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TOWARDS AN IMPROVED URBAN SEISMIC RESILIENCE: THE PILOT CASE STUDY OF SANREMO MUNICIPALITY

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Abstract

Recent Italian earthquakes highlighted the need of effective mitigation policies to improve the resilience of urban systems. To this aim, proper tools need to be developed and implemented to support the design of preparedness interventions before the event (phase a), the emergency management (phase b) and the recovery/reconstruction time (phase c). Within this context, the Italian Civil Protection Department (CPD) outlined specific Limit Conditions (LC) for urban settlements, similarly to the definition of Limit States for buildings in Codes. They aim to define the target which mitigation policies have to tend to during the three aforementioned phases. For some of them, the CPD has already developed also specific operative procedures that are being ongoing implemented at national scale, such as the I.OPà.CLE method. While the latter is essentially oriented to the phase b and to assess the structural operational efficiency of strategic functions during the emergency management (emergency coordination, medical relief, road networks, …), other LCs involve also the preparedness and recovery/reconstruction phases. Within this context, the paper proposes a methodology for the *analysis* and *assessment* of the so-called "Limit Condition for Safeguarding the existence of the settlement" (shortly tagged as SLC), that at present has been only conceptually defined by the CPD. According to this LC, the focus becomes to preserve the urban functions essentials to start with the recovery of the system, necessary to ensure the rapid return to all its functions. From that it emerges the strong multidisciplinary character of the SLC that requires to integrate the structural aspects with the economic, social, cultural and identity dimensions of a community. The procedure presupposes: a first step aimed to identify the "minimum system" necessary to guarantee an effective recovery of the urban settlement; a second step addressed to assess if the performance of the "minimum system" is adequate or not according to the requirement of SLC. Both steps are based on a quantitative procedure that involves, in the first step, the attribution of a proper score to each building to define an effective priority list for the selection and, in the second step, the assessment of both structural damage and relative economical losses. Both steps benefit of the use of simplified observational and mechanical based vulnerability models, which are particularly suitable for an application at large scale. In the paper, the methodology developed is tentatively applied to the pilot case study of Sanremo municipality placed on the western coast of Liguria (Italy) focusing the attention in particular to the first step.

Keywords: risk mitigation policy, urban resilience, settlements existence safeguarding, seismic vulnerability

1. Introduction

Nowadays the concept of seismic resilience is one of the main keywords in earthquake engineering. According to [1], it can be defined as the ability of a system to reduce the chances of a shock, to absorb such a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance). The seismic resilience of a system can be improved by reducing: its probability of failure during an earthquake; the consequences due to such failures; and the time to recovery [2]. These scopes can be achieved through: the execution of interventions aimed to decrease the structural vulnerability of the built environment before the event (phase a); a plan of efficient emergency management (phase b); the execution of a fast and effective recovery/reconstruction process (phase c).

Indeed, recent Italian earthquakes, above all L'Aquila 2009 [3] and Centre Italy 2016/2017 [4,5], highlighted strong critical issues in these different resilience phases as proven in Fig. 1 and Fig. 2. Fig.1 highlights the obstruction in managing and ensuring the efficiency of the emergency system due to: the collapse of strategic buildings (as the prefecture in L'Aquila or the hospital in Amandola); or the interruption of roads for the failure of the interfering buildings. Fig.2 illustrates some emblematic examples of difficulties in reconstruction and recovery phases as: the extensive destruction occurred in Amatrice; and the loss of relevant assets for the identity of the community, like churches or historical buildings in particular if located in public meeting places. These examples highlight the need of effective mitigation policies to improve the resilience of urban systems and justify the growing interest on that not only at academic level, but also at institutional level.

a) b) c)

Fig. 1 – a) L'Aquila 2009; b) Amandola 2016; c) Accumoli 2016

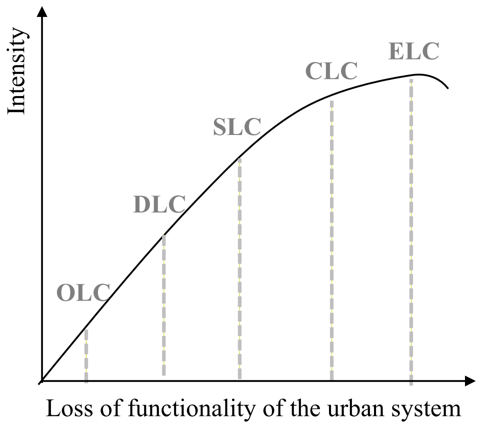
a) b) c)

Fig. 2 – a) Amatrice and b) S. Benedetto square in Norcia after the Centre Italy 2016/2017 earthquake; c) Santa Maria in Paganica Church after L'Aquila 2009

