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# EQ-DIRECTION Procedure towards an Improved Urban Seismic Resilience: Application to the Pilot Case Study of Sanremo Municipality

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**Abstract:** This paper discusses the critical importance of effective mitigation policies to enhance earthquake resilience in urban systems, especially in light of recent seismic events in Italy. The Italian Civil Protection Department (ICPD) has delineated specific Limit Conditions (LCs) for urban settlements, serving as benchmarks for targeted mitigation policies, and akin to Limit States for buildings in Codes. While the ICPD has already developed operational procedures for some LCs, concentrating on evaluating the structural operational efficiency of strategic functions during emergency management, only a conceptual outline exists for other LCs involving preparedness and recovery/reconstruction phases. To address this gap, this paper introduces the EQ-DIRECTION (EarthQuake Disaster-REsilient City acTIOn plan) procedure. This method aims to analyze and assess the "Limit Condition for Safeguarding the Existence of the Settlement" (referred to as SLC). The procedure entails identifying the "minimum urban system" required for effective recovery and evaluating the performance of this system in terms of structural damage and economic losses against the SLC requirement. The practical application of this methodology to a real-world case study in Sanremo municipality on the western coast of Liguria (Italy) demonstrates the feasibility and potential effectiveness of the procedure for earthquake resilience in urban planning and management.

**Keywords:** risk mitigation policy; urban resilience; seismic vulnerability; large-scale assessment



**Citation:** Cattari, S.; Ottonelli, D.; Mohammadi, S. EQ-DIRECTION Procedure towards an Improved Urban Seismic Resilience: Application to the Pilot Case Study of Sanremo Municipality. *Sustainability* **2024**, *16*, 2501. https://doi.org/10.3390/su16062501

Academic Editor: Gwenaël Jouannic

Received: 21 January 2024
Revised: 9 March 2024
Accepted: 12 March 2024
Published: 18 March 2024



## 1. Introduction

Resilience and resilient thinking have gained attraction among decision-makers [1] as well as academics across disciplines, sectors, and different spatial–temporal scales as a way to survive in the uncertain, risky environment of today's world and deal with incremental unforeseen events of various natures (from natural hazards to terroristic attacks) [2,3]. According to [4], resilience can be defined as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management".

Among the various contexts where notions of resilience are employed, this research focuses on urban seismic resilience [5]. Several researchers have presented a detailed definition of urban resilience by focusing on many networks and subsystems that are present in urban systems [3,6,7]. The 25 most influential urban resilience definitions were collected by [3] after reviewing 40 years of urban resilience-related publications. According to these definitions, the main characteristics of urban resilience include the following:

- Absorb and tolerate the impacts of disasters;
- Recover from disasters and "bouncing back" or "bouncing forward";
- Remain as a functional urban system after a disaster;
- Improve to cope better with future risks.

Despite the fact that there are generic definitions of resilience in relation to natural hazards, academics and policymakers argue that the idea of community resilience is very context-specific and depends on the type, location, and scale of the hazard [8–10]. Roughly half of the urban resilience definitions are presented in the context of a specific threat (e.g., climate change or flooding, earthquakes), while the other half focus on the resilience of an urban system to respond to all risks [3]. Definitions of seismic resilience and resilient systems against earthquakes specifically have been offered in certain studies in this regard [11,12]. One of the most referable definitions for seismic resilience in the literature is provided by [13], that defines seismic resilience as "the ability of the exposed system (e.g., urban system, organization, ...) to decrease risk, encompass the impact of disasters when they happen, and carry out recovery operations in a way that minimizes social disruption and reduces the effects of future earthquakes". They argue that resilience could be achieved by strengthening structures, reducing their probability of failure during an earthquake, and putting measures in place to quickly return to pre-disaster or other acceptable levels of functioning following disaster occurrence [13,14].

The resilience concept's temporal span extends from before a disaster happens to after it has occurred, during the recovery period, as well as during the time the disaster takes place. In other words, the state of the system and the actions taken throughout each phase of the disaster risk management cycle (that includes mitigation, preparedness response, and recovery) determine how resilient the urban system would be [15]. Therefore, carrying out interventions to lessen the built environment's vulnerability before the event [16,17], planning an effective emergency management strategy [18], and executing quick and efficient recovery [19] are all effective measures that raise the system's resilience. The actions performed in each phase not only affect the overall resilience of the urban system but also the ability of the urban system in subsequent phases to continue functioning and take the planned actions [20].

Some actions, such as strengthening vital structures and infrastructure, can help the system be more resilient [21] from two aspects and throughout two different time domains. On the one hand, it can reduce the likelihood of failure of the system during the disaster occurrence, and on the other, it can result in the preservation of critical structures that can facilitate the recovery and emergency process following an earthquake [22]. One of the primary issues in this context is identifying and determining the important infrastructures and structures, especially when resources are limited and decision-makers must select among several buildings to invest in [23–25]. Resilience could be measured in terms of a person's, a community's, or a country's primary survival values or assets, such as life, livelihood, and culture. From this viewpoint, the objective of any "disaster resilience" program ought to be to preserve the fundamental values, assets, and resources that can be used in the process of adapting to challenging situations [26].

