The DESCRIPTIVE CHARACTERISTICS section refers to: the total number of floors starting from the ground floor; the number of above-ground floors, including the penthouse; the number of residential apartments; the presence of occupied or unoccupied basement; the height of the second floor; the minimum and maximum heights of all floors up to the roof; the presence of obstacles with a height of more than 2m; the orientation (angle between the longest or main facade and the North); and the position in the unit within the aggregate;

Section 5: STRUCTURAL CHARACTERISTICS section refers to: the main type (reinforced concrete, masonry, wood, steel, and mixed); vertical structures (sack masonry with or without reinforcement, rough-hewn stone masonry, tuff block masonry, reinforced concrete frame with weak or strong infill, etc.); to horizontal structures (wooden slab, steel beam slab, concrete slab, vaults, etc.); to the thickness of walls; and to the type of curtain walls (tuff blocks or squared stones, concrete blocks, etc.);

Section 6: The OPENINGS section refers to the percentage of openings on the façade; the number of small, medium, and large windows; the material (wood, PVC, aluminum or wood-aluminum, light steel, and anti-intrusion type steel); their protection and condition;

Section 7: The INTERVENTION section refers to the age and type of intervention (special maintenance, upgrading and retrofitting);

Section 8: The REGULARITY section refers to: the distribution of masses and stiffnesses in plan and elevation; the type of structure (single- or double-framed one-way, single- or double-walled directional, or framed walls); the presence of soft floor (pilotis on part of the ground floor, completely open ground floor, or intermediate soft floors); and the possible presence of squat elements.

2.4 The geo-database construction

The format of the surveyed data and the coding of the identifiers are organized so that the information collected can be easily entered into the PLINIVS Centre data base. The buildings are all georeferenced and reported in a G.I.S. system.

- The site survey operation was carried out according to the following procedure:
- Selection of the building aggregates to be surveyed;
- Identification, within the aggregate, of individual buildings, (understood as autonomous structural units);
- Subdivision, on the paper map, of each aggregate into buildings and assignment to each listed building of an identification code, consisting of the aggregate code (PROG_ED) and a building code, with progressive numbering within the aggregate (EDIF);
- Completion for each building of the survey form. In it, the building was identified by reporting the aggregate code and the building code.

If, within the areas to be surveyed, an aggregate is found that is not shown on the reference map, it is plotted on the paper service map provided and identified by a temporary "new aggregate code." Any subdivisions into multiple buildings are still coded with progressive EDIF identifier.

If, on the contrary, it has been found that buildings shown on the map are not in fact present, an indication of this is given on the service map.

If, finally, macroscopic differences in geometry were found between an aggregate on the cartography and the actual situation, appropriate corrections were reported on the service map, and new provisional codes were assigned where necessary:

- Transfer of the material produced in the field to the G.I.S. operators, who reported the subdivisions and any corrections on the cartography and replaced the "provisional aggregate code" with a new unique identifier (PROG_ED);
- Entering the contents of the surveyed sheets into a special data base;
- Linking, through the identification codes, of the collected data to the "shapes" of the G.I.S.

2.5 The vulnerability classes on Ischia Island

The seismic vulnerability class has been assessed for each building surveyed (2,000 CARTIS BUILDING form + 3,000 PLINIVS form). The criteria adopted to assign the vulnerability class is identified in the SAVE method [11], already widely used in the past for similar research carried out by the PSC.

This methodology involves the assignment of a base score, depending on the type of vertical structure, which is subsequently updated through the application of modifier coefficients (based on the typological, geometrical and structural characteristics of the building). The weight of these modifiers is previously calibrated on the statistics of seismic damage detected as a result of earthquakes that have occurred in the past. The most significant parameters for the vulnerability class assignment are the vertical structure, that gives the general behavior of the structure, and the age of construction. The latter, although it’s not a structural parameter, inherently considers the remaining building types, which adapt over time. The vulnerability class considered in the SAVE method are four, identified with the letters A, B, C and D ordered by decreasing vulnerability.

In Figure 1 is represented the surveyed buildings distribution on the vertical macro-typologies (reinforced concrete, masonry and mixed structure). It is shown that Ischia Island has a high percentage of masonry buildings that in 5 municipalities on 6 is recurrent more than 50% of the structures. The municipality of Serrara Fontana has a high percentage of mixed structure (78%), but this type of building is generally obtained from an extension of pre-existing masonry buildings. The municipality of Ischia has the highest percentage of reinforced concrete (20%).

Figure 2 shows the distribution of the surveyed buildings on the age of construction. A very noticeable color variation has been used used for buildings constructed before 1980 (in blue scale) and after 1980 (in green scale) because in this year, regulations for construction in seismic zones came into effect for the first time in Italy. It is highlighted that Barano di Ischia and Serrara Fontana are the municipalities with the most recent constructions: more than the 50% of the buildings have been built after the entry into force of the legislation. The municipalities with the oldest buildings, however, are Casamicciola Terme and Lacco Ameno.