Within this context, in Italy the Civil Protection Department (CPD) outlined specific Limit Conditions (LC) for urban settlements [6,7] aimed to define the specific target/objectives which mitigation policies have to tend to during the three aforementioned phases (a/b/c). The LCs define conceptual thresholds of physical and functional damage of the components that compose the settlement able, if exceeded during an earthquake, to produce its loss of functionality (Fig. 3). The components include different urban functions: i) the strategic functions necessary for the emergency management (buildings for emergency coordination, medical relief, operational intervention, road networks, emergency area); ii) the strategic functions for the recovery phase, the most important buildings and activities from the social, productive and cultural point of view, according to the specific features of the settlement; iii) general urban functions (industrial, commercial,…); iv) dwellings (housing). Analogously to the Limit States introduced in Standards and Codes [8,9] at the scale of a single building, the main objectives of the LCs are: i) the safety of the settlement life; ii) to protect the buildings and infrastructures that compose it; iii) to preserve the environmental and the social identity of urban system. Fig. 3 summarizes all the LCs introduced in [6,7] by the CPD with their progressing targets.

For some of these LCs, the CPD has already developed also specific operative procedures that are being ongoing implemented on pilot cases study at national scale, such as the I.OPà.CLE method [10] aimed to assess the structural operational efficiency of the Emergency Limit Condition (here after tagged as ELC). While the latter is essentially oriented to phase b and to assess the structural behavior of the strategic functions for the emergency management (emergency coordination, medical relief, road networks, …), other LCs involve also the preparedness and recovery/reconstruction phases.

Within this context, the paper focuses to the "Limit Condition for Safeguarding the existence of the settlement" (here after tagged as SLC) after the occurrence of a disastrous seismic event, that at present has been only conceptually defined by the CPD. Main objective of this LC is to preserve the urban functions essential for starting the recovery of the system and necessary to ensure the rapid return of all its functions. From that it emerges the strong multidisciplinary character of the SLC that requires to integrate the structural aspects with the economic, social, cultural and identity dimensions of a community. The fulfillment of the SLC condition in general presupposes that of the ELC. In particular, in the paper an operative methodology for the *analysis* and *assessment* of the SLC is illustrated that has been originally developed within the framework of the research done on the pilot case study of Sanremo municipality placed on the western coast of Liguria (Italy). The *analysis* phase is mainly addressed to individuate all the components whose functionality have to be strictly guaranteed for an effective recovery; instead the *assessment* phase aims to actually verify their performance and capability to satisfy such requirements. After having illustrated the basics of the proposed procedure (§2), the application to Sanremo municipality is presented focusing to the *analysis* phase (§3). The application to this pilot case study has been supported by the funding of the CPD and Liguria region.



ELC - The Emergency Limit Condition, when the entire urban settlement suffers physical and functional damage enough to produce the interruption of almost all its urban function, except for most of its strategic functions for an emergency and their connection and accessibility with its surroundings.

CLC - The Limit Condition of Collapse, when only a few primary urban functions resist, while many other functions, including housing, are compromised overall in the medium term. Strategic urban function are interrupted.

SLC - The Limit Condition for Safeguarding the existence of the settlement, when the damage is significant or prolonged in time, though not enough to compromise the general characteristics of the settlement. Main urban function are interrupted.

DLC - The Limit Condition of Damage, when a reduction in functions is partial or limited in time. Normal urban function are damaged.

OLC - The Limit Condition of Operations, when the settlements is not affected by significant modifications. The dwellings are compromised.

Fig. 3 – Conceptual graphical representation of the Limit Conditions proposed by the Italian CPD (adapted from [6]) and their definitions [7]

2. Basics of the proposed procedure for assessing the SLC condition

According to [6,7], the limit condition for safeguarding the existence of the settlement following an earthquake represents the condition for which the urban settlement as a whole suffers physical and functional damage able to interrupt some urban functions for its entire or partial extension. However, the urban settlement is assumed to preserve the functionality of strategic functions for the emergency and that for the post-event recovery, and the connection and accessibility with the territorial context. Moreover, the possibility of maintaining or resuming the residential functions is guaranteed, according to extensions and within times compatible with the maintenance and recovery of the essential characteristics of the settlement, also following a substantial limitation or interruption of use. In summary, the SLC must therefore meet three objectives:

1. Ensure the emergency management following a disastrous event.
2. Guarantee the main urban functions after the event for the start of the recovery.
3. Ensure the rapid recovery of other major urban functions.

The first, as already mentioned, in practice presupposes the fulfillment of the ELC, while the second and the third items characterize the SLC.

Preliminary step before passing to the *analysis* and *assessment* of the SLC is the definition of *Strategic Urban Functions (SUFs),* that is the individuation of the different activities with a key role for the community with the perspective of the recovery of the settlement, following a disastrous event. They consist of the main services of the city, the relevant economic activities, the fundamental cultural assets and the most representative urban and social places. In particular, they can be traced back to the following categories: *schools, religious and historical buildings, supermarkets and productive structures.* Then the *strategic buildings for the emergency* have to be added too, being the fulfillment of the ELC implicitly included in the SLC objectives.

