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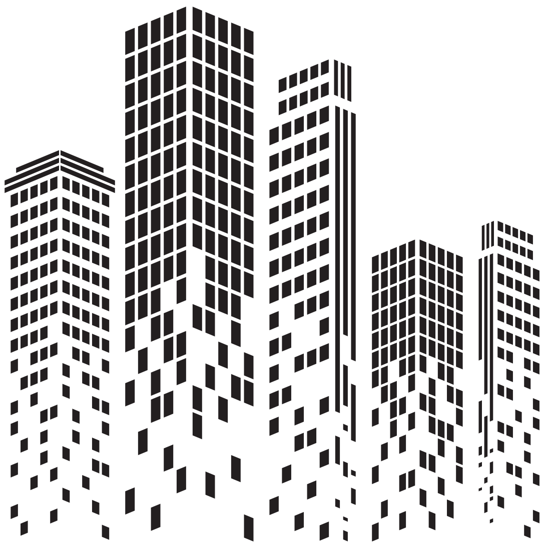

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The economic assessment of seismic damage: an example for the 2012 event in Northern Italy

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Abstract: The study aims at quantifying the monetary losses caused by a moderate earthquake happened on a densely populated and economically well-developed area. The loss estimation refers to the damage of residential buildings and takes into account the cumulative effects of the sequence of the 2012 Emilia earthquake, characterized by a series of shocks with a magnitude range between 5.5 and 6 that lasted for nearly a month. The earthquake ground shaking was characterized by long-period component amplifications due to the presence of thick banks of sediments; nevertheless, there was a great damage to ordinary residential structures, characterized by short periods.

The present study estimated the building damage using an approach based on the definition of the EMS-98 macroseismic scale, which is able to depict a damage scenario by means of observed intensity. Then we used the value of real estate assets (OMI) to quantify the economic losses, instead of the commonly adopted cost of reconstruction, because it is both an official and a yearly updated economic indicator. As the trade negotiations value is easily available throughout all the national territory, the present loss assessment can be effortlessly reproduced in case of future events.

The proposed method consists of a multidisciplinary approach taking advantage of seismic, engineering, and economic skills, which is able to depict an attainable ex-post losses scenarios.

Keywords: EMS98 Intensity, earthquake damage, economic losses, Emilia Romagna.

1. The seismic events of 2012 in Emilia Romagna

An earthquake with magnitude M_L 5.9 (M_W 5.86) struck a large part of the Po river plain (Northern Italy) on May 20th, 2012. More than 2200 events happened in the following weeks, with six events of magnitude bigger than M_w 5. The subsequent largest event was on May 29th, with M_L 5.8 (M_w 5.66) (Scognamiglio et al. 2012) (Figure 1). The first earthquake was located in Finale Emilia (MO), a town located about 30 km West of Ferrara, then the earthquake sequence moved further West covering an area of about 50 km in W-E direction from the first event.

The sequence matches the well-known tectonic settings of the area, characterized by a North convergent active thrust buried under a broad thickness of sediments of the Po plain, with no evidence on the surface. The historical seismicity of the area reports few events (CPTI11, Rovida et al. 2011) with moderate magnitude around 5.5, of which the Ferrara (1579) and the Argenta (1624) events represent a typical case. However, it is well know that the historical seismicity of the area is far from being complete (Castelli et al. 2012).

Right after the first damaging event, an extensive macroseismic survey was performed by two independent groups, covering a total number of 196 localities, belonging to 88 municipalities (Figure 1c and Figure 2). The data collected by the two groups lead to the assessment of different maximum intensities expressed in two different scales: one group adopted the EMS-98 scale (Grünthal et al., 1998) assessing a maximum intensity of VIII (Tertulliani et al. 2012) and examined 87 localities, whereas the other group adopted the MCS scale (Sieberg 1930) assessing a maximum intensity of VII-VIII (Galli et al., 2012) and examined 187 localities. As the proposed damage estimation method is based on the EMS-98 scale definition, the existing 87 localities evaluated with the EMS-98 should be somehow integrated with the additional 109 localities evaluated with the MCS scale, by comparing 79 localities evaluated by both groups. The comparison showed a systematic higher estimation of the EMS-98 intensity values (Figure 2a).

