MiCHe project

Flood and seismic risk of Firenze historical center

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Summary

INTRODUCTION

The development of a risk scenario for the city of Firenze requires knowledge of both the seismic and flood vulnerability of the building heritage. The definition of a vulnerability map of the buildings, which is one of the objects of the present research project, is therefore an essential basis for a future and efficient resources planning for flood and seismic adaptation and improvement works with important consequences in the sectors of urban, social and civil protection.

The historic center of Firenze, included within the fourth walls, has been first the subject of two single-risk analyses. Flood and seismic single-risk assessments have been carried out respectively by DICEA and DIDA research units. After, a multi-risk analysis has been carried out in order to account for their interaction. In particular, a quantitative estimation of the total mean annual economic loss due to flood and earthquake has been developed. A procedure for a complete multi-risk analysis have been also provided. (see Fig. 1). In the next section, the multi-risk procedure adopted in the present work has been explained. After, the current scenario and some possible improvements on the existing system have been analyzed.

MULTI-RISK METHOD

The multi-risk assessment method is represented in Fig. 1. Both flood and seismic hazard are described by the probability of occurrence of the event (or return period), but they differ with respect to their intensity measures. For floods, a key role is played by the inundation extents and water depth. For earthquakes, the magnitude of the event is a function of the PGA (Peak Ground Acceleration) or EMS-98. Exposure modelling is common to both hazards. In fact, the building cartography (1:2000, Tuscany Region) is used to determine, in combination with on-site inspections, the built-up area, number of storey, presence of basement, etc. The monetary assessment of exposure is based on market values (OMI, Agenzia del Territorio).

Vulnerability modelling is based on stage-damage vulnerability functions developed at site scale for buildings with cellars (Arrighi et al. 2018) and give a relative percent damage of the exposed floors. For seismic vulnerability is adopted the methodology proposed by Lagomarsino and Giovinazzi, which allows estimating the damage level for a given earthquake intensity level.

The outcome of the risk analysis is estimation of monetary building losses for the analyzed system (city center of Florence). The risk is expressed as the annual average loss in terms of €/year. It is quantified through the integral of the frequency-loss curve obtained by plotting the mean annual frequency against the corresponding monetary cost.

The multi-risk analysis for flood and earthquake hazards is here outlined.

The total mean annual loss produced by the damages caused by floods and earthquakes is the main descriptor of the problem. Let us consider the two random variables C_F and C_E, which represent, respectively, the annual costs due to flood and earthquake. Our attention is first focused on the total annual cost, which is given by the sum of the two random variables:

$$C_T = C_F + C_E$$

It is known that the mean value of the sum of two random variables is just the sum of their mean values, i.e.

$$E[C_T] = E[C_F] + E[C_E]$$

which means that, starting from the average annual losses of the single hazards, the total average annual loss can be obtained straightforward by adding the two mean values.

To have a complete description of the statistical behavior of the total annual cost, a probability distribution is needed. In the present problem, since the two random variables are independent (the occurrence of floods is not relate at all to that of the earthquakes), the probability density function (PDF) of the total annual cost f_{C_T} can be defined according to the following expression:

$$f_{C_T}(c_T) = \int_{-\infty}^{\infty} f_{C_E}(c_T - c_F) f_{C_F}(c_F) dc_F$$

where f_{C_E} represents the PDF of the random variable C_E (earthquake annual cost), f_{C_F} is the PDF of C_F (flood annual cost). It is evident, once the PDF of the total annual cost is known, any other distribution can be straightforward obtained and them compared with the single-risk analysis curves.