Figure 3 shows, for each municipality, a qualitative distribution of the buildings for the combination of the age of construction and the vertical macro-typologies. It is evident in the entire island the choise of build with reinforced concrete and mixed structure in the recent years. At the end, the use of the SAVE criteria has furnished the surveyed buildings distribution on the vulnerability classes, shown in Figure 4. Analysis of the buildings surveyed shows that the building fabric appears to be of good quality, being characterized by the prevalence of buildings with classes C and D, as opposed to classes A and B. The municipality with higher vulnerability classes (A and B) is Serrara Fontana, but in general a fairly homogeneous situation is observed, with no substantial differences among the six municipalities.

It is important to emphasize, however, that these results refer to a sample of buildings, chosen randomly, which may not effectively represent the overall built environment of Ischia.

3. THE IMPACT ASSESSMENT: THE EVENT OF 21 AUGUST 2017

3.1 The model

The EASE model [6,7], developed and engineered by the PSC for the Department of Civil Protection under Conventions, has been adopted to estimate the effects of the reference earthquake.

The model discretizes the territory under consideration through a square-mesh grid of size 250x250m. Each cell is assigned: hazard data, in terms of macroseismic intensity; and exposure data, in terms of the number of buildings for each structural vulnerability class and number of occupants. Combining these data with seismic vulnerability (percentiles 16, 50 and 84%), the model provides, cell by cell, the following outputs:

- Number of collapsed buildings, as the sum of buildings with D4 and D5 damage;
- Number of uninhabitable buildings, as the sum of buildings with D4 damage and 60% of buildings with D3 damage.

3.2 The Hazard

The event of 21 August 2017 (Lat. 40.738; Long. 13.897) of magnitude 3.91 and depth 1.5 km, inferred from the Parametric Catalogue of Italian Earthquakes CPTI15, version 2.0, has been adopted as the reference hazard.

Immediately after the event, National Institute of Geology and Volcanology (INGV) developed and made available a shake-map that provides an immediate visualization of the shaking level of the affected area. The shake-map reports the peak values recorded by accelerometers and seismometers, mainly provided by the National Accelerometric Network (RAN) of the Civil Protection Department and by the National Seismic Network (RSN) of INGV, present in the area of the earthquake. Where no observed values are present, the software interpolates the data using ground motion attenuation laws, which are empirical laws for predicting shaking parameters as a function of distance, magnitude and ground conditions.