In particular, the *analysis* phase is divided into the following steps:

- A1) *recognition of the eligible buildings* ($i=1, \ldots, N$): aimed to identify and collect in a GIS environment all the buildings that cover the above-mentioned SUFs;
- A2) *assignment of a score* P_i *to each eligible building,* through an analytical procedure that aims to combine the different economic, social and structural aspects which contribute to the SLC performance;
- A3) *definition of the* SLC_{MIN} (where MIN states for "minimum system") consisting of a subset of the eligible buildings ($i'=1 \ldots N'$, with $N' < N$) able to fulfil the required SLC performance and guarantee the start of recovery. The $\mathrm{SLC_{MIN}}$ is defined through optimization decision criteria that take into account the scores attributed in A2 phase but also the location of the buildings in the urban context (i.e. proximity to the other strategic buildings or infrastructures included in the ELC system).

The score P_i is defined by the following expression:

$$P_i = w^{SE} P_i^{SE} + w^{SV} P_i^{SV} \quad (1)$$

where: w^{SE} and w^{SV} are the weights associated to the socio-economic (SE) and structural vulnerability (SV) aspects, respectively; and P_i^{SE} and P_i^{SV} represent the scores resulting from the combination of the different factors which concur to define the role in the SLC of the i^{th} eligible building in relation to both socio-economic and structural aspects. The sum of the weights w^{SE} and w^{SV} is assumed to be 1. The partial scores attributed to the building (P_i^{SE} and P_i^{SV}) vary from 0 to 1. The socio-economic and structural factors, with the relative rules that contribute to the evaluation of these scores are clarified at §3.1 through their particularization in the case of pilot case study of Sanremo. The assignment of these scores, which is extended to the whole sample of eligible buildings, presupposes the acquisition of data based on fast field survey (compatible with large scale analysis), archive researches, analysis of the documentation already held by the administrations (for example the results of structural safety analyses previously carried out).

The introduction of the concept of $\mathrm{SLC_{MIN}}$ (object of the step A3) follows the above-mentioned SLC objectives. In fact, the relation with the ELC system is aligned with the first (1), while the second and the third objectives recognize that it is difficult to guarantee the complete functionality of the whole system, due to usually limited economic resources available to implement the risk mitigation strategies. For this latter reason, $\mathrm{SLC_{MIN}}$ includes the minimum number of buildings such to ensure the critical mass able to guarantee the recovery after the event. In other words, this critical mass should be able to create the appropriate economic recirculation through new investments and jobs to return at least to the pre-event condition or even better to an improved condition. A fast and affective recovery time is essential to avoid the delocalization of the population, that could be irreversible. In this sense, the SLC_{MIN} would be a support tool for the planning of mitigation policies to identify the priorities on which start to act for program to extend these actions to all the eligible buildings.

The SLC_{MIN} is composed by:

- the *SLC strategic buildings*, that is key elements for the specific context under examination, whose presence is essential for the recovery whatever their current structural performance (even if insufficient in the pre-event phase and that therefore require strengthening interventions);
- the selection of the eligible buildings (step A1), as result of the optimization decision criteria (A3).

At this point, the procedure pass to the *assessment*. It requires the application of vulnerability models that can be based on different approaches: empirical-heuristic, mechanical (based on analytical methods) and numerical (based on detailed models) [11]. Thus, the *assessment* entails a greater effort in the data collection and computational than the *analysis* phase. For this reason, the SLC_{MIN} is defined before and not after the *assessment* phase. Once the assessment has been carried out on all buildings, it is useful to represent the results in a map taking advantage of the GIS representation, in order to show them at the scale of the urban settlement.

In particular, the *assessment* is performed on:

- all the *buildings of the SLC_{MIN}* and their relative connections;
- all the *interfering buildings to those that compose the SLC_{MIN}*, namely those buildings whose structural response and damage can compromise the correct usability of the connections and buildings of the SLC_{MIN}. Their definition follows the criteria of the ELC system [12] based on considerations related to the height of the fronts of the buildings than the width of the street they overlook.

For the *buildings of the SLC_{MIN}*, this phase implies the evaluation of the structural performance and the expected economic losses of the buildings, in accordance with the multidisciplinary approach of the SLC. In particular:

- for the *buildings included in the SLC_{MIN}* mainly for their economical and functional role, it is determined the risk class (from G to A^{+}) [13, 14]. In particular, according to [6] it is computed as the minimum between the class defined as a function of the safety index (*SI*) at the ultimate limit state and the one associated to the Expected Annual Loss *(EAL)*. The *EAL* [13], representing the likely loss for any given year (seen as fraction of the overall value of the building), is the area under the loss curve that correlates the mean annual frequency of excedeence of each LSs and its economic losses. The quantities required for the loss curve and *SI* are evaluated through a vulnerability model. In particular the risk class is assigned as reference in the assessment phase for the schools, supermarkets, historical and productive buildings;
- for the *buildings included in the SLC_{MIN}* mainly for their social role in preserving the identity of the community in terms of safety index *SI*. In particular, this approach is adopted for the religious buildings, such as the churches. For a first estimate of *SI* of religious buildings, the procedure proposes the application of the simplified method introduced in [15], that implies the computation of a vulnerability index function of the vulnerability indicators and earthquake-resistant details of the asset.

