Urban seismic risk:
Land use planning in Portimão City, Portugal

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ABSTRACT

Over the last century due to migration from rural to urban areas, urbanisation was one of the most typical land-use processes and is set to continue into the 21st century.

At the city level, local governments must be encouraged to carry out an integrated land-use planning to comprehensively address adverse impacts of urbanisation, including hazard-prone areas. Until now no detailed analysis about earthquake risks was included on Portuguese Municipal Master Plans.

This paper structured the Portimão Master Plan considering the earthquake threat. Several important aspects like surface geology - with the scope to identify the most "vulnerable areas" – or, for the existing buildings their aptitude according to their functions and soil location were addressed. Finally, a Seismic Risk Indicator in Urban Spaces (SIRIUS) was created to identify most critical areas. Recommendations were addressed in order to cause minor earthquake urban impact for a life time.

Keywords: urban seismic risk, master plan, mitigation, Portugal

1. THE CONTEXT OF THE STUDY

The historical and instrumental earthquake studies about Portugal demonstrate that damaging earthquakes had caused severe devastation and many casualties in the past, therefore it is of prime importance to focus the research in multi-hazard and risk mitigation (earthquakes, tsunamis, landslides) in the Portuguese urban areas.

Algarve, the southernmost important region in mainland Portugal, comprises important active faults and the most damaging earthquakes (1755 or 1969) were felt in the region. It is also the most attractive tourism region not only for Portuguese people but also to Northern Europeans. Portimão, an important city in the region with a rapid urbanisation growth in the last 20-30 years, has a total population of circa 50 000 inhabitants (winter season, and three-fold in summer) and a built environment of about 11 630 buildings (Municipality). It is anticipated that some buildings and networks are expected to experience severe damage or collapse in the case of the occurrence of a moderate to large event (see Ferreira *et al.*, 2010 for further details).

Until now no detailed analysis comprising earthquake risks (or other natural disasters) were included on Portuguese Municipal Master Plans. Although Portuguese cities have land use legislation - better in expansions than in the demanding management of the existent city -, it's common to see urban expansion, without previous seismic information about the area or other considerations such as landslides or faults. Other problem we could emphasize is that Portuguese cities have their old urban areas of patrimonial value with almost no rehabilitation programs.

Within the scope to prepare a land-use zoning map for prevention and mitigation of seismic hazard in the city and consequently reduce the potential damage, Portimão Master Plan was drawn and it will include recommendations and guide-lines for the new urban developments as well as for the retrofit of the most vulnerable existing building stock.

1.1. General

Portimão city, the second largest city in the Region of Algarve - the southern coast of Portugal - is also known for its superb beaches and a very popular destination for tourists (Figure 1).

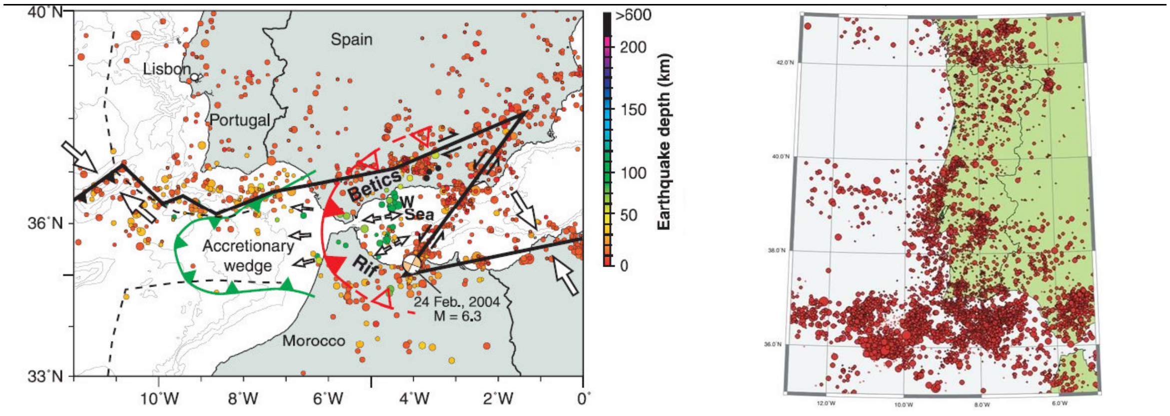
Land-use in Portimão changed greatly due to a significant increase of population (double in the last 30 years) and in the tourism incentive. The growing importance of Portimão tourism attraction was matched by rapid and often unplanned land-use in a haphazard way.