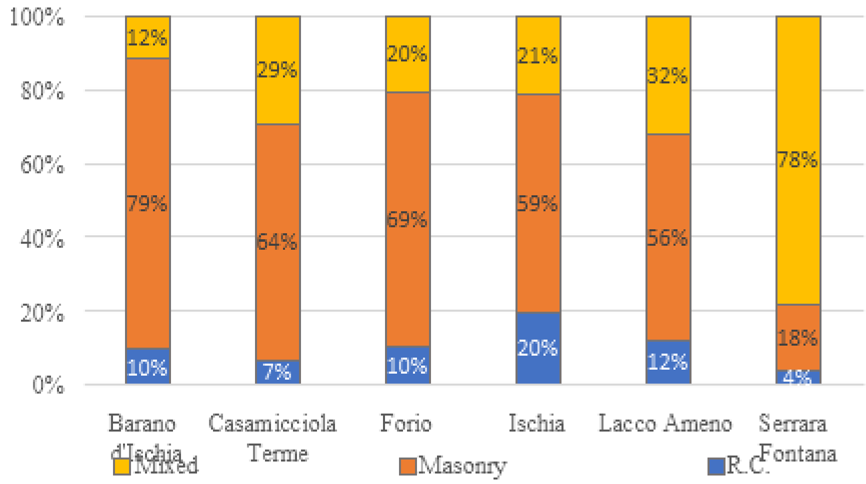

Figure 1. Surveyed buildings distribution on the vertical macrotypologies

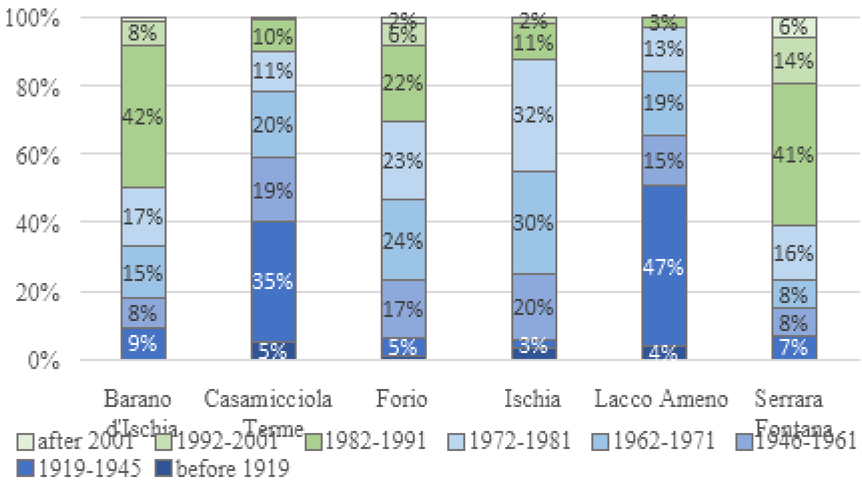

Figure 2. Surveyed buildings distribution on the age of construction

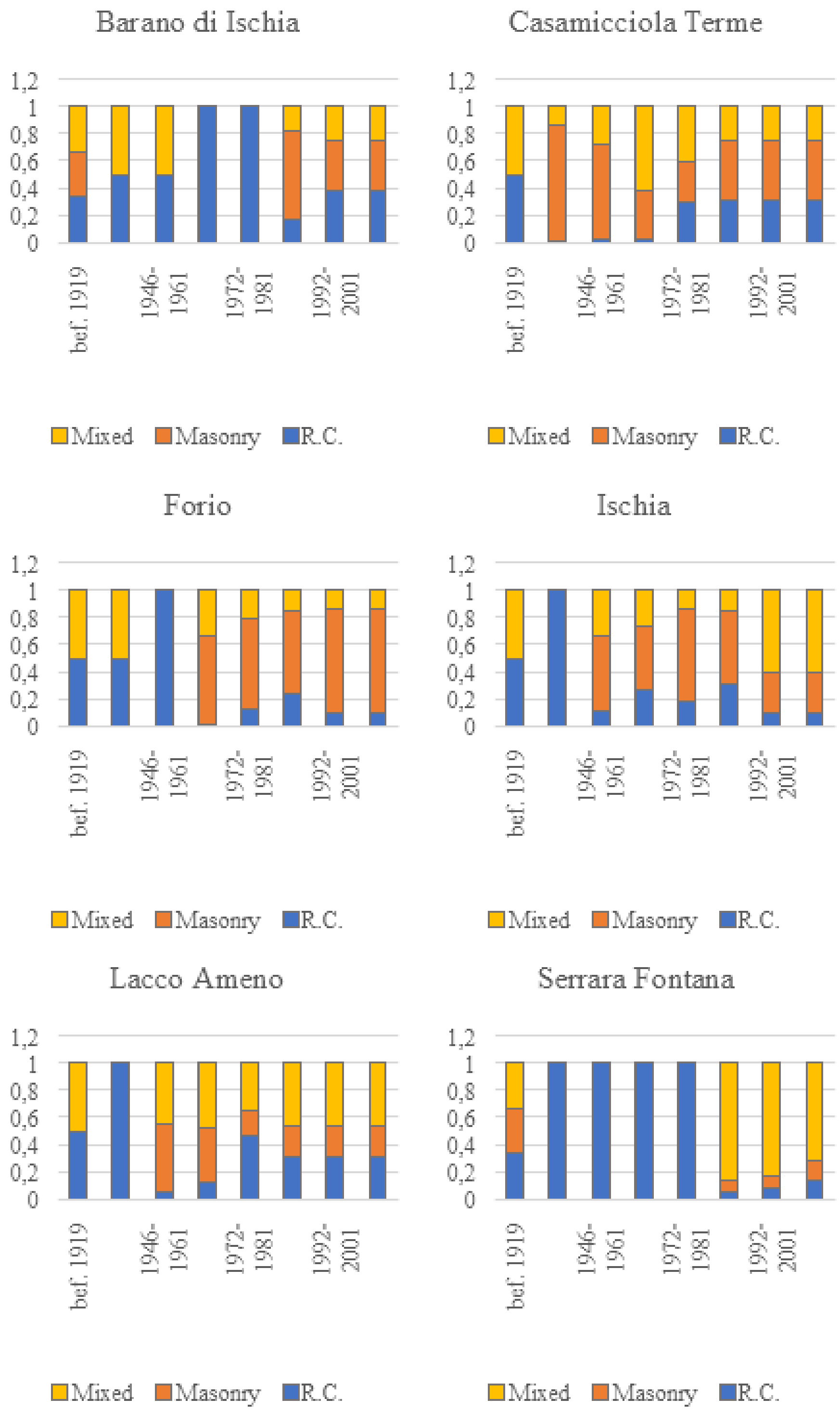

Figure 3. Surveyed buildings distribution for vertical macro-typologies and age of construction