L'Aquila 2009 [27] and Central Italy 2016/2017 [28,29] earthquake experiences are examples that highlight the need to improve the response of strategic buildings beside the residential ones and their capability to satisfy their role in emergency and recovery phases. An overview of the impact of the recent Italian earthquake from different perspectives (i.e., social, economic, and disaster management) is provided in [30]. As shown in Figure 1, emergency operations are hampered by the collapse of the Prefecture (a) and hospital (b) buildings in L'Aquila and Amendola, respectively, as well as the obstruction of roads due to the failure of the interfering buildings (c). Figure 2 depicts several structures that have cultural value and play an important role in the community's identity, like churches and historical buildings, that were destroyed by the earthquake, resulting in the emergence of loss feelings amongst inhabitants before they were rebuilt [31]. The huge repercussions of Italian seismic disasters in economic terms have also been documented in [32–34].

(**a**) (**b**) (**c**)

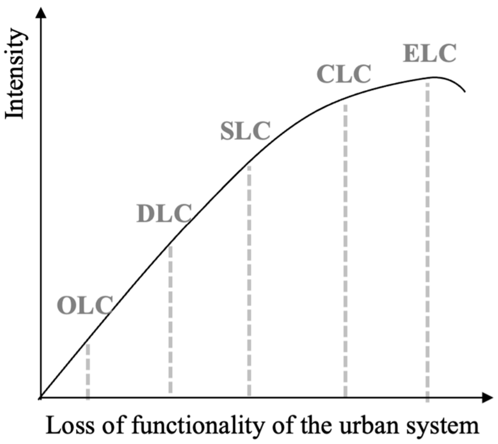
**Figure 1.** (**a**) L'Aquila 2009; (**b**) Amendola 2016; and (**c**) Accumoli 2016.

(**a**) (**b**) (**c**)

**Figure 2.** (**a**) View of the Accumoli historical center; (**b**) S. Benedetto square in Norcia after the Centre Italy 2016/2017 earthquake; and (**c**) Santa Maria in Paganica Church after L'Aquila 2009.

In this context, the Italian Civil Protection Department (ICPD) outlined specific Limit Conditions (LCs) for urban settlements [35,36], which were intended to specify the explicit target/objectives that mitigation plans have to define accordingly in the course of various risk management cycle's phases (i.e., pre-, post-, and during disaster [37]). An overview of the potential application of such concepts is provided in [38]. The LCs correspond to different conceptual thresholds. The conceptual thresholds set out by the LCs describe the physical and functional damage levels of an urban system and its constituent parts. Urban systems lose a certain level of functionality if any of the established LC thresholds are exceeded as a result of an earthquake (Figure 3). The main objectives of LCs are in line with the goals of specified limit states in Standards and Codes, but at a larger scale than that of a single building [39,40], and include the following: (i) ensuring the safety of the settlement's resident life; (ii) protecting the buildings and infrastructures that compose settlement; and (iii) preserving the environmental and the social identity of the urban system.

All of the LCs introduced by the ICPD in [35,36] are summarized in Figure 3, along with a description of the urban system state to which they refer. Some of these LCs, such as the Emergency Limit Condition (ELC), have undergone exploratory investigations, and the ICPD has provided manuals and operational instructions for using them to analyze urban systems and put their concerns into action in practical situations [41]. Moreover, a probabilistic method was developed in 2013 by the ICPD to evaluate the operational effectiveness of a municipal emergency plan in the event of an earthquake. The method is called I.OPà.CLE, which stands for the "Index for Evaluation of Operational Efficiency of Limit Condition of Emergency" [42,43]; it has been used in several research and case study analyses (e.g., [23,44–46]). ELC focuses on the response phase of the risk management cycle and evaluates how the urban system can well continue to function for emergency activities immediately following a disaster.




**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 functions 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 functions are interrupted.

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

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

**Figure 3.** Conceptual graphical representation of the Limit Conditions proposed by the ICPD (adapted from [35]) and their definitions [36].

The other LCs are instead crucial for the system's state in other phases of disaster risk management, such as recovery and preparedness [36]. In particular, the "Limit Condition for Safeguarding the Existence of the Settlement" (hereinafter called SLC) following the occurrence of a disastrous seismic event is the main subject of this paper. The primary objective of SLC is to protect the urban essential functions that are vital for starting the system's recovery process and are required to ensure the rapid return of all urban system functions. According to [47], recovery is a lengthy process that could take years or decades to complete. Ignoring the socio-economic aspects of this process, which involve the entire affected community, would result in a defective recovery process that eventually would result in a not resilient city with social fragmentation and nonfunctional living conditions [27,48–51]. In this context, it could be claimed that characterizing the SLC necessitates multidisciplinary analysis and evaluation of a community's economic, social, cultural, and identity dimensions. Moreover, in general, fulfillment of the SLC requirement presupposes satisfaction of the ELC.