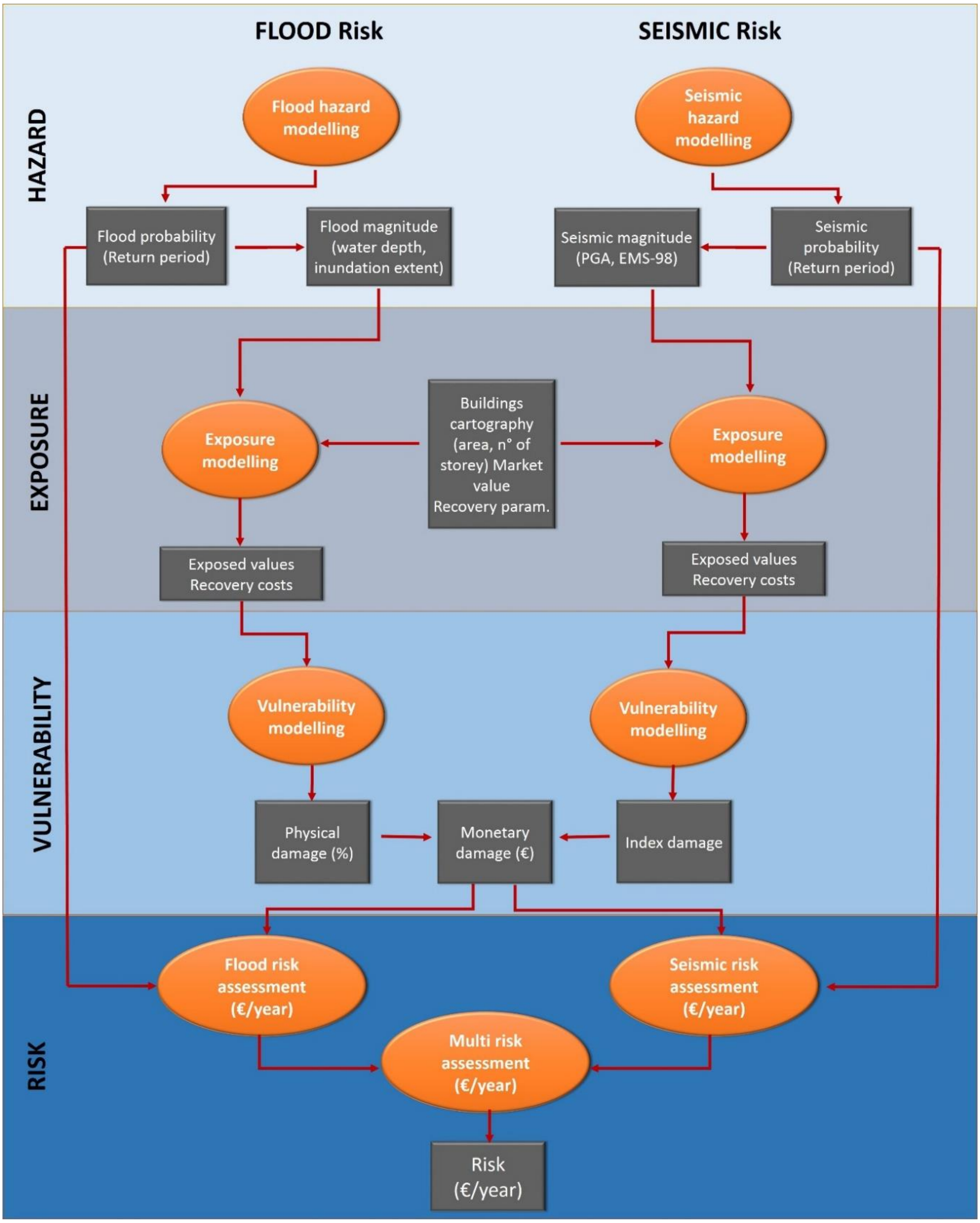
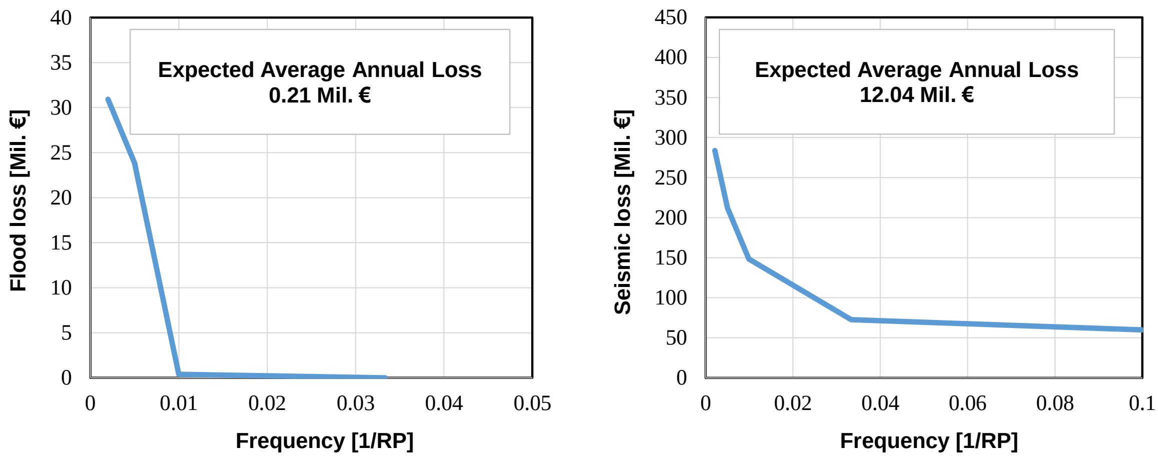