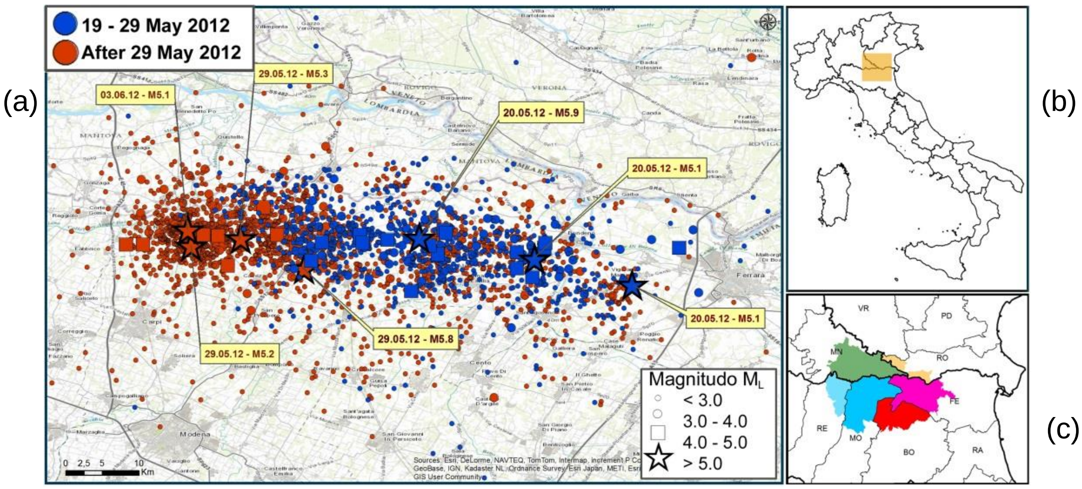

Figure 1 –Seismicity for the period May 20 - June 21, 2012 (modified from/source http://ingvterremoti. wordpress.com/2013/05/20/un-anno-dopo-il-terremoto-in-emilia/).

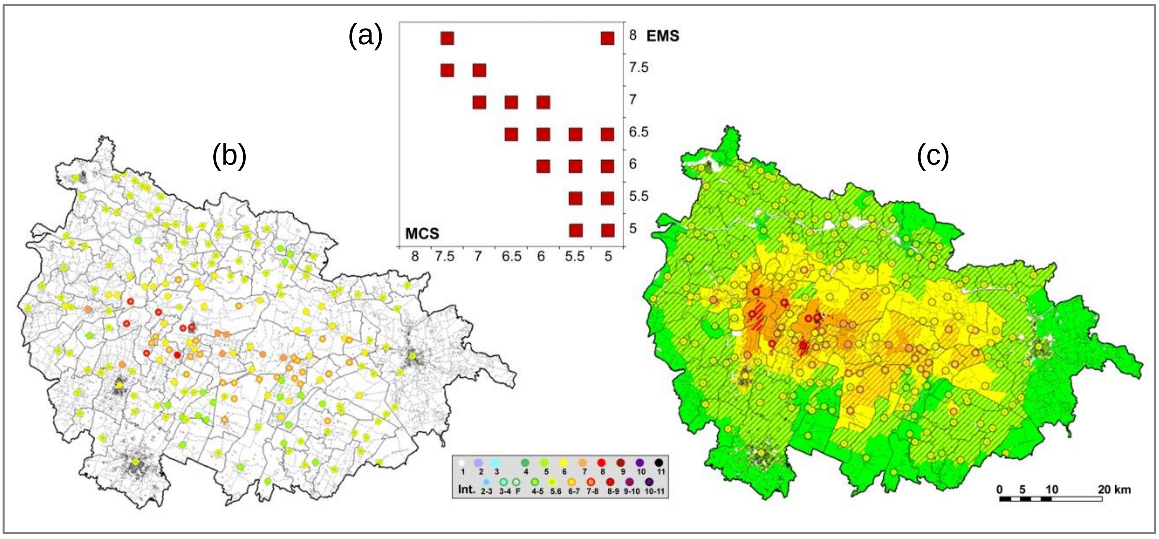

Figure 2 – (a) Comparison between EMS-98 and MCS macroseismic observations. (b) Map of 196 macroseismic observations integrating the EMS data with the MCS adapted observations. (c) Map of EMS intensity scenario obtained by the data interpolation.

We therefore integrated the EMS-98 estimations with the MCS ones by increasing their intensity value by the difference observed in the comparison (0.5), obtaining a total number of 196 macroseismic observations (Figure 2b). In order to further wider the intensity scenario, the localities not examined by the two surveys were integrated by geographically interpolating the 196 macroseismic observations with the Natural Neighbour method (Sambridge et al. 1995), which is able to preserve the originally assessed intensities (Figure 2c).