While the ICPD has defined the SLC only conceptually so far, this study specifically establishes an operational procedure for the analysis and assessment of the SLC, which was initially developed within the context of the research conducted on the pilot case study of Sanremo municipality located on the western coast of Liguria (Italy). The procedure is named the EQ-DIRECTION, which stands for "EarthQuake-DIsaster REsilient City acTION plan". The EQ-DIRECTION aims to introduce a practical tool for mitigating seismic risk that enables decision-makers to take action in the context of urban planning. The output of the methodology is a priority list of the buildings that should continue to be functional during the reconstruction phase, which considers both the built environment's structural response and its economic and historical relevance. In-depth structural analysis, better resource management, and the strengthening of intervention are all issues that should be tackled in the priority list determination.

Resilience stands as a pivotal aspect of sustainability, especially in the context of post-disaster recovery [13,52–54]. Both sustainability and resilience intertwine, highlighting a system's capability to progress towards favorable developmental trajectories [55]. They share a fundamental objective of safeguarding societal health, well-being, and local economies [56]. In the current study, resilience underscores the aim of enhancing an area's capacity to mitigate risks and facilitate recovery from future disasters.

After having illustrated the general goals and principles of the proposed procedure (Section 2), the specific methodology and practical outlined tools are presented (Section 3). Then, the procedure is tentatively applied to a pilot case study consisting of the Sanremo municipality (Section 4) to show its feasibility in real-world situations. The application to this pilot case study was supported by the funding of Sanremo Municipality and Liguria region within mitigation national programs supported by the ICPD.

## 2. EQ-DIRECTION: Goals and Key Principles

### *2.1. Basics of the Proposed Procedure for Assessing the SLC Condition*

According to [35,36], the Limit Condition for Safeguarding the Existence of the Settlement (SLC) following an earthquake represents the condition for which the urban settlement—as a whole—suffers physical and functional damage that interrupts some urban functions for its entire or partial extension.

Urban systems offer a variety of functions. According to how they are utilized and the type of services that they provide within the system, system components can be categorized into functions [57]. In an upper-level classification, a group of these functions could make up a major functions class. If the major functions classes are categorized by their significance and involvement in risk management following the occurrence of the disaster, the following four distinct major classes could be found:

(i) The strategic urban functions in emergency management that concern buildings for emergency coordination, medical relief, operational intervention, road networks, and emergency areas;
(ii) The main urban functions in the recovery phase that consist of the most important buildings and activities from the social, productive, and cultural point of view, considering the socio-economic characteristics of the city;
(iii) Normal urban functions and services;
(iv) Dwellings (housing).

According to the SLC's principles, the urban settlement is assumed to preserve the functionality of strategic functions for the emergency and post-event recovery and the connection and accessibility with the territorial context. Moreover, the possibility of partially maintaining or resuming 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 the following three objectives:

1. Ensure 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 item, as already mentioned, in practice, presupposes the fulfillment of the ELC, while the second and the third items characterize more specifically the SLC.

Figure 4 provides a synthetic illustration of the EQ-DIRECTION procedure aimed at providing a first tentative operative tool to address the SLC. The preliminary but essential step is the definition of the strategic urban functions (SUFs) of the system, which is the individuation of the different activities with a key role in the community from the perspective of the recovery of the settlement following a disastrous event. They consist of the main services of the city (e.g., schools, policies, pharmacies, markets, . . .), the relevant economic activities (e.g., productive structures, hotels in the case of urban systems funded on touristic activities, . . .), the fundamental cultural assets (e.g., monumental buildings), and the most representative urban and social places (e.g., religious buildings, relevant squares, . . .). Then, the strategic buildings for the emergency have to be added too, being the fulfillment of the ELC implicitly included in the SLC objectives.

This preliminary step is followed by two phases, i.e., "analysis" and "assessment".

The analysis phase is aimed, firstly, at the listing and reconnaissance of all the buildings that potentially have a role in carrying out the full strategic urban functions of the SLC (i.e., the identification of all eligible buildings); secondly, at the analytical quantification of their potential performance to prioritize them; and thirdly, at defining—within the set identified in the first phase—a subset of buildings (called $SLC_{MIN}$, where MIN stands for "minimum") representative of the minimum core necessary to guarantee an effective recovery following a calamitous event.