Figure 1. Left: Algarve region and Portimão. Right: Praia da Rocha (beach) in Portimão

2. THE EARTHQUAKE MASTER PLAN FOR PORTIMÃO

2.1. Geology environment and historical seismicity

Geologically, the region is located near the border between the Eurasian and the African plates. Besides the several offshore geological structures capable of generating large magnitude events, there are a few inland faults crossing the Portimão municipality, one of which is of great importance due to its length (Figure 3).

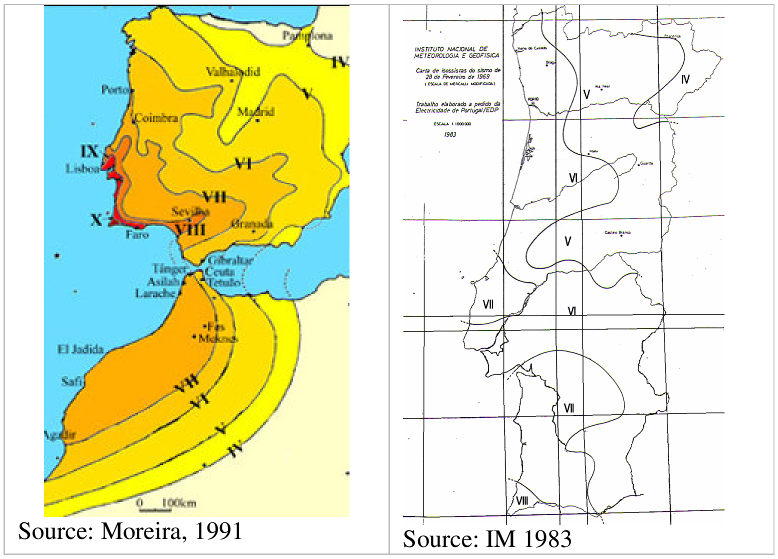


Source: Gutscher 2005

Source: IM 2007

Figure 2. Left: Seismic environment with main geological structures. Right: Historical epicentres.

Historical seismicity provides evidence that several near-shore and inland events of large magnitude occurred in this area in the last centuries (Figure 2, right). The 1755 earthquake that hit Lisbon (Figure 3, left) and produced considerable damage in the Algarve or the 1969 earthquake which produced a maximum intensity of VIII (MMI) in this region are examples of this important seismic activity (see Figure 3, right).



Source: Moreira, 1991

Source: IM 1983

Figure 3. Left: Isoseismal map of the 1755 earthquake. Right: Isoseismal map of the 1969 earthquake

2.2. Geotechnical soil characterization

The collection and analysis of existing data from previous geotechnical investigations including boreholes with SPT tests were useful for the geotechnical characterization, and was possible to classify the soils of type A, B, C, D, S1 according to EC-8 standards(EN-1998, 2004) as depicted in Figure 4.

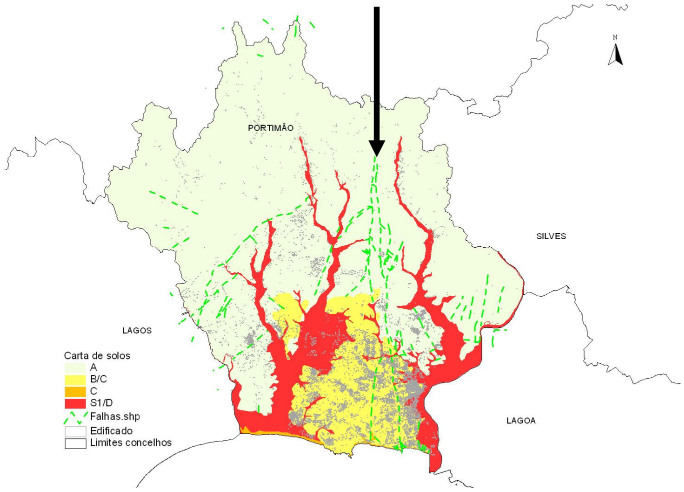


Figure 4. Portimão soil map; black arrow indicates Portimão fault trace

This classification was supported also by a campaign of ambient seismic noise on which we applied the Nakamura technique based on H/V ratios. On December 17, 2009, an M6.0 earthquake with epicentre 150 km SW was recorded at two strong motion stations, located in Portimão, one on a soft soil (S1/D) and the other on B/C soil (Figure 4). The two records even at short distance from one to the other were quite different in nature due to the soil influence, supporting the classification recommended.