2. The residential building stock and its vulnerability

The Italian National Institute of Statistics (ISTAT), regularly conducts a census of dwellings that provides the basic information on residential buildings useful for seismic damage assessment. It is worth mentioning that ISTAT splits each Italian municipality into many census units, and for each unit it is possible to estimate the number of buildings and their volume, derive the type of structure, their context (whether isolated or aggregate), the maintenance status, the age of construction or retrofitting, and the number of floors (Table 1).

Table 1 – Typological parameters of the buildings, according to 1991 ISTAT census data

Structural Typology	Building age	Number of floors	Isolated or contiguous	Maintenance status
Masonry Reinforced concrete Soft story building Other typology No info	before 1919 from 1919 to 1945 from 1946 to 1960 from 1961 to 1971 from 1972 to 1981 after 1981	1 or 2 from 3 to 5 more than 6	Isolated Contiguous	Good Bad

The ISTAT census is performed every ten years, but only the 1991 one publicly provides disaggregated data for each census unit, that, conveniently cross-referenced, can be used to infer a simple vulnerability assessment according to the EMS-98 scale guidelines.

After 25 years, the 1991 census is clearly outdated, and it does not describe the characteristics of the area at the time of the earthquake in 2012, whose resident population increased by 100.000 units since 1991. In order apply some sort of correction to update the 1991 census data, we analysed both the population growth in the area, and the change of its housing stock in the period 1991-2011. An overview of the demographic growth for 88 municipalities hit by the event is shown in Figure 3 (percentage values). The most evident demographic growth is associated to the Bologna and Reggio Emilia provinces, which increases of 30% and 22% respectively.

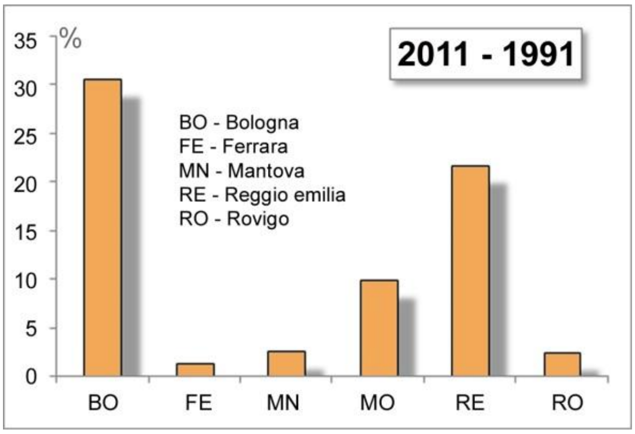

Figure 3 – Demographic trend in the last decades related to the 88 municipalities hit by the earthquake sequence, grouped into provincial administrations (shown in Figure 1c)

The attribution of an average vulnerability index is consistent with an evaluation process calibrated on more than 28.000 detailed vulnerability forms collected over the years on the whole Italian territory (Meroni et al. 2000), and it is based on the method shown in Bernardini et al. (2008) that defines a score for homogeneous groups of buildings (first column of Tab. 1), accounting for the age of construction (or renovation) of the building and its typological factors (the number of floors and the aggregation status). The method considers also the maintenance status and the date of the seismic classification of the territory.

3. The damage estimation

The EMS-98 scale macroseismic methods for the assessment of building damage classify the residential buildings into 6 vulnerability classes (A to F), and evaluate their damage distribution in five discrete classes (D1 ÷ D5), one for each intensity degree, accounting for the level of damage both of the main structural and non-structural components.

Once the vulnerability index is assigned, the EMS-98 vulnerability classes (A-F) are defined according to the ranges of the vulnerability scores shown in Bernardini et al. (2008). Roughly masonry buildings belong to the classes from A to D, with a vulnerability index in the range 0 ÷ 60; reinforced concrete buildings (classes from B to E) are in the range -20 ÷ 45; soft story buildings (classes from B to D) have a vulnerability index between 0 and 50. In general, the investigated area is characterized by the predominance of buildings in C (40%) and D (34%) classes, while the presence of buildings in class B (18%) and E (8%) is lower.

The damage scale is expressed by self-explaining terms (e.g., few, many, most) describing the interaction between the vulnerability classes and the intensity. These terms can be expressed in fuzzy mode into numerical values of probability (damage probability matrix) as formalized by several authors (Lagomarsino and Giovinazzi 2006; Bernardini et al. 2008). We adopted the definitions proposed by Bernardini et al. (2007) for the quantification of terms in the damage probability matrix (Table 2).