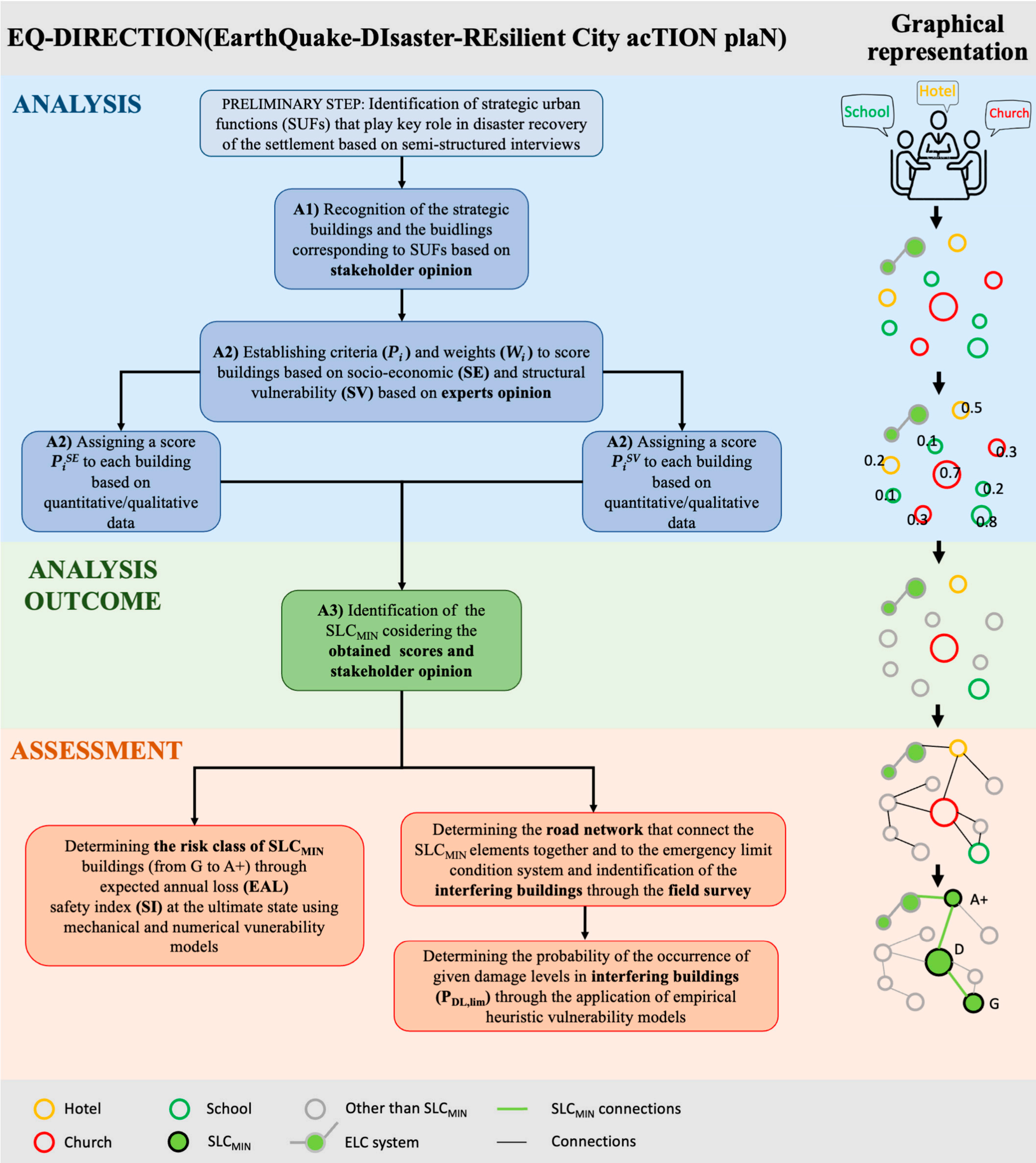



**Figure 4.** Schematic representation of the procedure.

The assessment phase then aims to provide a more detailed estimate of the seismic performance of the components of the $SLC_{MIN}$ to eventually assign them mitigation actions. In the assessment phase, the evaluation is not limited only to the subset of strategic buildings that compose the $SLC_{MIN}$, but it is extended also to all the interfering buildings whose damage could potentially compromise their performance.

Both phases, i.e., "analysis" and "assessment", make use of vulnerability models based on different approaches and require a different burden of data acquisition (through expeditious inspections of the territory, archive research, or more detailed inspections of buildings) as well as computational effort. Their use is therefore diversified depending on the number of buildings to be examined. In general, where possible, the criterion is to adopt more simplified approaches in the analysis phase and for the evaluation of buildings interfering with the $SLC_{MIN}$; greater detail is required for the evaluation of the buildings that make up the $SLC_{MIN}$. In general, the approach is to prioritize simplified methods for the analysis phase and for evaluating interfering buildings neighboring the connections of the $SLC_{MIN}$ while opting for more detailed methods for buildings of $SLC_{MIN}$ like the ones corresponding to SUFs and strategic buildings.