2.3. Evaluation of liquefaction susceptibility and tsunami potential

Because of the potential adverse effects of seismically-induced liquefaction, "liquefaction hazard map" (Figure 5) was developed which is a important tool for planning and engineering point of view because shows the likelihood of liquefaction – after an earthquake the liquefied sandy soil may flow and the ground may move and crack, causing damage to surface structures and underground utilities.

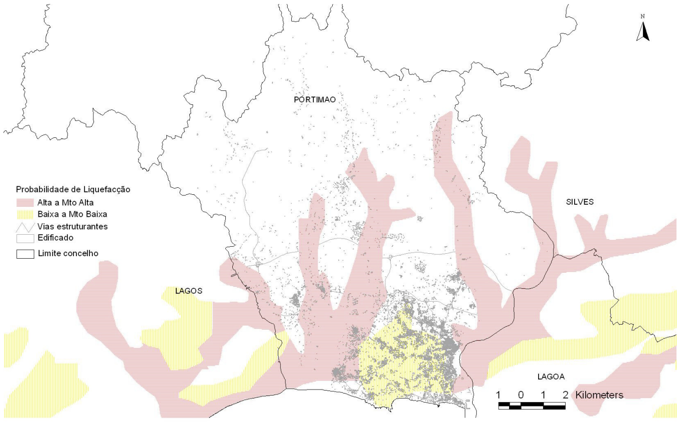


Figure 5. Liquefaction hazard map (adapted from Jorge, 1994)

A map showing the potential tsunami flood zones was created adapted from the study developed to the Portuguese region by Baptista (2009). In this map a protection area up to 10 m level was proposed.

3. BUILDING APTITUDE ASSESSMENT

We are looking for an urban risk indicator, which could identify the most critical areas or/and rapidly hierarchize the priority of interventions (rehabilitation, strengthening, new development urban areas, etc.).

3.1. Building stock

In this case study the building stock is characterized using the information provided by the Census (INE, 2008). For this propose we used 27 typologies (T1-T27) based on epoch of construction, material and number of storeys, denoting the Portuguese code evolution along the time. (PDM Portimão, 2010).

We used the European Macroseismic Scale (EMS-98) (Grünthal, 1998) to study the vulnerability of building stock taking into account the different building typologies.

3.2. Risk induced by resilience deficit (ΔVu)

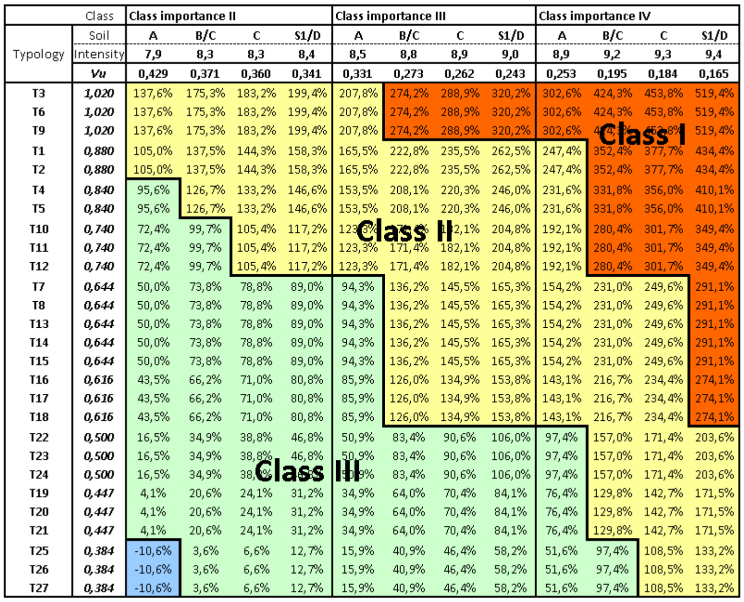
A first approach to measure the urban risk uses as indicator the deficit of structural resistance of a given building typology (one-dimension analysis).