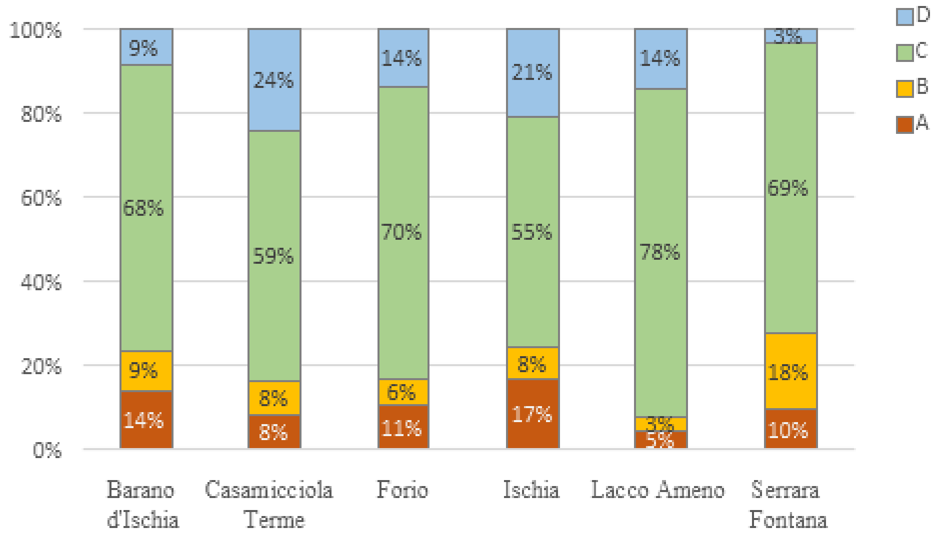

Figure 4. Surveyed buildings distribution on the vulnerability classes

The confidence of a shaking map is a function of the density of recording stations contributing to the calculation. The case of the Ischia earthquake is particularly complex and difficult to make an accurate reproduction of the real shaking observed using the ShakeMap procedure because:

- there is only one usable datum on the Island of Ischia (IOCA seismic station, accelerometric sensor, located at the Casamicciola Observatory);
- the currently developed Shakemap procedure uses predictive ground motion laws that have not been implemented for volcanic areas;
- local ground motion amplification effects were observed at the IOCA station.

For the reasons stated above, the Shakemaps of the 21 August 2017 Ischia earthquake do not allow to accurately represent the shaking due to the earthquake on the island [12]. They are essentially derived from the application of the attenuation law alone [13, 14] and represent a compromise, leading to an underestimation of the shaking in the epicentral area, but to a more correct estimate of the shaking of the rest of the Island, in agreement with the available macro-seismic surveys [15].

However, it is always possible to use the data provided by the accelerometer recordings of the IOCA seismic station to investigate the shaking locally (a few tens of meters) near the station. For shaking outside the Island, the maps, however, show a relevant attenuation of ground motion with distance-a common phenomenon in volcanic areas.

Having observed the low accuracy of the Shakemap, it was considered to produce acceleration maps in Figure 5 by interpolating the macroseismic intensity distribution maps [8] and using which acceleration-intensity conversion law of Faenza and Michelini [13].

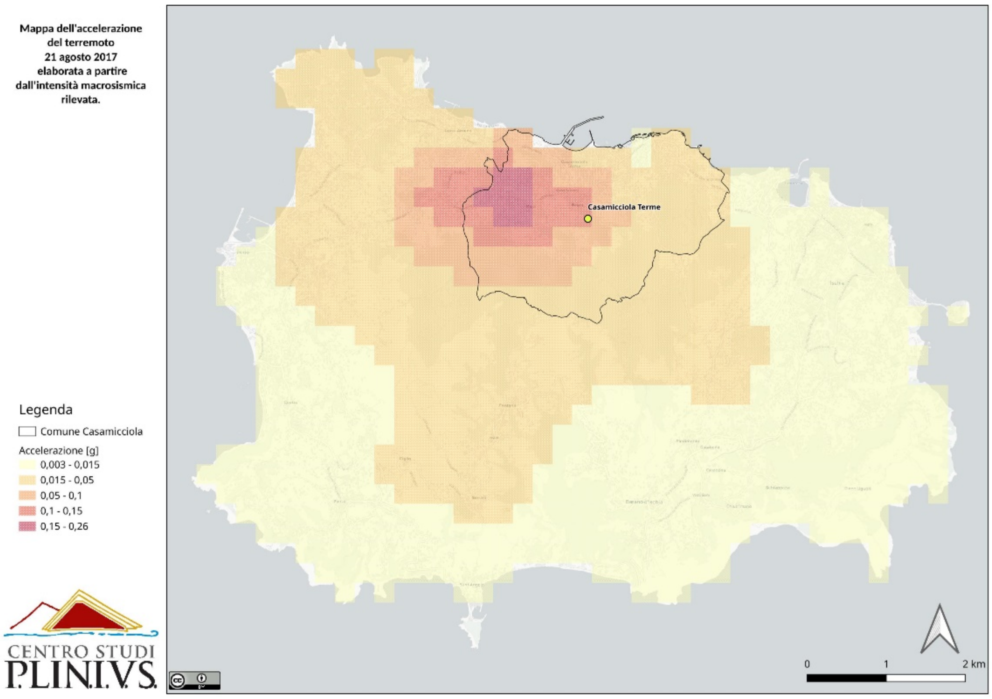

Figure 5. Acceleration map produced by the PLINIVS Centre, on a grid of 250x250 m based on the macroseismic intensity map

3.3 The Vulnerability

For each class of building vulnerability, the seismic vulnerability of ordinary buildings is represented by the vulnerability curves shown in Figure 6 calibrated to the data from the damage probability matrices shown in Table 2 and converted to PGA through Margottini's law [16]. These curves relate the continuous value of acceleration to the discrete damage parameter Di (D0: no damage; D1: light damage; D2: moderate damage; D3: severe damage; D4: partial damage; D5: total collapse), through a statistical analysis of damage observed following earthquakes occurring in Italy since 1980 [17].