The following sections aim to illustrate the objectives and role of $SLC_{MIN}$ (Section 2.2) in more detail as well as those of the "analysis" and "assessment" phases (Section 2.3) and the operative tools proposed for the latter ones (Section 3).

### *2.2. Minimum Urban System: Objectives and Role*

Considering the limitation of the available resources for investments necessary to pursue the SLC objectives, the identification and recognition of an urban sub-system is very useful for more effectively orienting and prioritizing the mitigation action.

As a result, in addition to the SLC general principles, which have already been established by ICDP [35,36], the $SLC_{MIN}$ concept was introduced in the proposal of the EQ-DIRECTION procedure. Figure 5 illustrates a graphical representation of the goals that the $SLC_{MIN}$ concept aims to pursue in the change in the perspective for the actions to be planned in the disaster risk management (DRM) circle (i.e., before the event or after the completion of a whole recovery phase—in green, during the emergency phase after the disastrous event—in red, and during the reconstruction/recovery time—in yellow).

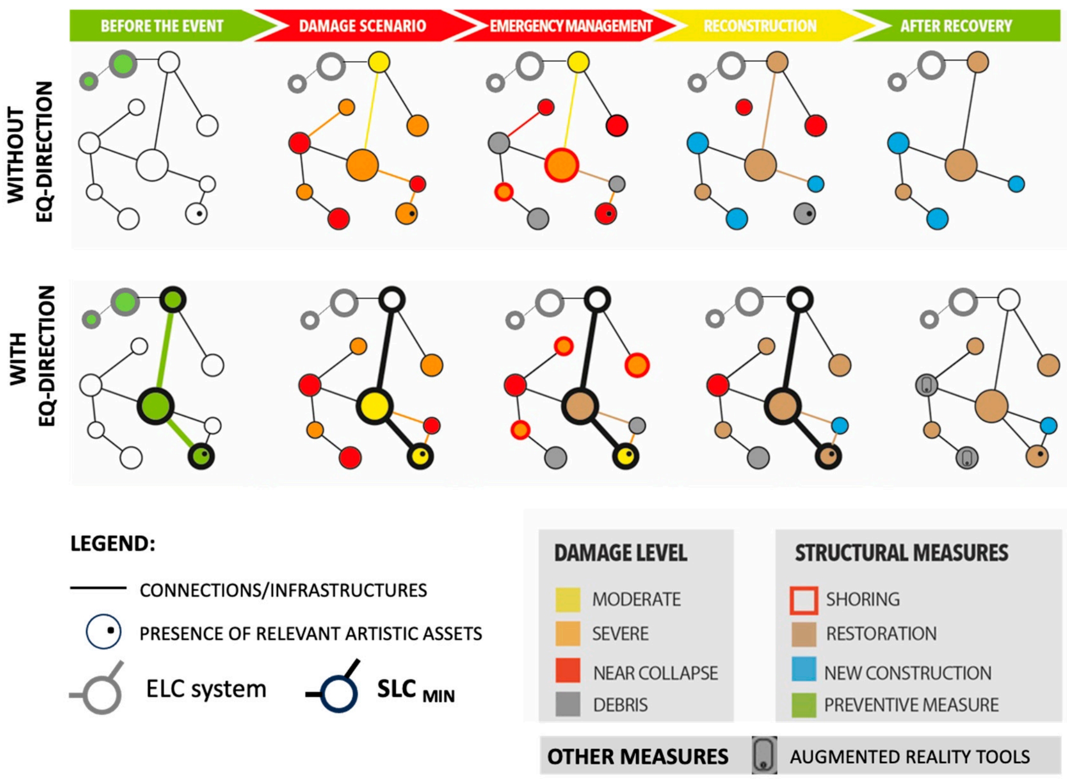



**Figure 5.** Graphical representation of the goals that the $SLC_{MIN}$ concept aims to pursue.

The first row of Figure 5 depicts a scenario in which mitigation actions in the pre-event phase are mainly oriented to guarantee an adequate seismic response of just the sub-system addressed to manage the emergency phase (e.g., as the result of decisions taken following the ELC analysis of the urban system). As a consequence of a severe seismic event, the system suffers severe damage that makes the full restoration of some components impossible, leading to the loss of them or the complete new construction of others. The fact during the emergency phase, some components are subjected to an even worsening of the damage highlights the possible impact of damage accumulation phenomena not effectively countered by prompt actions, such as shoring or delay in the damage surveys. The second row of Figure 5 instead hypothesizes actions in the "green" period also on additional components, identified as crucial for preserving the cultural, social, and economic identity of the urban system (i.e., the $SLC_{MIN}$ system), leading not only to lower overall damage but to a configuration after recovery that leads to maintaining almost all components (even if, in some cases, recurring to the only solutions compatible with the very huge damage that occurred, like augmented reality for assets relevant to the cultural identity of the community).