Once the vulnerability parameters of a building are obtained from EMS-98 and its location is known (soil of type A to S1 according to EC-8), we calculate for each building type (and to each building importance class: II to IV) the difference (ΔVu) between the *real* vulnerability and the *required* vulnerability by current design codes (Mota de Sá *et al.*, 2010).

$$\Delta Vu = Vu_{Actual} - Vu_{required} \tag{3.1}$$

This difference is determined considering the vulnerability of buildings of a certain typology *t* (Vu=0 if typology *t* have a good performance to ground motion; Vu=1 if typology *t* is extremely sensitive to ground motion). In this context, ΔVu measures the risk associated with buildings vulnerability. This means that a building is considered risky only if its vulnerability is far from what is desirable taking into account the expected ground motion.

Using this first approach of measure, priority of interventions is given in Figure 6 where priority is organized by Class I, II and III, where Class I has higher priority and Class III lower priority. The blue cells mean buildings without deficit.



	Class	Class importance II				Class importance III				Class importance IV			
Typology	Soil	A	B/C	C	S1/D	A	B/C	C	S1/D	A	B/C	C	S1/D
	Intensity	7,9	8,3	8,3	8,4	8,5	8,8	8,9	9,0	8,9	9,2	9,3	9,4
	Vu	0,429	0,371	0,360	0,341	0,331	0,273	0,262	0,243	0,253	0,195	0,184	0,165
T3	*1,020*	137,6%	175,3%	183,2%	199,4%	207,8%	274,2%	288,9%	320,2%	302,6%	424,3%	453,8%	519,4%
T6	*1,020*	137,6%	175,3%	183,2%	199,4%	207,8%	274,2%	288,9%	320,2%	302,6%	424,3%	453,8%	519,4%
T9	*1,020*	137,6%	175,3%	183,2%	199,4%	207,8%	274,2%	288,9%	320,2%	302,6%	424,3%	453,8%	519,4%
T1	*0,880*	105,0%	137,5%	144,3%	158,3%	165,5%	222,8%	235,5%	262,5%	247,4%	352,4%	377,7%	434,4%
T2	*0,880*	105,0%	137,5%	144,3%	158,3%	165,5%	222,8%	235,5%	262,5%	247,4%	352,4%	377,7%	434,4%
T4	*0,840*	95,6%	126,7%	133,2%	146,6%	153,5%	208,1%	220,3%	246,0%	231,6%	331,8%	356,0%	410,1%
T5	*0,840*	95,6%	126,7%	133,2%	146,6%	153,5%	208,1%	220,3%	246,0%	231,6%	331,8%	356,0%	410,1%
T10	*0,740*	72,4%	99,7%	105,4%	117,2%	123,3%	171,4%	182,1%	204,8%	192,1%	280,4%	301,7%	349,4%
T11	*0,740*	72,4%	99,7%	105,4%	117,2%	123,3%	171,4%	182,1%	204,8%	192,1%	280,4%	301,7%	349,4%
T12	*0,740*	72,4%	99,7%	105,4%	117,2%	123,3%	171,4%	182,1%	204,8%	192,1%	280,4%	301,7%	349,4%
T7	*0,644*	50,0%	73,8%	78,8%	89,0%	94,3%	136,2%	145,5%	165,3%	154,2%	231,0%	249,6%	291,1%
T8	*0,644*	50,0%	73,8%	78,8%	89,0%	94,3%	136,2%	145,5%	165,3%	154,2%	231,0%	249,6%	291,1%
T13	*0,644*	50,0%	73,8%	78,8%	89,0%	94,3%	136,2%	145,5%	165,3%	154,2%	231,0%	249,6%	291,1%
T14	*0,644*	50,0%	73,8%	78,8%	89,0%	94,3%	136,2%	145,5%	165,3%	154,2%	231,0%	249,6%	291,1%
T15	*0,644*	50,0%	73,8%	78,8%	89,0%	94,3%	136,2%	145,5%	165,3%	154,2%	231,0%	249,6%	291,1%
T16	*0,616*	43,5%	66,2%	71,0%	80,8%	85,9%	126,0%	134,9%	153,8%	143,1%	216,7%	234,4%	274,1%
T17	*0,616*	43,5%	66,2%	71,0%	80,8%	85,9%	126,0%	134,9%	153,8%	143,1%	216,7%	234,4%	274,1%
T18	*0,616*	43,5%	66,2%	71,0%	80,8%	85,9%	126,0%	134,9%	153,8%	143,1%	216,7%	234,4%	274,1%
T22	*0,500*	16,5%	34,9%	38,8%	46,8%	50,9%	83,4%	90,6%	106,0%	97,4%	157,0%	171,4%	203,6%
T23	*0,500*	16,5%	34,9%	38,8%	46,8%	50,9%	83,4%	90,6%	106,0%	97,4%	157,0%	171,4%	203,6%
T24	*0,500*	16,5%	34,9%	38,8%	46,8%	50,9%	83,4%	90,6%	106,0%	97,4%	157,0%	171,4%	203,6%
T19	*0,447*	4,1%	20,6%	24,1%	31,2%	34,9%	64,0%	70,4%	84,1%	76,4%	129,8%	142,7%	171,5%
T20	*0,447*	4,1%	20,6%	24,1%	31,2%	34,9%	64,0%	70,4%	84,1%	76,4%	129,8%	142,7%	171,5%
T21	*0,447*	4,1%	20,6%	24,1%	31,2%	34,9%	64,0%	70,4%	84,1%	76,4%	129,8%	142,7%	171,5%
T25	*0,384*	-10,6%	3,6%	6,6%	12,7%	15,9%	40,9%	46,4%	58,2%	51,6%	97,4%	108,5%	133,2%
T26	*0,384*	-10,6%	3,6%	6,6%	12,7%	15,9%	40,9%	46,4%	58,2%	51,6%	97,4%	108,5%	133,2%
T27	*0,384*	-10,6%	3,6%	6,6%	12,7%	15,9%	40,9%	46,4%	58,2%	51,6%	97,4%	108,5%	133,2%