3.4 The Exposure

In order to assess the distribution of vulnerability classes for each minimum model reference unit (250x250m cell of a regular square-mesh grid), the BINC procedure [9], based on statistical correlations between the 2011 ISTAT census data and the data collected in the field, has been adopted.

ISTAT data on buildings refer to individual census area, and it for each of these sections it gives information on the number of buildings and their distribution on the age of construction. Through a statistical correlation between the vulnerability classes and the age of construction derived on the damage database, the BINC procedure furnishes the buildings distribution on the vulnerability classes for each census zone.

In a second step, a criterion is adopted to transfer available information by census section to grid. In accordance with relations (1) and (2), having defined "zones" as the areas of intersection between census sections and the grid (Figure 7), are calculated:

Table 2. Damage Probability Matrices (DPMs) obtained through a statistical analysis on observed damages after seismic events occurs in Italia since 1980 [17]

Vulnerability Class	Macroseismic intensity	D0	D1	D2	D3	D4	D5
A	V	0,3487	0,4089	0,1919	0,0450	0,0053	0,0002
B		0,5277	0,3598	0,0981	0,0134	0,0009	0,0000
C		0,6591	0,2866	0,0498	0,0043	0,0002	0,0000
D		0,8587	0,1328	0,0082	0,0003	0,0000	0,0000
A	VI	0,2887	0,4072	0,2297	0,0648	0,0091	0,0005
B		0,4437	0,3915	0,1382	0,0244	0,0022	0,0001
C		0,5905	0,3281	0,0729	0,0081	0,0005	0,0000
D		0,7738	0,2036	0,0214	0,0011	0,0000	0,0000
A	VII	0,1935	0,3762	0,2926	0,1138	0,0221	0,0017
B		0,3487	0,4089	0,1919	0,0450	0,0053	0,0002
C		0,5277	0,3598	0,0981	0,0134	0,0009	0,0000
D		0,6591	0,2866	0,0498	0,0043	0,0002	0,0000
A	VIII	0,0656	0,2376	0,3442	0,2492	0,0902	0,0131
B		0,2219	0,3898	0,2739	0,0962	0,0169	0,0012
C		0,4182	0,3983	0,1517	0,0289	0,0028	0,0001
D		0,5584	0,3451	0,0853	0,0105	0,0007	0,0000
A	IX	0,0102	0,0768	0,2304	0,3456	0,2592	0,0778
B		0,1074	0,3020	0,3397	0,1911	0,0537	0,0060
C		0,3077	0,4090	0,2174	0,0578	0,0077	0,0004
D		0,4437	0,3915	0,1382	0,0244	0,0022	0,0001
A	X	0,0017	0,0221	0,1138	0,2926	0,3762	0,1935
B		0,0313	0,1563	0,3125	0,3125	0,1563	0,0313
C		0,2219	0,3898	0,2739	0,0962	0,0169	0,0012
D		0,2887	0,4072	0,2297	0,0648	0,0091	0,0005
A	XI	0,0002	0,0043	0,0392	0,1786	0,4069	0,3707
B		0,0024	0,0284	0,1323	0,3087	0,3602	0,1681
C		0,0380	0,1755	0,3240	0,2990	0,1380	0,0255
D		0,0459	0,1956	0,3332	0,2838	0,1209	0,0206
A	XII	0,0000	0,0000	0,0000	0,0010	0,0480	0,9510
B		0,0000	0,0000	0,0006	0,0142	0,1699	0,8154
C		0,0000	0,0001	0,0019	0,0299	0,2342	0,7339
D		0,0000	0,0002	0,0043	0,0498	0,2866	0,6591