The $SLC_{MIN}$ aims to comprise the bare minimum structures required to establish the necessary critical core system for starting the post-event recovery process and is intended in this research to form a strict relationship also with the ELC system. This crucial core system must be able to maintain and create the social and economic connections and circulation required in order to make the urban system capable of functioning and, if not improve, at least return it to the pre-disaster state. The speeding up of the recovery process is greatly impacted by the core system preservation as well. To prevent population displacement, which could have irreparable effects, it is imperative that the recovery process be quick and effective. The $SLC_{MIN}$ would serve as a planning guide for decision-makers to prioritize the core system for risk-reduction measures and optimize their investment.

Therefore, for the $SLC_{MIN}$ recognition it is required to complete the following:

- Identify the SLC strategic buildings that are critical components in the urban system, in the particular context under consideration, and whose presence is crucial for the recovery regardless of their current structural performance;
- Select the eligible buildings from strategic buildings in accordance with decision criteria and importance aspects.

### *2.3. Analysis and Assessment Phases*

The general framework of the EQ-DIRECTION is divided into two sub-steps, as shown in Figure 4. The following steps are the ones that characterize the *analysis* phase in more detail:

(A1) Recognition of the eligible buildings (i = 1, . . ., N), which entails locating and collecting in a GIS environment all the structures that support the continuance of SUF services.

(A2) Assigning a score (Pi) to each eligible building using an analytical process that strives to combine the various physical, environmental, social, and economic factors for the determination of the importance of different urban system components and their contribution to ensure the SLC of the whole system (Section 3.1).

(A3) Identifying the $SLC_{MIN}$, which is a subset of the eligible buildings (i′ = 1 . . . N′, with N′ < N) that allows for the urban system to achieve the required SLC state and ensure the beginning of recovery. The A2 phase scores and the location of the buildings in the urban context (i.e., proximity to the other strategic buildings or infrastructures included in the ELC system) are the factors that are considered primary criteria for identifying the optimized $SLC_{MIN}$.

After recognition of $SLC_{min}$, the procedure passes to the *assessment*. In fact, the analysis phase concentrates mostly on the SLC from a systemic point of view by taking into account the function of buildings in the urban context, whereas the assessment phase primarily focuses on the behavior of the recognized building in $SLC_{min}$. This phase entails evaluating the structural performance, expected damage, and consequent loss of functionality of the associated buildings to SLC in accordance with the socio-economic aspects that are considered in this limit condition. The assessment phase should be followed by the adoption of vulnerability models. Different vulnerability models have been developed using various methodologies, including empirical-heuristic, mechanical (based on analytical techniques), and numerical (based on detailed models) models [58]. Although the volume and details of the data needed vary depending on the vulnerability model that is chosen, all the aforementioned methodologies that are preferred to be applied in the assessment phase require more effort in the data gathering and computing processes than in the analysis phases. For this reason, the $SLC_{min}$ is established before the assessment phase rather than following it to reduce the required computing time power of the assessment phase. Once the assessment has been carried out on $SLC_{min}$ buildings, it is useful to represent the results on a map, taking advantage of the GIS representation, and showing them at the scale of the urban settlement. In particular, the *assessment* is performed on the following:

- All the buildings of the $SLC_{MIN}$ and their relative connections;
- All the structures that interfere with $SLC_{MIN}$ accessibility, particularly those whose structural response or damage can impair the correct utilization of $SLC_{MIN}$ connections and structures. They could be identified based on parameters relating to the height of the building fronts (H) compared to the width of the street (L) they overlook. According to rules established for the ELC assessment in [41], the interfering buildings are those characterized by H > L.

## 3. Methodology and Tools Proposed for the Analysis and Assessment Phases

### 3.1. Analysis

A rapid field survey (compatible with large-scale analysis), research archival investigation, and an evaluation of administrative documents (i.e., the results of structural safety analyses previously carried out) are the main sources of data collection in the analysis phase.

Additionally, semi-structured interviews with stakeholders must be conducted in order to identify the primary SUF for the city, identify the most significant buildings that should be included in the minimum urban system regardless of the building scores, and, finally, assign weights to the various examination categories in order to evaluate the final scores, which will be discussed in more detail in this section.

As aforementioned, the identification of the list of strategic buildings and the individuation of those buildings for supporting strategic urban functions constitute the first step of the analysis phase (A1—Figure 4). Since this recognition necessitates in-depth contact with the community and understanding of the urban area, this step should be taken in close collaboration with the local government (i.e., municipal) and decision-makers. Depending on the case study of analysis and the characteristics of the examined urban area, some SUFs can be further explored. For instance, the productive structures may include public, industrial, or touristic buildings depending on the primary economic source or the activities of the local populations.