Table 2 – Numerical values for the quantitative expression of the Damage Probability Matrix.

Nearly Few	0.015	2 Few	0.18	Many + 7/3 Few	0.56
1/3 Few	0.03	7/3 Few	0.21	Most – Few	0.655
1/2 Few	0.045	8/3 Few	0.24	Most	0.745
2/3 Few	0.06	3 Few	0.27	Most + 2 Few	0.925
5/6 Few	0.075	Many	0.35	All – Few	0.91
Few	0.09	Many + Few	0.44	Nearly All	0.97
4/3 Few	0.12	Many + 2 Few	0.53	All	1

As an example, figure 4 shows the distribution of the volume of buildings into the classes of vulnerability C and D, and the percentage distribution of the damaged volume (D1 and D2 level) calculated in each census unit of Medolla municipality. Most of the buildings have no damage (D0) or slight damage (D1) given the relative moderate magnitude of the earthquake sequence and the building. Moderate damage (D2, D3) are restricted only to the epicentral area while the other damage quantities (D4 and D5) are very low. Figure 5 shows the distribution of the volume of buildings with D2 damage level for the whole investigated area.

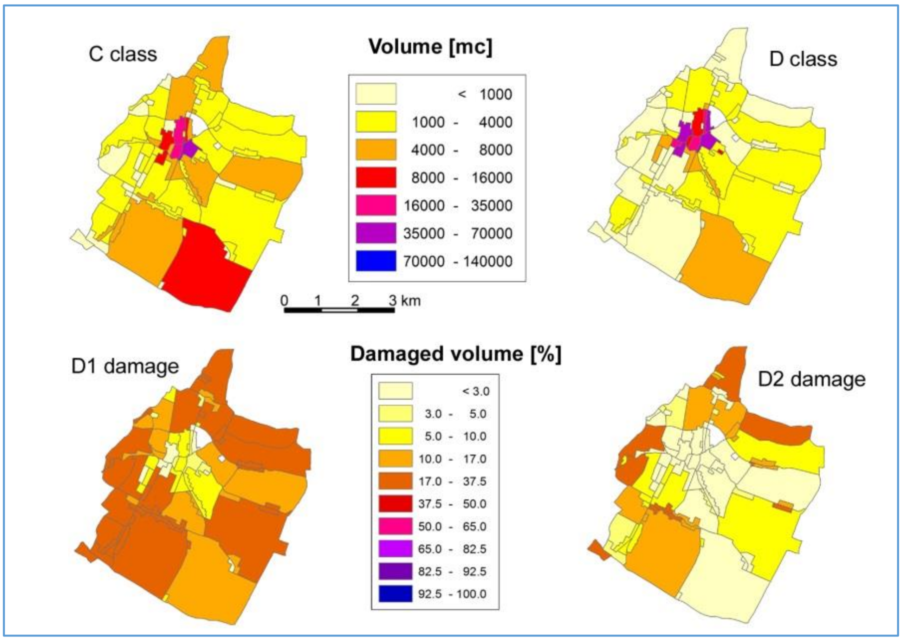

Figure 4 – Distribution of volume of residential buildings in Medolla according to the C and D vulnerability classes (top), and damaged volume of residential buildings in D1 and D2 classes (bottom).

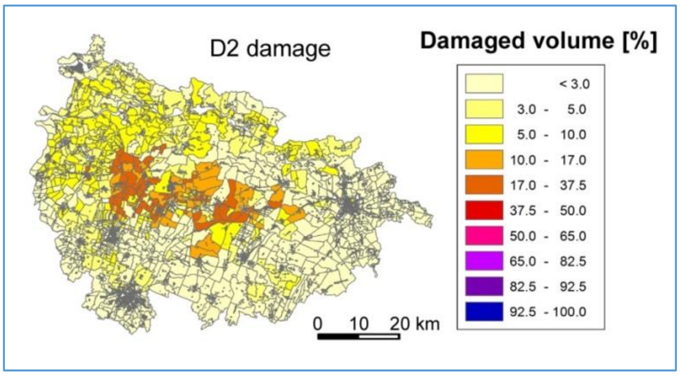

Figure 5 – Percentage of distribution of volume of buildings whit D2 damage level.