This difference arises from the following considerations: i) in the SLC_{MIN} system, generally, the buildings essentials to preserve identity are limited in number and their choice is almost obliged; ii) for monumental buildings – which those buildings belong to – the attribution of an economic value is complex and often questionable posing difficulties in the reference values to be adopted for the *EAL* computation.

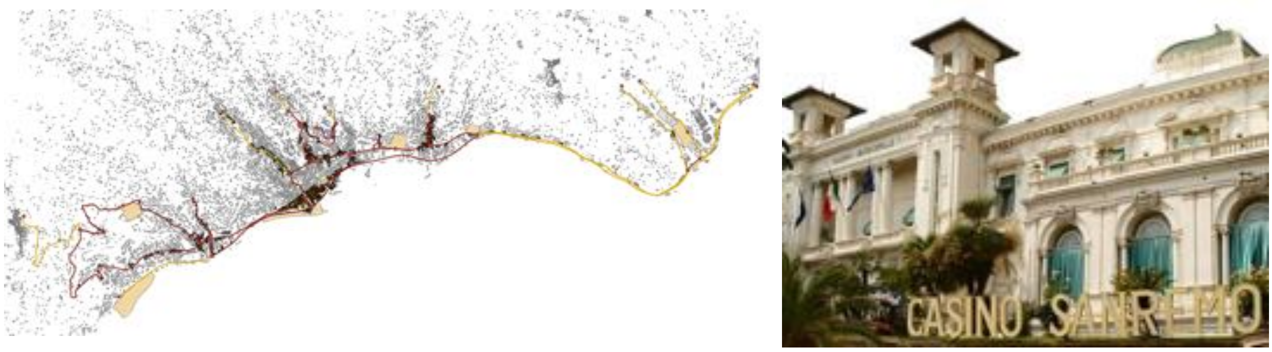
The limited number of buildings of the SLC_{MIN} than the interfering ones allows to carry out more detailed models, following the analytical approach (e.g for reinforced concrete buildings [16,17], for masonry buildings [18]). The latter limits the computational effort than the numerical models, still being based on a limited number of parameters which however include geometrical and mechanical characteristics. In general, they require the acquisition of more detailed information on the resistant system and the execution of more specific surveys.

Finally, for the *interfering buildings*, the performance is evaluated in terms of probability of occurrence of the damage level ($P_{DL,lim}$) deemed incompatible with the correct functionality of the connections among the buildings of the SLC_{MIN} and the buildings of the SLC_{MIN} that interfere with them. For this purpose, it is necessary to establish a threshold damage level and then calculate the probability of exceeding, which can be differentiated according to the structural typology (e.g. if masonry or reinforced concrete). Since in general the number of interfering buildings is quite high, the adoption of simplified vulnerability models is suggested. They are based on a limited number of parameters, which can be collected through rapid site-survey and integrated with analysis of archive data. In particular, it is proposed to use the macroseismic model originally proposed by [19] and recently developed in [20]. The method can be applied in its most simplified form with the data from the population census [21], as: structural typology, number of stories and age of construction. These should be then integrated with the data that particularize the seismic vulnerability of a structure as obtained from the above-mentioned surveys. These surveys can be supported by the ELC survey form [12], too.

In the *analysis* and *assessment* phases, the seismic action compatible with the ultimate limit state proposed in Standards for ordinary buildings (i.e. the Life Safety or Near Collapse LS) is assumed as reference. Of course, the definition of the seismic action can benefit of the most advanced studies available for the study area, for example the results of the microzonation study.

3. Pilot study area: the city of Sanremo (IM, Italy)

The methodology proposed and briefly outlined in §2 has been tentatively applied to the pilot case study of Sanremo municipality placed on the western coast of Liguria (Italy). Sanremo is a city on the Mediterranean coast of Liguria, in north-western Italy. Founded in Roman times, it has a population of 57000. According to the Liguria's configuration, the municipality presents an elongated shape (Fig. 4.a). It hosts numerous cultural events, such as the Sanremo Music Festival and the Milan–San Remo cycling classic. The Sanremo's Mediterranean climate and attractive seacoast setting on the Italian Riviera make it a popular tourist destination. Besides tourism, the city is active in the production of extra virgin-grade olive oil, whose regional "designation of origin" is protected. It is one of the agricultural commodities in western Liguria and in particular within the province of Imperia. Sanremo is known as the City of Flowers, this being another important aspect of the economy of the city. Sanremo is also important for the presence of the Municipal Casino, built in 1905 and that is an example of Art Nouveau building, and the Ariston Theatre, that offers annual series of famous concerts, operas and theatre plays. According to that, it emerges how the key feature for the specific SUFs of this municipality is constituted by the tourism and, thus, how accommodation facilities represent one of main productive activity for the economy.