FIGURE 1: MULTI-RISK ASSESSMENT METHOD.

CURRENT RISK

The expected average annual loss is calculated considering two hazards (flood and seismic). Fig. 2 shows the trend of the loss as a function of frequency (1/RP). Fig. 2 (a) shows the trend relative to flood risk with an AAL of 0.21 million €/year, while Fig. 2 (b) shows the trend relative to the seismic risk with an AAL of 12.04 million €/year. It should be noted that the economic value shown is equal to 488 million €. As a percentage with respect to the exposure, the expected average annual loss is equal to 0.04 % for flood risk and equal to 2.47% for seismic risk. It is worth mentioning that for floods exposure corresponds to ground and underground floors, while for earthquakes the whole building is exposed.

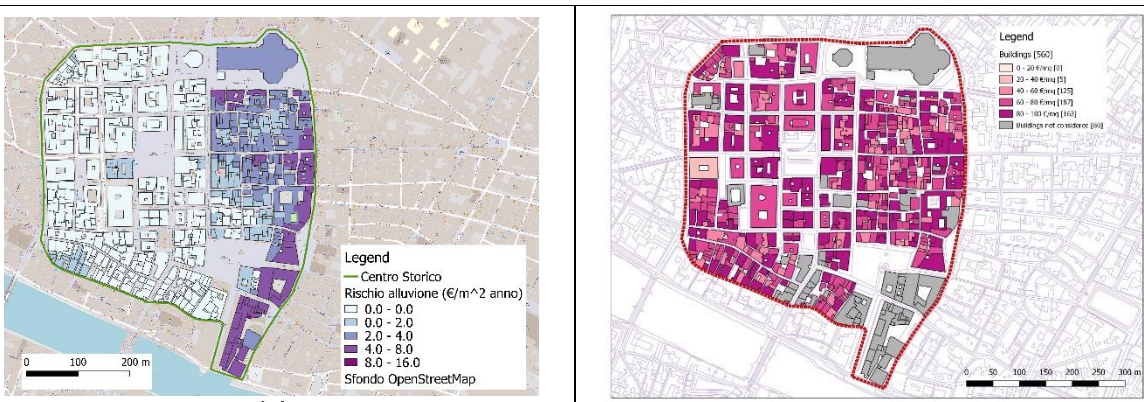


(a) (b)

FIGURE 2: CURRENT CONDITION - EXPECTED AVERAGE ANNUAL LOSS – FLOOD RISK (a) – SEISMIC RISK (b).

Fig. 3 (a) shows the map of flood risk. The eastern portion of the study area is the most at risk with values ranging from 4 to 16 €/mq/year. The risk is not homogeneous because the central part of the study area is less exposed to floods, also for high return period due to higher terrain elevations.

Fig. 3 (b) shows the distribution of the expected Average Annual Loss, referred to seismic risk, divided into 5 classes (between 0 and 100 €/mq/year) with a minimum value of 38 €/mq/year, a maximum of 97.5 €/mq/year and an average value of 75 €/mq/year. A fairly homogeneous distribution of the values starting from the third range of the scale (40 €/mq÷60 €/mq) can be seen.