Figure 6. Matrix of priority of interventions (rehabilitation): *Class I* – High-priority interventions, very vulnerable buildings; *Class II* - Intervention needed, buildings with vulnerability far removed from the recommended; *Class III*- Intervention Desirable; Blue cells – No deficit.

4. SIRIUS – SEISMIC RISK INDICATOR IN URBAN SPACES

A second approach to measure the urban risk consists on a two-dimension analysis.
In this Master Plan one of our aims is to identify critical areas that required protection for actual and future land-use development. As we know risk is a function of hazard, vulnerability and exposition. A place with no hazard, even if buildings show a great vulnerability and human presence is high, must have a null risk. Similarly, a place where hazard exists should be considered with some potential to suffer damages, if buildings are vulnerable and people exist - this is the principle that reflects the two-dimension SIRIUS indicator.
Assuming that, we can say that risk can be defined as:

$$Risk = f\,(RRD, RHP) \tag{4.1}$$

where:
RRD is an indicator of buildings proneness to suffer damages (risk due to buildings resilience deficit) and RHP is an indicator of people concentration (induced risk by human presence).
Following the above assumptions, we can write:

$$Ri = RRD \times RHP \tag{4.2}$$

It is worth noting that when (RRD=0 or RHP=0) => R=0, means that SIRIUS is not applied to zones where buildings are abandoned.

SIRIUS parameters shall be computed based on the following relationship:

$$RRD = \frac{\sum_{t=1}^{nt} n_t \times \Delta Vu \;\; (\times 0 \; if \; \Delta Vu < 0)}{n_B} \tag{4.3}$$

where:

$\Delta Vu = Vu_t - Vu$

Vu_t is the vulnerability of buildings of typology *t* (Vu=0 if typology *t* is “immune” or have a good performance to ground motion; Vu=1 if typology *t* is extremely sensitive to ground motion)

Vu is the desired or required vulnerability to certain intensity

n_B is the total number of buildings in a certain area (census tract in this study)

n_t is the number of buildings of a certain typology *t*;

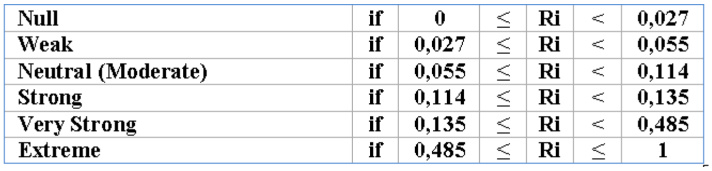
The risk associated with urban density is defined as:

$$RHP = \frac{Pop_d}{Pop_{d\,\max}} \tag{4.4}$$

where:

Pop_d is the population per hectare and $Pop_{d\ \max}$ is the maximum population per hectare, here defined as 300 persons per hectare[1].