a) b)

Fig. 4 – a) ELC map for Sanremo municipality where emerges the elongated shape; b) View of the Casino

The following section illustrates more in detail the *analysis* phase of the procedure applied to this case study providing more information about the operative methodology developed to assign the score P_i introduced in §.2.

3.1 The analysis phase

The first step deals with the definition of the list of eligible buildings (A1) and the individuation of those strategic for the SLC. This is developed in strong synergy with the local administration, for example municipal, since it requires a deep knowledge of the territory and community. It is at this stage that some SUFs can be further detailed, according to the context of analysis, for example the productive structures can be related to industry, tourism, public, etc. In the case of Sanremo the *eligible buildings* that perform the different SUFs are 184 (Fig. 5.a) and belong to the following categories: *schools (45), churches (24), historical buildings (51), supermarkets (21)* and *hotels (43).* As introduced, the latter represents the main productive function for Sanremo.

For the aim of assigning the scores P_i^{SE} and P_i^{SV} to each eligible building and then applying (Equ.1), different *performance fields* have been defined for both socio-economic and structural vulnerability aspects (identified by the counters s and m, respectively). In particular, the following performance fields have been identified:

- related to the socio-economic fields:
  1. *Use (s=1)*. It states the importance of an asset in terms of size, adjacent area and number of occupants;
  2. *Economy (s=2)*. It states the importance of an asset as a function of the economic activities that the structure guarantees;
  3. *Heritage conservation and cultural identity (s=3).* It states both the artistic value and the cultural importance of the asset for the community; in particular, it expresses how it is essential for the preservation of the history and identity of the settlement.
- related to the structural vulnerability fields:
  1. *Structural response (m=1).* It quantifies the seismic vulnerability of the structure, in terms of expected damage and safety index. In the *analysis* phase, it is assessed through empirical vulnerability models that require an effort (computational and for the collection of data) compatible with a large scale analysis. For Sanremo, the structural capacity has been determined with the macroseismic model [19, 20]. Vice versa for the demand, the results of the Seismic Microzonation of Level 3, carried out by the Department for the Earth, Environment and Life Sciences (DiSTAV) of the University of Genoa (Responsible-Prof.G.Ferretti) have been adopted. These studies account for the specific amplification phenomena expected in the area and highlighted reference values of the peak ground acceleration higher than those proposed in the Italian Seismic Hazard Maps [22] passing from a reference value equal to 0.145 m/s^2 for the soil A to a range of variation between 0.22 and 0.265 m/s^2 (excluded the topographical effects);
  2. *Hazard risk (m=2).* It accounts for other possible hazards deriving from the studies of Seismic Microzonation level 1;
  3. *Relation with the ELC (m=3).* It allows to discriminate the performance of the building in relation to its proximity to the internal connections and access routes from outside to the urban system identified for the emergency management; also the potential risk induced by the presence of faults and liquefaction phenomena in the connections that correlate the building under examination with the ELC system is considered. As already mentioned, to establish a relation between ELC and SLC is convenient in order to efficacy integrate the risk mitigation policies already started in the area.

Then, to each performance field it is assigned:

- a weight $w_{i,s}^{SE}$ and $w_{i,m}^{SV}$, which may be differentiated according to the SUF. For both SE and SV aspects, the sum of the weights is equal to 1. They are function of the urban system analyzed, and the assignment is carried out in concert with the administration with a strong interdisciplinary character. Fig. 5.b shows the weights $w_{i,s}^{SE}$ and $w_{i,m}^{SV}$ defined for the implementation of the procedure in the case study, that vary according to the SUF: for example, among the socio-economic performance fields, in the case of schools and supermarkets the "Heritage conservation and cultural identity" has a very modest weight compared to the churches;

– a partial score variable between 0 and 1, $P_{i,s}^{SE}$ and $P_{i,m}^{SV}$, for the socio-economic and structural vulnerability aspects, respectively. It requires the definition of appropriate criteria (specified for Sanremo from Table 1 to Table 3), firstly clarifying what are the parameters to be investigated and secondly, for each parameter, the definition of a range for grading the score between 0 to 1. When there are multiple partial criteria that define the score of a factor (for example in the case of religious building in Table 3), for each is assigned a score ranging from 0 to 1, then the sum is normalized in such a way that it is comparable with the others.