(a) (b)

FIGURE 3: CURRENT CONDITION - EXPECTED AVERAGE ANNUAL LOSS MAP - **Flood risk (a) - Seismic risk (b).**

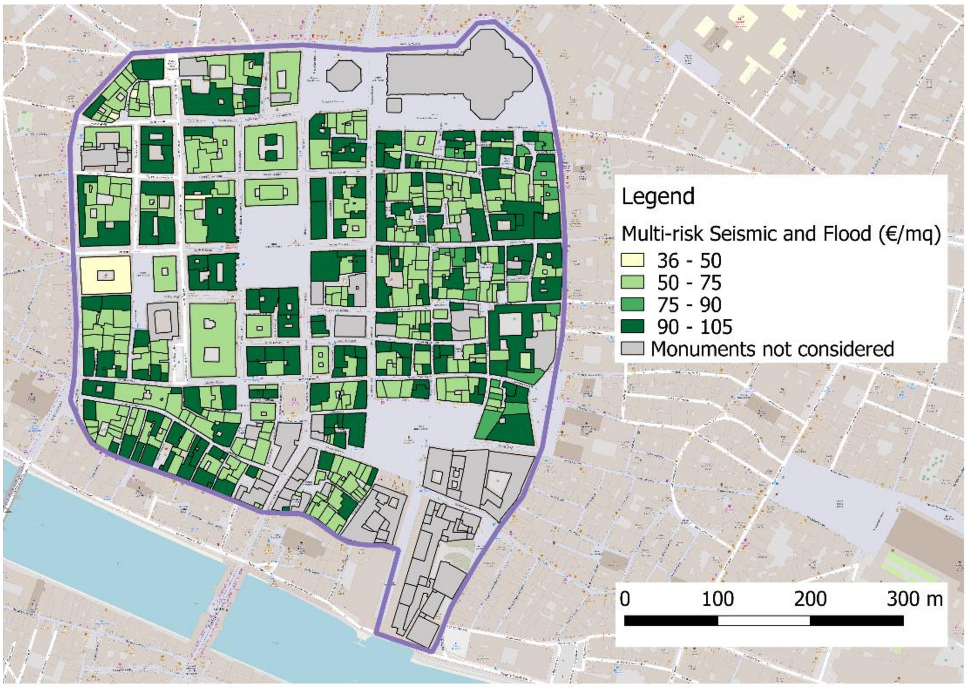


FIGURE 4 CURRENT CONDITION - EXPECTED MULTI-RISK AVERAGE ANNUAL LOSS MAP

MITIGATION

Once the economic and efficiency loss of the system has been determined in the current situation, two preventive intervention levels have been defined, which consist in reducing the vulnerability, intervening on the modifiable parameters $V_{m,k}$. As in the previous case, the new vulnerability of the buildings was defined and the same assessments were carried out to obtain the expected Average Annual Loss values to be compared with the pre-intervention ones as well as the relative costs to implement the interventions. The cost estimate was defined in the previous section and relates to the economic evaluations of the costs experienced after the L'Aquila post-earthquake.

For the floods, the reduction of risk can be obtained by reducing the hazard, i.e. reducing the frequency of occurrence of a flood in a certain area, or reducing water depths, and by reducing exposure and vulnerability. Flood hazard reduction is usually achieved by the design of higher dikes or construction of retention basins. For a better comparison with seismic risk, whose hazard cannot be reduced, we consider only flood vulnerability reduction strategies. A common flood vulnerability reduction measure for urban areas where underground floors are present is the waterproofing of basements. Waterproofing of basement is obtained by sealing lower openings and by installing backwater valves in the sewerage system to avoid the return of floodwaters from the drainage network. These interventions are cheap and affordable by most of homeowners and are very effective for low flood depths (e.g. of the order of 0.4 m), while they become negligible for inundation depths above 1.1.5 m.

To simulate the effect of this kind of mitigation the shape of the building vulnerability function has been modified to assume that basements are waterproof.

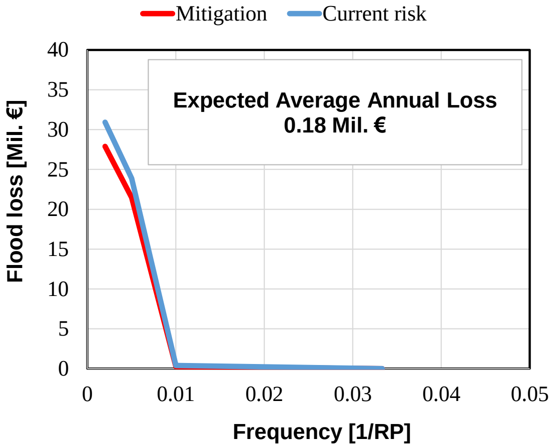
The effects of the seismic mitigation strategies have been taken into account by modifying the values of some modifiers $V_{m,k}$ of the seismic behavior (see Fig. 2 of final report), which contributes to the reduction of vulnerability as well as influence the damage index of the individual building.