Having found a numeric index to measure the seismic risk (Ri), yet useful, it is not a sufficient way to communicate (or capture our perception of) risk. People usually express themselves in a semantic (linguistic human) language, not in a scientific or more abstract one. So, we want some form of mapping the numeric risk index into a semantic scale. Stated in another way, we want to find “how much risk are we expressing” when we say that Risk is “Extreme”, “Weak”, “Strong”, …, which is the way we, humans, perceive the external stimulus. This allows us to convert a numeric value of seismic risk in a human semantic scale, SIRIUS=f(Ri) (Figure 7).



Null	**if**	**0**	≤	**Ri**	<	**0,027**
Weak	**if**	**0,027**	≤	**Ri**	<	**0,055**
Neutral (Moderate)	**if**	**0,055**	≤	**Ri**	<	**0,114**
Strong	**if**	**0,114**	≤	**Ri**	<	**0,135**
Very Strong	**if**	**0,135**	≤	**Ri**	<	**0,485**
Extreme	**if**	**0,485**	≤	**Ri**	≤	**1**

Figure 7. SIRIUS scale

Figure 8 shows an example of SIRIUS in the summer season when the population growth and global risk increase too. As we can see the risk is almost Very strong (“Mto Forte”) due to high urban density and buildings vulnerability.

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[1] Note: Densities in urban areas vary widely, from 10 persons per hectare in very low density areas such as many Azorean cities, to 300 persons per hectare in some Asian cities.

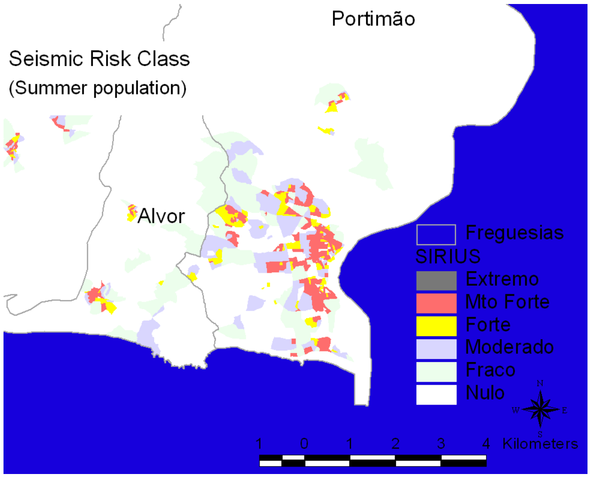

Figure 8. SIRIUS – an indicator of seismic risk in urban areas. Example of application for summer population

5. PROPOSALS FOR FUTURE ACTIONS

5.1. Smart growth

Community planning efforts must integrate smart growth policies to existing urban areas, where the densest population concentrations exist, and to future urban areas.
In this sense new equipments (like schools, hospitals) must be not programmed in urban areas where high concentration of buildings and population are expected, because in case of disaster access to such equipments can be very difficult.
Better access to the hospital should be studied, as well as the access to the outside of the city. Main road connections must maintain its accessibility, not subject to the collapse of buildings, pedestrian crossings, bridges collapse or disruption of tunnels. In this context several bridges and road access should be examined in order to see the ability to remain functional, after an earthquake of moderate to high intensity.

Historic buildings and older masonry structures shall be subject to preservation/rehabilitation/restoration in order to preserve lives and prevent its collapse or operationally during an earthquake. Retrofit older downtown areas and redevelopment some areas to protect architectural diversity and promote disaster-resistance should be a priority.

6. FINAL CONSIDERATIONS

In this paper we briefly describe the Master Plan of Portimão city taking into consideration the earthquake threat (earthquake hazard, site effects, tsunami, etc.) and the associated expected impacts on the urban tissue (building stock and population).
To communicate more effectively the seismic risk we have also developed a bi-dimensional indicator (Ri) composed by two indicators of urban risk: one based simply on vulnerability deficit (RRD) and the other taking into account the potential for human losses (RHP). Then, Ri was transformed into a semantic scale to better translate risk in a human language, SIRIUS.
Other aspects of urban seismic risk are being developed in a more sophisticated fashion, considering a broader set of concerns (criteria) covering dimensions such as, Social Resilience and Vulnerability, Functional Interdependencies, Critical Services and Infrastructures. Because seismic impacts are not restricted to a single point in time, social and system disruption are being analysed and computed along the Time.

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