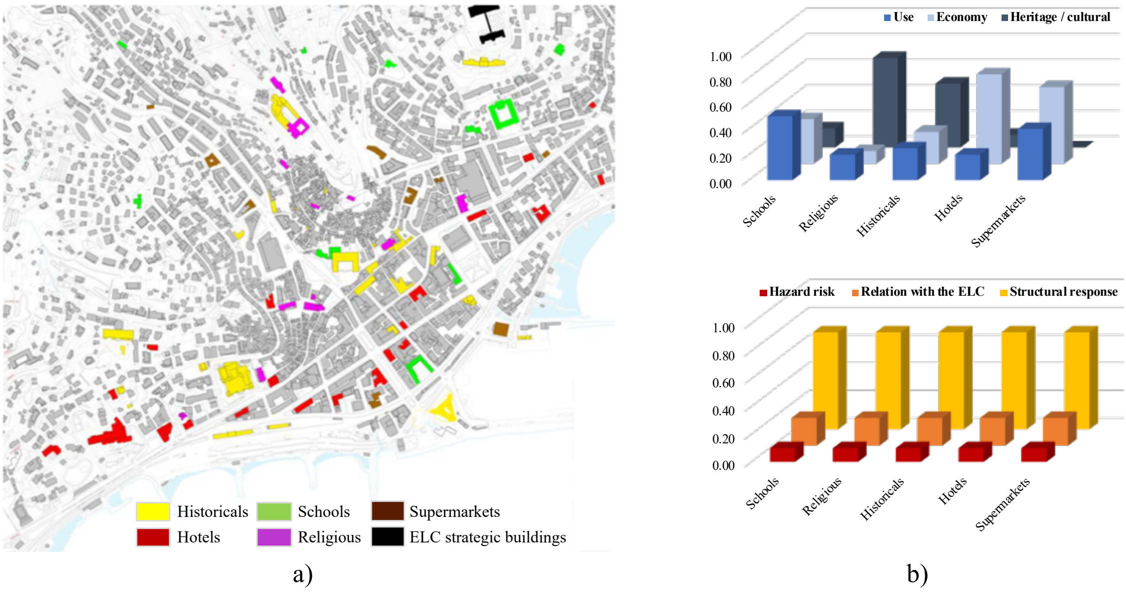


Fig. 5 – a) Phase A1: portion of the eligible buildings and relative SUF for Sanremo; b) Phase A2: definition of the weights $w_{i,s}^{SE}$ and $w_{i,m}^{SV}$ for Sanremo

The following tables define the factors considered for the attribution of the afore-mentioned scores, according to the different SUFs considered.

Table 1 – Criteria assigned to the *Structural Vulnerability fields – Relation with the ELC*

Criteria for the score - Relation with the ELC		$P_{i,3}^{SV}$
Distance from ELC system	>500 m From 250 to 500 m From 100 to 250 m From 50 to 100 m From 0 to 50 m	0 0.25 0.50 0.75 1
Presence/absence of active faults that insists on the connection that correlates the building under examination with the ELC system	Susceptibility to landslide failure very high Susceptibility to landslide failure high Susceptibility to landslide failure medium Susceptibility to landslide failure low Susceptibility to landslide failure very low	0 0.25 0.5 0.75 1
Ratio front length and distance from CLE	From 1 to 2 m From 0.6 to 1 m From 0.3 to 0.6 m From 0.6 to 0.9 m	0 0.3 0.6 1

Table 2 – Criteria assigned to the *Structural Vulnerability fields – Structural response and Hazard*

Structural response	
Criterion	$P_{i,1}^{SV}$
$I_S <= 0.4$	0.2
$0.4 < I_S <= 0.6$	0.4
$0.6 < I_S <= 0.8$	0.6
$0.4 < I_S <= 1$	0.8
$I_S > 1$	1

Presence of hazard	
Criteria	$P_{i,2}^{VS}$
Relation with MOPS*: building on unstable or liquefiable zone	Excluded from the list of buildings
Susceptibility to landslide failure high	0.25
Susceptibility to landslide failure medium	0.50
Susceptibility to landslide failure low	0.75
Susceptibility to landslide failure very low	1
*Maps of the homogeneous microzones in seismic perspective	

Table 3 – Criteria assigned to the *Socio-Economic fields*

Strategic Urban Functions	***Criteria for the score - Use and Economy***			$P_{i,1\text{-}2}^{SE}$
Schools	Number of Alumni or Staff	< 100	< 10	0.2
		100 – 200	10 – 20	0.4
		200 – 500	20 – 50	0.6
		500 - 1000	50 - 100	0.8
		> 1000	> 100	1
Supermarkets	Sales area	< 200 m^2		0.25
		200 – 500 m^2		0.5
		500 - 1000 m^2		0.75
		> 1000 m^2		1
Hotel	Number of beds	< 20		0.2
		20 – 50		0.4
		50 – 100		0.6
		100- 200		0.8
		> 200		1
Religious	Size	Small		0.3
		Medium		0.6
		Large		1
	Adjacent area	No		0
		Yes		1
Historical	Intended use	Other		0
		Residential		0.3
		Museum		0.4
		Tourist		0.6
		Public		1