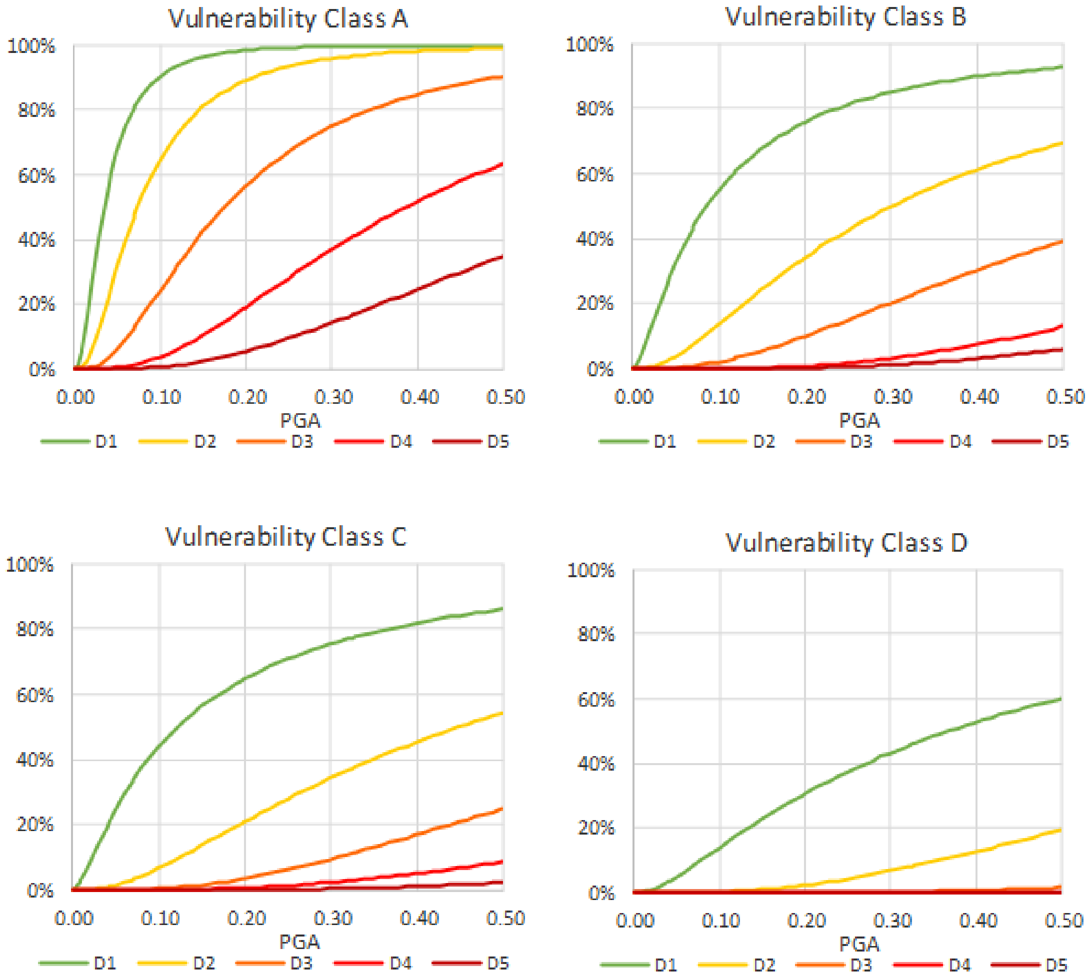

Figure 6. Vulnerability curves in PGA based on the DPMs in macroseismic intensity

- Number of buildings in the zone i of the census area j having vulnerability class k:

$$E_{i,j}^{k} = \begin{cases} E_{ij}^{\kappa,\kappa} & if: E_{j}^{ISTAT} / E_{j}^{R} \leq 1 \\ E_{ij}^{k,R} + E_{ij}^{k,R} = E_{ij}^{k,R} + E_{j}^{k} / E_{j}^{ISTAT} \cdot \left(E_{ij} - E_{ij}^{R}\right) & if: E_{j}^{ISTAT} / E_{j}^{R} > 1 \end{cases}$$

(1)

- Number of buildings in the cell c having vulnerability class k:

$$E_{c}^{k} = \sum_{i=1}^{n} E_{i,j}^{k} \tag{2}$$

where:

c cell
j census area
i zone, intersection of the grid with the census area
k vulnerability class (*k* = A, B, C, D)

n number of zone in the cell *i*

E_j^{ISTAT} number of buildings in the census area *j* (ISTAT)

E_j^k number of buildings in the census area *j* with vulnerability class *k* (BINC)

E_j^R number of surveyed buildings in the census area *j*

E_{ij}^k number of buildings in the zone *i* of the census area *j* and vulnerability class *k*

$E_{ij}^{k,R}$ number of surveyed buildings in the zone *i* of the census area *j* having vulnerability class *k* (SAVE)

$E_{ij}^{k,R}$ number of not surveyed buildings in the zone *i* of the census area *j* and vulnerability class *k*

E_c^k number of buildings in the cell *c* with vulnerability class *k*.