For the second step (A2—Figure 4), as already introduced, the main methodology that is used is scoring. To complete this step, an equation was defined to calculate the score of each asset considering different performance categories. More specifically, the total score $P_i$ is determined through the following expression:

$$P_i = P_i^{SE} + P_i^{SV} = \sum w_{i,s}^{SE} P_{i,s}^{SE} + \sum w_{i,m}^{SV} P_{i,m}^{SV} \quad (1)$$

where ${P_i}^{SE}$ and ${P_i}^{SV}$ are normalized scores derived from the fusion of the various criteria that contribute to defining the significance of the *i*-th eligible building in the SLC of the urban system, taking into account the socio-economic (SE) importance and structural vulnerability (SV) of the building. The partial scores attributed to the building (${P_i}^{SE}$ and ${P_i}^{SV}$) vary from 0 to 1. For both the SE and SV factors, various performance categories are defined, which are identified by the counters $s$ (=1,. . ., 3) and $m$ (=1,. . ., 3), respectively. Moreover, ${w_s}^{SE}$ and ${w_m}^{SV}$ represent the weight factors that vary based on the SUF being examined. The total of the weights for each SE and SV is 1. Then, the values of the two scores ($P_{i,sSE}$ and $P_{i,mSV}$) are renormalized to be employed in Equation (1).

In particular, the following performance categories are considered:

- Concerning socio-economic (SE) importance:

Occupancy ($s$ = 1), which expresses the value of an asset in terms of its size, adjacent area, and occupant number;

Economy ($s$ = 2), which indicates the significance of an asset in terms of its contribution to the urban system's economic activities;

Heritage conservation and cultural identity ($s$ = 3), which expresses the asset's artistic value as well as its cultural significance for the area, highlighting in particular how the asset is crucial for the preservation of the settlement's identity and history.

- Concerning structural vulnerability (SV):

Structural response ($m$ = 1). This factor quantifies the seismic vulnerability of the building and its potential to be subjected to damage. It is expressed by a safety index (SI) computed by considering the reference return period of the seismic action selected by the municipality (in general, the one also compatible with ELC evaluations, which are usually carried out referring to at least 475 years). At this stage of the procedure (i.e., the analysis phase), the SI is primarily computed through simplified approaches that require a very limited number of parameters, in other words, by selecting a few attributes of taxonomies that describe the seismic vulnerability [58,59] and that are capable, at the same time, of discriminating structural behavior while being easily collectable. A typical example, adopted also by the ICPD for carrying out the national seismic risk assessment [60], is the taxonomy based on ISTAT census data [61], i.e., describing the building seismic behavior as a function of the structural type, the number of stories, and the age of construction. A key issue is to adopt a method that is comparable (i.e., based on the same type of information and characterized by the same level of uncertainty and accuracy), as much as possible, among all building types (or at least within the same building type belonging to an analogous function) to avoid introducing possible bias.

Consequent hazard risk (m = 2). This factor considers the probability that subsequent potential hazards, such as landslides, will occur either immediately after or simultaneously with the earthquake.

Relation with the ELC system (m = 3). This factor enables considering the proximity of the building to both internal connections within the urban system and access routes from the outside to the urban system, all of which are required for emergency management. Additionally, the possible risk imposed by the existence of faults and liquefaction phenomena in all those connections that link the building under examination with the ELC system is taken into consideration. To effectively integrate the risk mitigation policies already initiated in the domain concerning ELC, it is crucial to develop a relationship across ELC and SLC.

For each of these performance categories, it is necessary to define the proper quantitative criteria and then it is necessary to provide a range for grading the score between 0 and 1 for each of those criteria (as exemplified in Section 4 for the case study of Sanremo). When a single category's score is determined by multiple partial criteria, each of them is given a score between 0 and 1, and the sum is then normalized such that it is comparable to the scores of the other categories.

As far as the weight factors ${w_s}^{SE}$ and ${w_m}^{SV}$ are concerned, their assignments are performed in consultation with the administrative sector and in accordance with the opinions of the stakeholders using a semi-structured interview approach. To take into account the various aspects of the role played by the strategic function in the urban system and compare them, the stakeholders should be chosen from a variety of disciplines. This multidisciplinary partnership approach in weighting the categories allows for comparing various aspects of the strategic function and gives each category the appropriate amount of weight so that the significance of the strategic function can be assessed based on how it is used in the urban system.

The results of the scores attribution to the complete set of eligible buildings (having ordered the results of the scores in ascending order to obtain a relative reference of their performances) constitute a first tool to address the choice of the $SLC_{MIN}$ system, aimed to include the minimum number of buildings to ensure the critical mass able to guarantee recovery after the event. Such a minimum number reflects the critical mass that should be able, on the one hand, to create the appropriate economic recirculation through new investments and jobs and, on the other one, to preserve the identity of the system, i.e., to return it at least to the pre-event condition or, even better, to an improved condition. However, it should be noted that while the scores may be used as a guide in choosing the buildings, they are not the only factor to consider. As previously mentioned, the active involvement of stakeholders plays a crucial role during the final selection of the buildings, and the position of the buildings from the other candidate buildings in the SLC and the connection infrastructures, already present in the ELC, must be considered as well.