Strategic Urban Functions	***Criteria for the score - Heritage conservation and cultural identity***		$P_{i,3}^{SE}$
Schools, Hotels and Supermarket	No restrictions from the authorities		0
	Historical - artistic value recognized		0.5
	Historical restrictions from the authorities		1
Religious and Historical buildings	Presence of decorative elements on the facade	No	0
		Yes	1
	Presence of frescoes and/or pictorial decorations	No	0
		Yes	1
	Presence of decorative plaques, headstones and coat of arms	No	0
		Yes	1
	Presence of historical collections	No	0
		Yes	1

The scores P_i^{SE} and P_i^{SV} are then computed as a weighted average of the partial ones ($P_{i,s}{}^{SE}$ and $P_{i,m}{}^{SV}$) attributed to the different performance fields.

$$P_i^{SE} = \sum P_{i,s}^{SE} w_{i,s}^{SE} \quad (2)$$

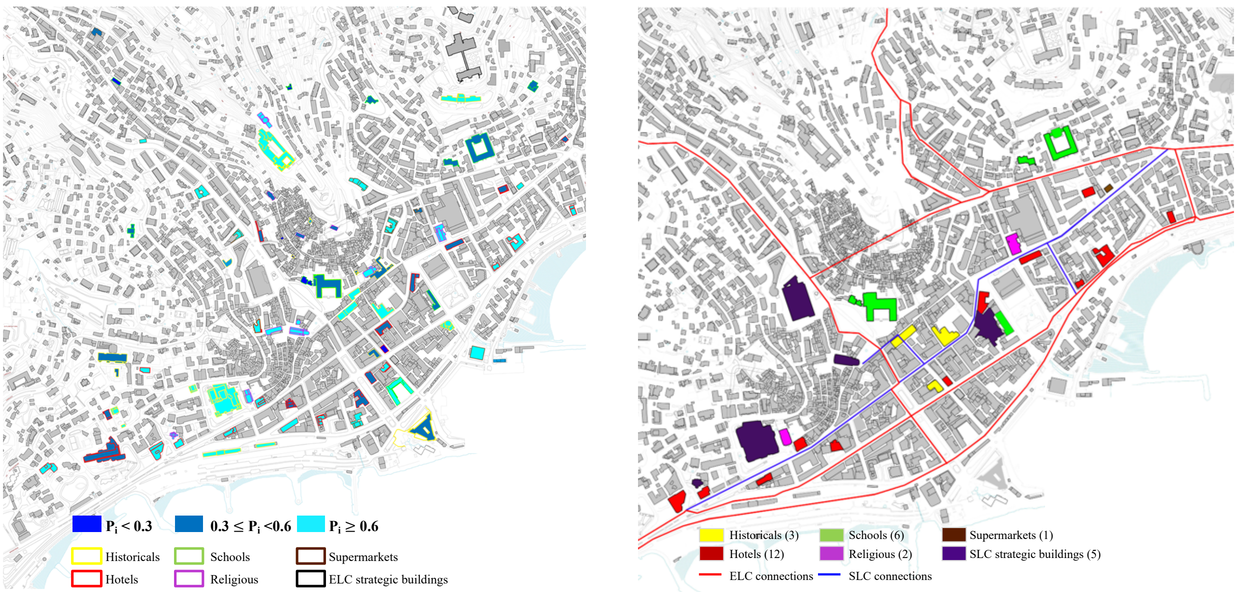
$$P_i^{VS} = \sum P_{i,m}^{VS} w_{i,m}^{VS} \quad (3)$$

Where the summations are extended to s (= 1, …, 3) and m (= 1, …, 3). Then, for the application of Equ. (1) the values of the two scores ($P_{i,s}{}^{SE}$ and $P_{i,m}{}^{SV}$) are renormalized.

Fig. 6.a illustrates as the resulting final scores (Equ. 1) to each building can be graphically represented for supporting the identification of the SLC_{MIN}. Each eligible building is marked with a thicker outline, whose color corresponds according to a legend to the respective SUF and an internal color, whose color identifies three ranges of the final score (>0.3, 0.3 - 0.6, >0.6).