Two intervention levels have been defined. A first intervention, of the local type, allows to modify only three parameters: conservation status, roofing system and anti-seismic protection. A second intervention implies a modification of all the possible modifiers (details on the interventions are reported in final report “MITIGATION”, pp. 13, 42). As in the evaluation of the existing condition, the new vulnerability of the buildings has be defined and then a average annual loss value has been estimated to be compared with the pre-intervention status, in which it is also taken into accout the relative costs to implement the interventions. The estimation of the costs have been defined in the final report and relates to the economic evaluations of the costs observed after the L'Aquila earthquake.

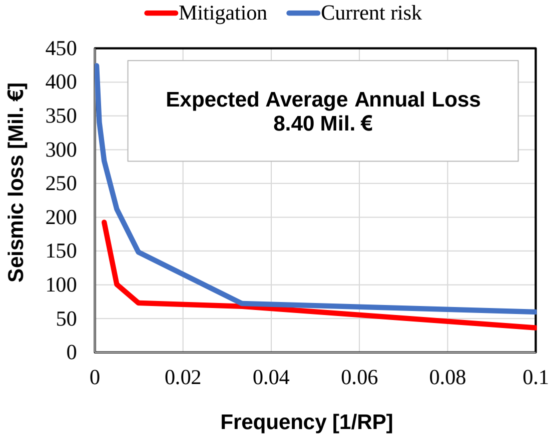
The expected Average Annual Loss is calculated considering again the two hazards. Fig. 5 shows the trends of the two losses as a function of frequency (1/RP) and the corresponding AALs. For the flood risk, a values of 0.18 Mio €/year with light waterproofing and 0.13 Mio €/year with both waterproofing and retention basins was obtained (Fig. 5 (a)), while for the seismic hazard, a value of 8.40 million €/year was estimated (Fig. 5 (b)). As a percentage with respect to the exposure, the average annual losses are 0.02 % and 1.72%, respectively.

It is highlighted for seismic risk that, for the return period of 30 years, corresponding to a frequency of 0.033, the difference between the current risk and the mitigated one is very small, just the 6% as reported in Fig. 5(b). This behaviour is a direct consequence of the assumptions standing behind the definition of the damage index μ_d for each class of damage, D (see Table 3 and Fig. 32 of the final report).

Fig. 6 shows the distribution of the expected Average Annual Loss on the area studied. The distribution is divided into 5 loss classes (between 0 and 100 €/mq/year) with a minimum value of 37 €/mq/year, a maximum of 74 €/mq/year and an average value of 54 €/mq/year.

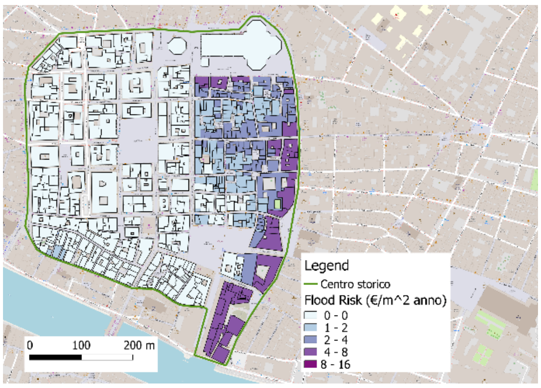


(a)

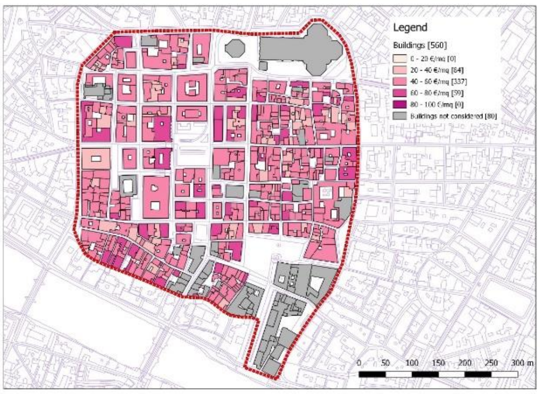


(b)

FIGURE 5: LOCAL INTERVENTION - EXPECTED AVERAGE ANNUAL LOSS – FLOOD RISK (a) – SEISMIC RISK (b).