4. Market values of residential buildings

The economic assessment of damage requires monetary parameters that should be easily accessible, updated, and consistently assessed for the whole country. In the present study, we adopted the housing value provided by the observatory of the housing market (OMI), a branch of the Italian Tax and Revenue Service (*Agenzia delle Entrate*). The OMI database publicly provides the average price of houses for each type and quality on the whole Italian territory. We considered the residential buildings only ('Civil', 'Economic', 'Prestigious', 'Territorial housing' and 'Villa'). The OMI data are made available through geographical areas delimiting a homogeneous local real estate market and uniform conditions both in economic (house prices) and socio-environmental terms. Contiguous and homogeneous OMI areas are aggregated in the macro-areas of the historical centre, semi-central, outskirt, suburb, or rural (Osservatorio Mercato Immobiliare 2009). The geographical polygons providing the OMI property classification substantially differs from the census unit polygons; their intersection was performed using a GIS software, generating 436 new sub-areas. As there is no link between the monetary and vulnerability classifications types, we calculated a synthetic average weighted value representative for all OMI structure typologies. This procedure is based on the use of socio-economic data (population, demographic variance, employment, number family members, etc.) and the presence of a specific property type in an OMI macro-area is evaluated by a Probit analysis, as well illustrated in Meroni et al. (2015). Figure 6 shows the distribution of the average OMI values estimated on update data in the first half of 2012. The highest property value is concentrated in the towns of Ferrara, Modena and Carpi, or in small localities surrounding Bologna (e.g. Argelato, Bentivoglio, and Sala Bolognese). The range between the maximum and minimum OMI value is generally less than 5% within the same municipality, especially for small villages in the same provinces.

The large variability of OMI values support the hypothesis that the economic impact of a seismic event cannot be limited to the mere reconstruction cost, but should take into account the entire value of the buildings.

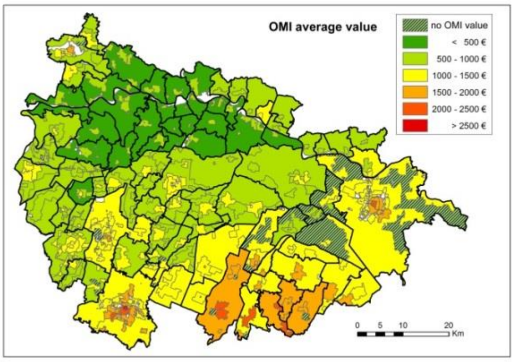

Figure 6 – Distribution of the average OMI value for each municipality. White polygons identify industrial areas with little or no presence of residential buildings.

5. Loss assessment: standard procedure and new formula

Most of the models for the earthquake losses assessment correlate the building repair costs to the replacement cost (cost ratio) (ATC 1985; FEMA 2003). Some cost ratio values are especially calibrated for the EMS-98 damage classes and for the Euro - Mediterranean area (Mouroux 2003; Roca et al. 2006). Among them, the cost ratios values reported in Table 3 were selected.

Table 3 – Adopted cost ratio values (decrease of real estate value in percentage)

EMS-98 damage class	Cr
D 1	5 (± 2)
D 2	20 (± 5)
D 3	45 (± 5)
D 4 - D 5	103 (± 3)

Once the damage distribution of the built-up area is known for each municipality, it is possible to calculate the total cost of damages according to the cost of construction. Assuming the cost of construction fixed at 100, the average Damage Ratio (D_R) is defined using the Cr value of Table 3 as following:

$$D_R = 100 * \left(\frac{5D_1 + 20D_2 + 45D_3 + 103(D_4 + D_5)}{100} \right) \quad (1)$$

The distribution of the damage ratio D_R is shown in Figure 7 (left).

Applying such a procedure to a real scenario is not easy, as the construction cost is rarely available because it is greatly influenced by a variety of factors such as the building type, the construction quality and of the used materials. Moreover, the economic loss includes either the repair cost or the induced losses as relocation, the unrealized losses and the loss of income and lease (Whitman et al. 1997). To overcome these limitations, we quantified the damage as a percentage of the building value (OMI value), that is different for each class of damage. By adopting this solution, there is no loss of value if the property did not suffer any damage (D0) or the economic cost depends on the percentage defined for D_R. The loss ranges between 3% and 7% of the real estate value if the building suffered a negligible damage D1; it increases up to the maximum loss of the entire real estate value in the event of serious damage (D4) or total collapse (D5) (Table 3). The average loss can be calculated using the same Cr value of Table 3, assuming the OMI market value instead of the cost of construction.