At this point, the definition of the SLC_{MIN} (Fig. 6.b) entails:

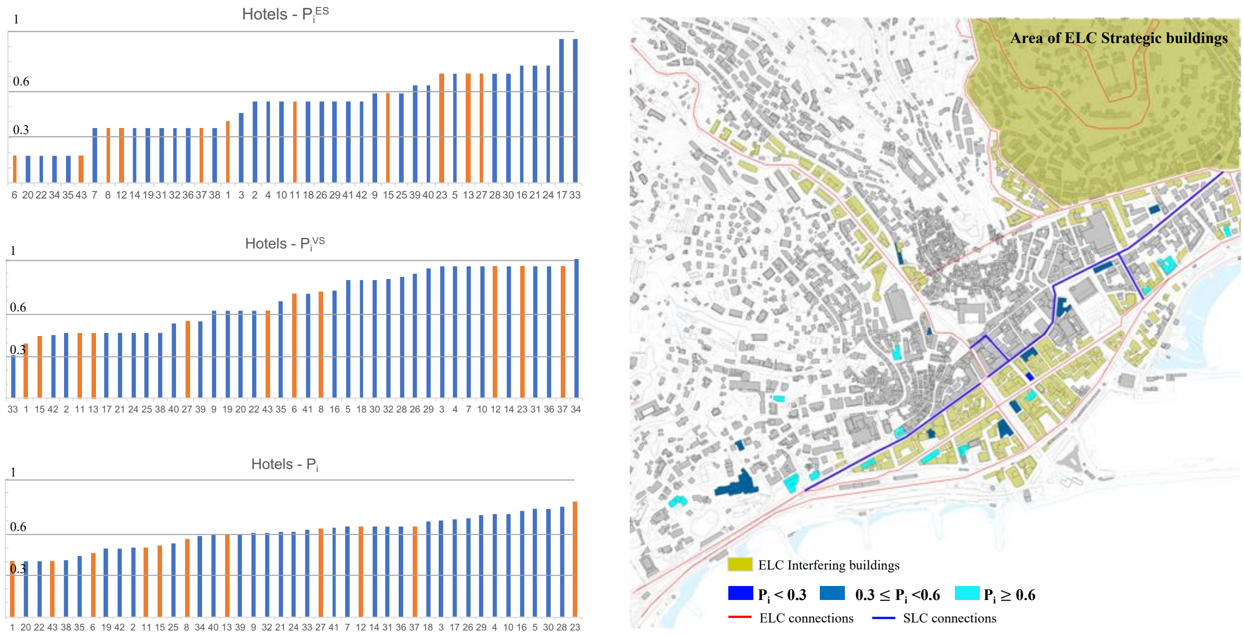
- the introduction of the SLC strategic buildings. These buildings are inserted whatever the score, since they are considered essential for the recovery. In the case of Sanremo are 5 (marked in purple in Fig. 6.b): the Ariston Theater, the Sanremo Casino, the San Siro Church, the Russian Church and the Annonario Market.
- the identification of a number of buildings such as to ensure the recovery (critical mass). The buildings are preferably selected from those characterized by the highest scores and favoring those located near to the ELC strategic buildings or easily connectable to them through the insertion of new connections (Fig. 7.b). In Fig. 6.b and Fig. 7.b, the connections of the ELC system are marked in red, while the added ones are identified in blue. The critical mass should also take into account economic criteria to verify that the number of buildings is adequate for actually guarantying the recovery; at this stage of the research this issue is just outlined as a methodological principle and in future it could be corroborated through the collaboration with economists. For Sanremo, the selected buildings for the SLC_{MIN} are in total 29.



a) b)

Fig. 6 – a) A2) phase: graphic representation of the score P_i assigned to each eligible building and relative SUF for Sanremo; b) A3) phase: definition of the SLC_{MIN} for Sanremo

Finally, Fig. 7.a illustrates the scores attributed by way of example to the hotels eligible for the SLC and identifies in orange those finally selected for the SLC_{MIN}. The scores are shown in ascending order. The results point out as most selected buildings have a score greater than 0.3.



a) b)

Fig. 7 – a) A2) phase: scores P_i^{SE}, P_i^{SV} and P_i assigned to each eligible buildings. The SLC_{MIN} selected buildings are in orange; b) Map of the hotels inserted in the ELC system

4. Conclusive remarks

The procedure proposed in the paper for the *analysis* and *assessment* of the SLC aims to be a tool for supporting the risk mitigation policies implemented by the local authority at urban scale. The paper focuses to the risk associated to the earthquake, but the concepts introduced could be extended in the future to other hazards in order to construe multi-hazard resilient communities. In particular in the Equ. (1) the weight and the score associated to structural vulnerability aspect could be particularized for different hazard involved (seismic, hydrogeological, …). The methodology developed has been applied to the pilot case study of Sanremo municipality placed on the western coast of Liguria (Italy). In particular, the paper focuses to the *analysis* phase aimed to identify the SLC_{MIN} necessary to guarantee an effective recovery of the urban settlement. This application has shown the feasibility of the methodology, able to provide the different characteristics and behavior of each building. The *assessment* step is still ongoing. Moreover, although all the whole general framework has been already outlined specific steps of the procedure would require in the future a strong interaction with others scientists such as economists and sociologists.

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7. References

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