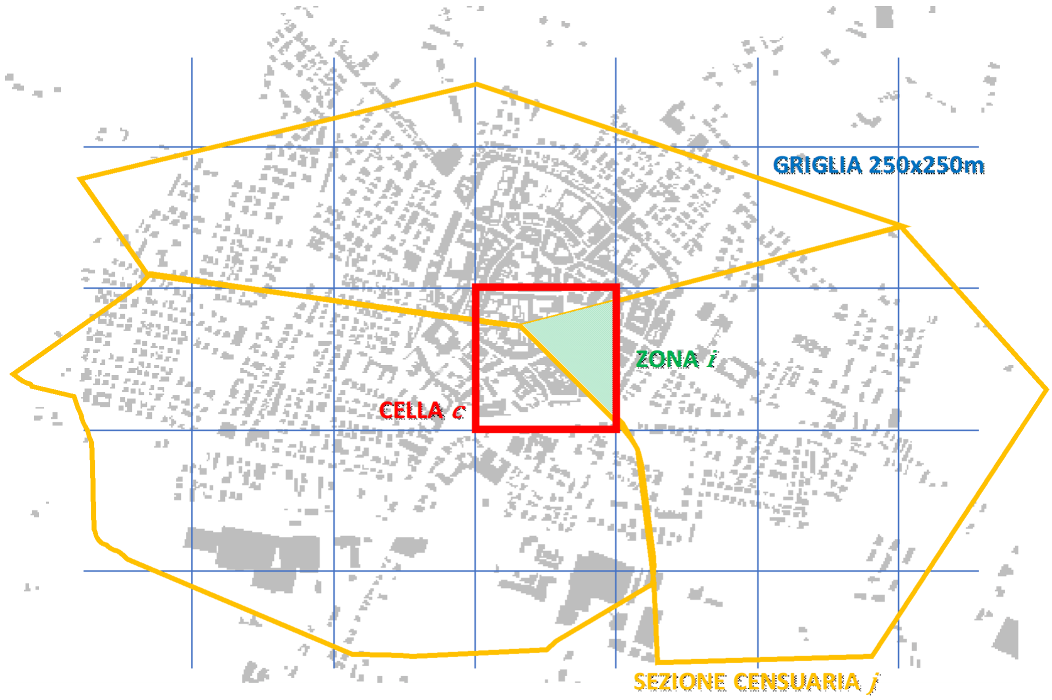

Figure 7. Illustrative depiction of the "zones" (green), defined as areas of intersection between the ISTAT census sections (yellow) and the 250x250m cells (red) of the model's reference grid (blue).

3.5 Outcomes and Validation

To estimate the damage caused by the reference earthquake, the input data are combined. The model discretizes the area under consideration through a square-mesh grid of size 250x250m. To each cell are assigned:

- hazard data, in terms of PGA,
- exposure data, in terms of number of buildings for each structural vulnerability class.

Combining these data with seismic vulnerability, the model provides, cell by cell, the number of lost buildings (D4+D5), the number of unsafe buildings (0.6xD3 + D4 + D5). In Table 3 is reported the number of lost and unsafe buildings for each municipality, in

Figure 8 and Figure 9 show a qualitative distribution on the grid for lost and unsafe buildings respectively.

Table 3. lost and unsafe buildings for the earthquake in Casamicciola(21 August 2017) according to the EASE model

MUNICIPALITY	lost buildings D4 + D5	unsafe buildings 0.6D3 + D4 + D5
Serrara Fontana	0	1
Lacco Ameno	2	7
Ischia	0	0
Forio	0	1
Casamicciola	11	35
Barano di Ischia	0	1

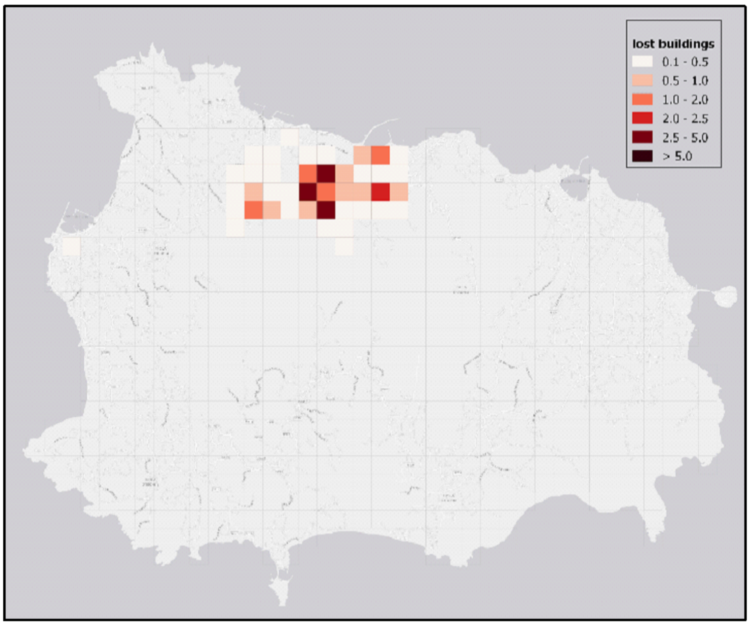

Figure 8. lost building on the grid for the earthquake in Casamicciola (21 August 2017) according to the EASE model

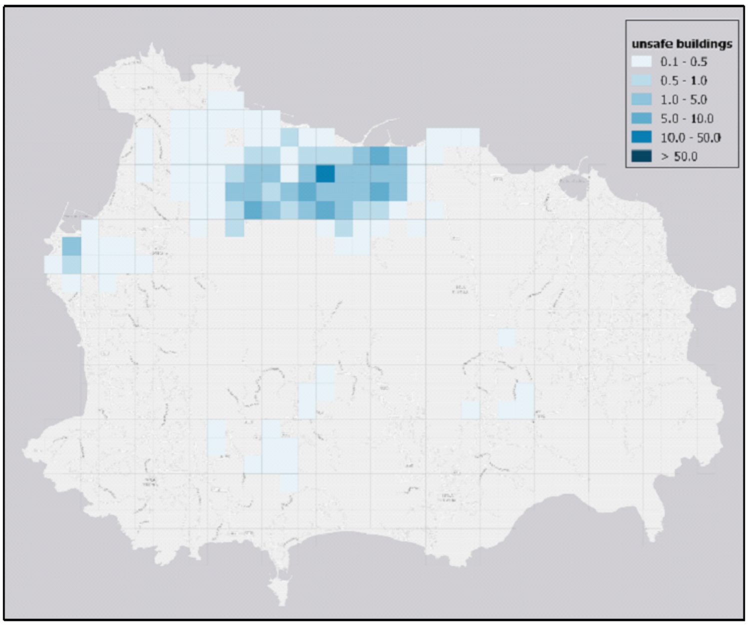

Figure 9. unsafe building on the grid for the earthquake in Casamicciola (21 August 2017) according to the EASE model