The damage distribution for each census unit is calculated overlaying the OMI area, and the final average loss distribution is visible in Figure 7 (right).

Based on the result of the present study, the town with the estimated greatest loss is Mirandola, for about 87 million euros, whereas the losses for Modena and Ferrara are about 76 million and 64 million euros respectively. Despite the low felt intensity in Ferrara, great losses have been estimated probably because of the large number of damaged buildings and their higher economic value in respect to the surrounding smaller urban areas. It is worth mentioning that the reported loss of property value does not account for damage to infrastructure or manufacturing activities.

The loss distribution indicator greatly depends on the population density, the economic significance, the industrial production capacity, the historical and artistic value of the territory. Taking into account these factors, a sensitivity analysis on the loss estimation indicator was performed, by checking the impact of changes in the Cost Ratio and the OMI market values (min and max range), and by testing all the possible combinations. The resulting analysis shows an average loss value ranges between -42% up to +50%.

A final test was performed to quantify the level of approximation introduced using the out-dated information of the ISTAT 1991 census. Using a subset made of 48 municipalities from the investigated area, we performed an independent economic loss analysis. The assessment was implemented at municipality level, with updated census data (ISTAT 2011) and assigning a macroseismic intensity to the entire municipal territory. The comparison between the new loss results and the one previously calculated on the basis of census units, shows a variation of about ±50%, which is comparable with the previous sensitivity analysis results.

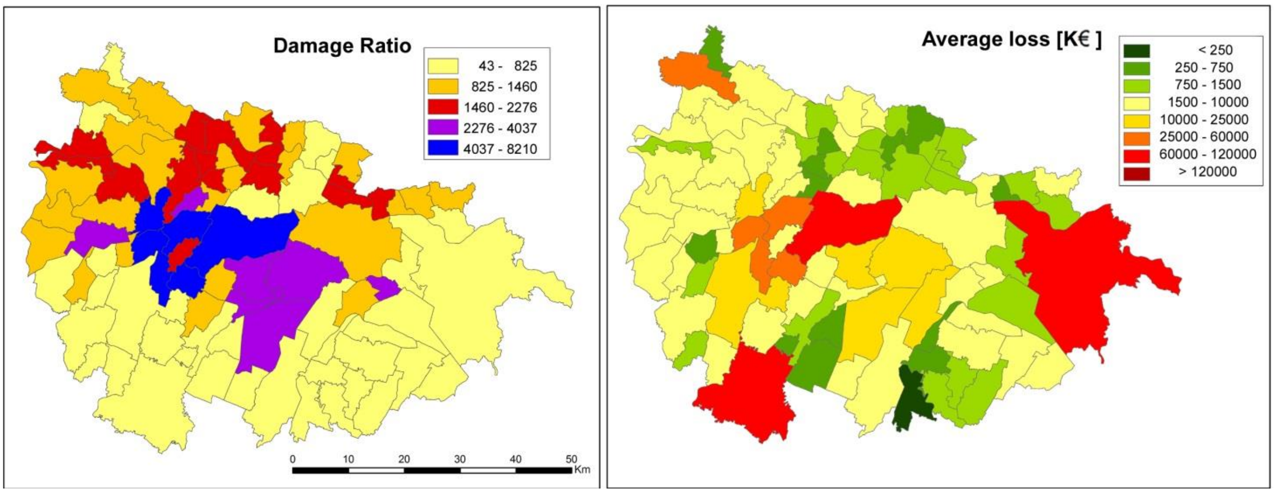

Figure 7 – Distribution of damage ratio Dr, normalized on the total built-up area (left) and average loss for each municipality (right).

6. Conclusions

The 2012 Emilia earthquake can be considered a representative case of a typical seismic event with low to medium magnitude affecting a well-developed urban area in Italy, and able to generate an extensive damage.

The use of a macroseismic approach for the damage assessment led to an up-to-date and detailed damage scenario for the entire affected area. The present study focuses on the economic quantification of the earthquake damage, and tried to adopt the housing market value as the reliable economic indicator, instead of the commonly adopted cost of reconstruction. The presented procedure is easily adaptable to the other Italian areas and can take advantage of reliable basic data which is addition constantly revised.

Given the large variability of the results in monetary terms, we investigated both the range of their plausible values, and the influence of updated exposure data (from 1991 to 2011). Both analyses indicate an average economic damage value to residential buildings with a range of ± 50%. The proposed procedure, that still needs further validation, can be implemented in ex-ante analysis of earthquake loss on large areas also.

Acknowledgments

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