(a)



(b)

FIGURE 6: LOCAL INTERVENTION - EXPECTED AVERAGE ANNUAL LOSS MAP - Flood risk (a) - Seismic risk (b).

Fig. 7 shows the map of the costs corresponding to the implementation of the mitigation strategies in the city center. It can be observed that the majority of costs is in the range 50-75 €/mq, which are mainly related to the seismic action. In addition, it can be seen that the distribution of the costs in presence of flood interventions results more concentrated to the east side, where the highest cost of 8-16 €/mq has been estimated.

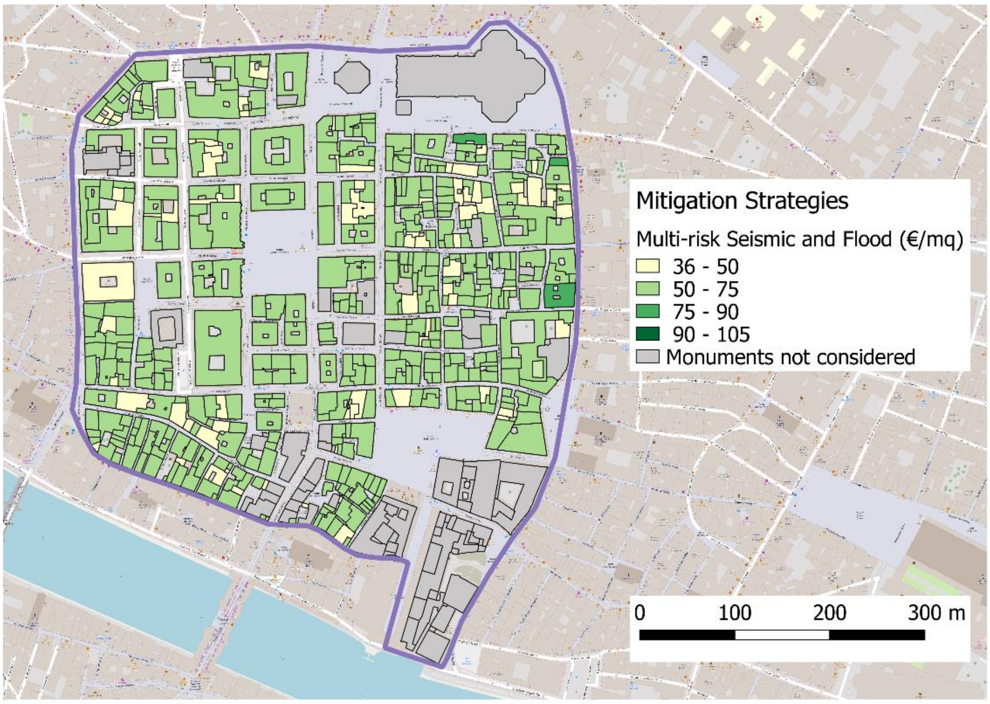
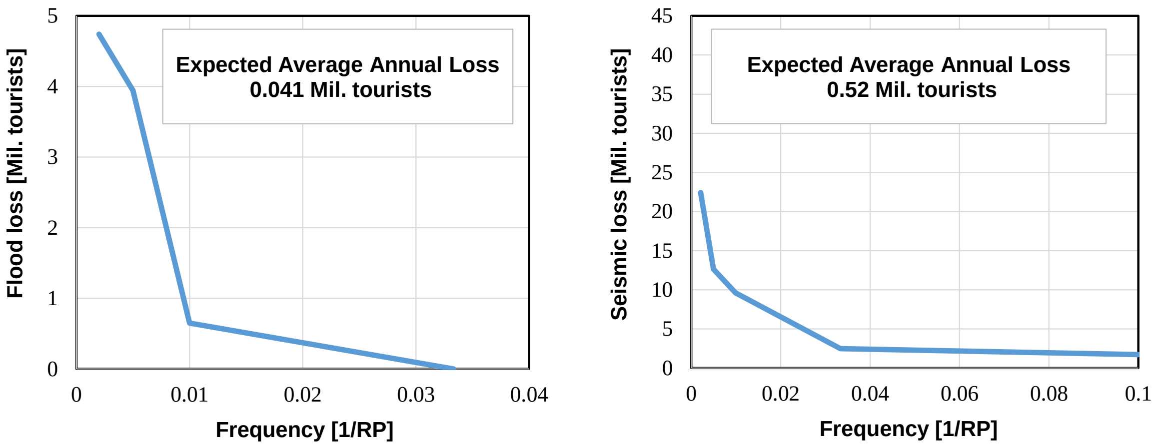