Comparing the hazard map in Figure 5 with the outcomes in terms of lost buildings Figure 8 and unsafe buildings Figure 9, it is shown that the high damages are in correspondence of the epicentre of the seismic event.

A validation of the outcomes has been done by estimating the damages to the buildings through the IRMA (Italian Risk MAp) platform developed by Eucentre for the Department of Civil Protection [4], a tool that can produce impact scenario at municipality scale. Exposure and vulnerability used as input are consistent or at least comparable with those used for the National Risk Assessment. To compare the results, we proceeded to assess the damage induced by the reference event, having assumed the following factors:

- HAZARD: the same shake map adopted for the elaborations presented here was adopted;
- VULNERABILITY: some specific vulnerability curves present in the platform were selected (Perelli et al. [18] for masonry and Rosti et al. [19] for reinforced concrete);
- EXPOSURE: building data provided by the 2011 ISTAT census.

Differently from the E.A.S.E. model, IRMA platform considers a single value of PGA on the entire municipality, corresponding to the PGA reported in the ShakeMap in correspondence of the centroid of the municipality. The scenarios calculated under these assumptions, through the IRMA platform, returned the results in Table 4, which are comparable with the values estimated with the E.A.S.E. model.

Table 4. lost and unsafe buildings for the earthquake in Casamicciola(21 August 2017) according to the EASE model and IRMA Platform

	EASE Model		IRMA Platform	
MUNICIPALITY	**collapsed buildings**	**uninhabitabiles buildings**	**collapsed buildings**	**uninhabitabiles buildings**
Serrara Fontana	0	1	0	1
Lacco Ameno	2	7	2	7
Ischia	0	0	0	0
Forio	0	1	0	1
Casamicciola	11	35	11	35
Barano di Ischia	0	1	0	1

The results show that the impacts achieved with the two models are orders of magnitude comparable. The biggest differences are found on the municipality of Casamicciola, which, being very large and having the centroid close to the epicenter, shows a clear overestimation of losses compared to the E.A.S.E. model.

4. CONCLUSIONS

Ischia is a quiescent volcanic complex with an explosive typology. The last eruption occurred in February 1302, when a crater opened in the Fiaiano area, emitted lava for over two months. Since then, the island's volcanic system has continued to manifest its activity through widespread fumarolic and hydrothermal activity and recurrent seismicity.

Each year, seismic stations detect few low-energy events, although in the past severe earthquakes occurred, causing extensive damage. In particular, the event of 4th March 1881 caused serious damage to Casamicciola and Lacco Ameno. The earthquake of July 28, 1883 has been one of the most catastrophic event of the recent centuries. In total, the earthquake caused 2,313 deaths and 762 injured, as well as 9500 homeless, who were housed in shacks. The last significant seismic event occurred on 21st August 2017, in the area of the municipality of Casamicciola.

The area has a high exposed value, in terms of population and buildings. The resident population is of 62,831 units, to which are added 4 million tourists a year. The increase in population has produced, at the same time, an increase in the number of buildings, often built-in derogation of the regulations on constructions with poor materials and/or on fragile soils and, therefore, particularly vulnerable to geophysical hazards. The high risk of the Ischia territory highlights the need to bring the sustainable planning at the centre of the debate, considering the vulnerability of the area.

In this perspective, the PLINIVS Study Centre conduced an activity of analysis of the ordinary Ischian built-up area aiming to know the constructive peculiarities of the area. A field data collection activity aimed at typological characterization of the island's urbanized built-up area has been done through a homogeneous sectors investigation (CARTIS form), and a building-by-building data collection activity (CARTIS BUILDING form and the PLINIVS form).

The field data collection activity was preparatory to the calibration of the exposure model to be used in the impact study using the approach of EASE, a tool developed by the PLINIVS Study Center that returns on a 250m x 250m grid the distribution of buildings on the damage caused by the investigated seismic event. The outcomes obtained through the EASE approach were compared with the outputs obtained through the IRMA platform.

It is shown that Ischia Island has a prevalence of masonry buildings with respect to reinforced concrete and mixed structures. Furthermore, most of Ischia's buildings has been constructed before 1980, when earthquake-resistant regulations came into effect. However, considering the quality of the used masonry in Ischia and the further typological parameters, it can be shown that, according to the SAVE method, the built-up can be considered resistant to seismic events: most of the half of the buildings can be considered class C or D.

In terms of impact, the outcomes obtained from the EASE approach are compatible with those observed in the field [8] and those derived from the IRMA platform.

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