FIGURE 7: LOCAL INTERVENTION – MULTI-RISK AVERAGE ANNUAL LOSS MAP

APPLICATION OF THE EXPECTED AVERAGE ANNUAL LOSS OF TOURISTS

Once the Average Annual Loss deriving from the damage to private or ordinary building has been defined, we move to the determination of the loss linked to the cultural heritage. The evaluation of the losses is conducted through the procedure described above and allows to reach an estimate of the number of lost tourists together with an economic estimate of the losses.

Fig. 8 shows the trend of tourist losses as a function of frequency (1/RP) and the corresponding value of the expected Average Annual Loss. For flood risk has been estimated 41582 visitors lost per year, while for the seismic hazard 0.52 million/year of lost visitors were obtained. An annual value of 8.2 million of tourists is present in the case study, which becomes about 115 million of tourists, if we consider the time span of 14 years (maximum recovery time in case of damage D=5). To have another reference value of lost tourists can be provided by the flood event of a magnitude similar to the 1966 in Florence. In this case, a loss of about 4.8 million visitors to cultural heritage can be reached.



(a) (b)

FIGURE 8: EXPECTED AVERAGE ANNUAL LOSS OF TOURISTS – FLOOD RISK (a) – SEISMIC RISK (b).

CONCLUSIONS

In this work, a multi-risk analysis accounting for both flood and seismic hazards has been developed for the part of the historic center of Florence belonging to the forth city wall. The single risks have been first estimated through the definition of their corresponding hazards, exposures and vulnerabilities. For each hazard, a curve representing the mean annual frequency of costs has been computed together with the corresponding mean annual costs. With the aim of highlighting the interaction between the two hazards, a mathematical procedure for combining the two curves has been outlined. Finally, the total mean annual costs associated to flood and seismic hazards have been estimated.

The effects of implementing mitigation strategies to face both the hazards have been also quantified. In particular, the previous curves (existing condition) have been compared with those obtained by considering a reduction of the vulnerability due to retrofits of the buildings.

The present multi-risk study represents an innovative methodology to treat the interaction of two or multiple risks. As a matter of fact, instead of adopting the well-known decision variable based on the direct economic losses (€/year), the number of lost tourists per year has been used as decision variable, which represents a measure of the indirect economic losses. This choice descends from the idea of making more simple the discussion of the results of a multi-risk analysis with the stakeholders of the municipal administrations, museums, etc.

It is worth noting that the results of both the single- and multi-risk analyses are affected by the assumptions introduced in order to make possible the treatment of the problem (no quantification of the costs for the damages in the structural contents, duration of the functionality loss as a function of the damage level, the correspondence between the limit states and the damage indices) as well as to compensate the lack of data (partial information on the reconstruction costs).

The results of the risk analyses can be summarized as follows:

a) A continuous and progressive increase of the mean annual frequency of the seismic costs has been observed compared to those of the flood risk analysis;
b) The seismic economic losses are well distributed in the system, while the flood losses are concentrated in the area of city center characterized by a lower ground level;
c) More consistent economic losses are associated to earthquakes with respect to those of the floods. This is clearly the effects of neglecting the losses of the structural contents as well as by the major spread of the damages in the buildings during the earthquake compared to the flood damages, which are concentrated to the ground floor and basement;
d) Earthquake mitigation strategies shows a significant reduction of the mean annual costs with respect to those the existing condition. The mitigation strategies proposed for reducing flood risk results less effective compared to the seismic ones, but to draw reliable conclusions a cost-benefit analysis should be carried out;
e) Finally, similar conclusions can be drawn by analyzing the results in terms of indirect costs, here explained through the number of lost tourists per year.