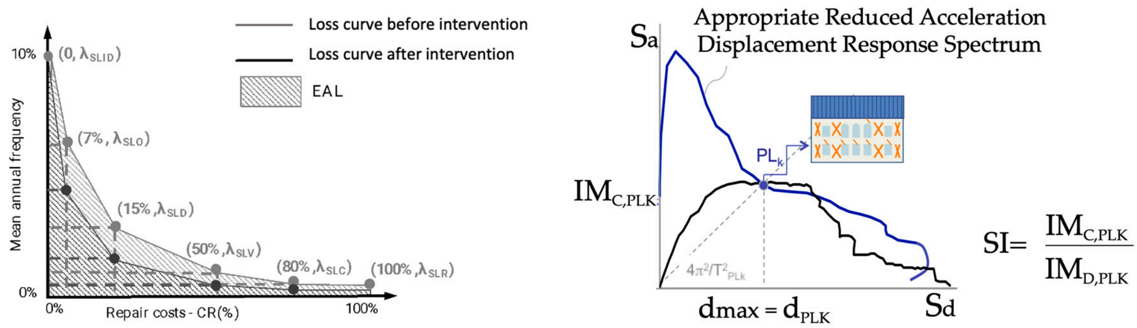
### 3.2. Assessment

This step entails evaluating the structural performance and expected economic losses of the buildings that compose and interact with $SLC_{MIN}$. Different approaches may be adopted for the buildings that strictly compose the $SLC_{MIN}$ and for the interfering buildings; moreover, also among the first ones, different criteria may be suitable depending on their function, i.e., if mainly related to an economic or functional role or, conversely, to a social one.

For the buildings included in the $SLC_{MIN}$, due to their economic or functional importance, it is recommended to assign a "seismic risk performance class", referring to principles associated not only with the safety index but also with the expected annual loss (EAL), as discussed in [62,63]. The EAL represents the likely average economic loss for any given year (seen as a fraction of the overall value of the building) [64] and may be expressed by the area under the loss curve that correlates the mean annual frequency of exceedance of each LSs ($\lambda_{LS}$) and its economic losses (CR—repair cost) (see Figure 6a). Various works in the literature explored the use of EAL as a decision variable for both the assessment of existing buildings ([65]) and, also, the design of new constructions [65–67]. However, because merely taking into account EAL does not offer sufficient assurances for the safety of those dwelling inside the structure, consideration of the safety index (SI) is also required (Figure 6b). In fact, highly stiff fragile structures can have low EAL values, which correlate with a good EAL class, despite having insufficient safety in the event of a collapse, which would endanger the lives of many occupants. The proposal discussed in [63] and adopted in [68] at the Italian national scale goes in this direction, illustrating a seismic risk classification of constructions from G to A+, according to which the risk class is determined as the lower of the two classes: one that is associated with the EAL and the other that is defined as a function of the SI at the ultimate limit state.

For other buildings primarily included in the $SLC_{MIN}$ to preserve the identity of the community through their social aspect and cultural values, it is difficult to always apply an analogous approach. Often, these buildings consist of monumental and religious structures for which assigning an economic value is difficult besides being very arbitrary in most cases; in addition to that, their specific architectural features present challenges in the reference values that must be used for the EAL computation. As a consequence, in that case, it is suggested to evaluate these buildings using only the SI.

Finally, the assessment of interfering structures is mainly addressed to evaluate if the damage level (DL) may potentially compromise the connections or the performance of buildings effectively inserted in the $SLC_{MIN}$. This is why, in this case, the parameter proposed as a reference is the probability ($P_{DL,lim}$) associated with the DL, assumed as the one that compromises the functionality of the $SLC_{MIN}$. Establishing a threshold damage level and calculating the likelihood of exceeding it is required for this purpose and can be performed differently depending on the structural type (e.g., if masonry or reinforced concrete). The deployment of simplified vulnerability models is advised due to the generally high number of interfering buildings.




(**a**) (**b**)

**Figure 6.** Assessment phase: (**a**) theoretical loss curve and *EAL* and (**b**) computation of the safety index according to nonlinear static procedures (in blue the seismic input and in black the capacity curve).

Additional practical hints on the vulnerability models that may be adopted for addressing the analysis and assessment phases are illustrated in the following section that focuses on the application to the Sanremo case study.

## 4. The Sanremo Pilot Case Study

### *4.1. General Overview*

The pilot case study of Sanremo municipality, which is located on the western coast of Liguria (Italy), was examined using the methodology proposed in the previous section. Located in Liguria, in northwest Italy, Sanremo is a city on the Mediterranean coast (Figure 7). It was established during the Roman era and has 57,000 inhabitants. The municipality has an elongated shape in accordance with the configuration of Liguria. Numerous cultural events are held there, including the Milan–San Remo cycling classic and the Sanremo Music Festival.

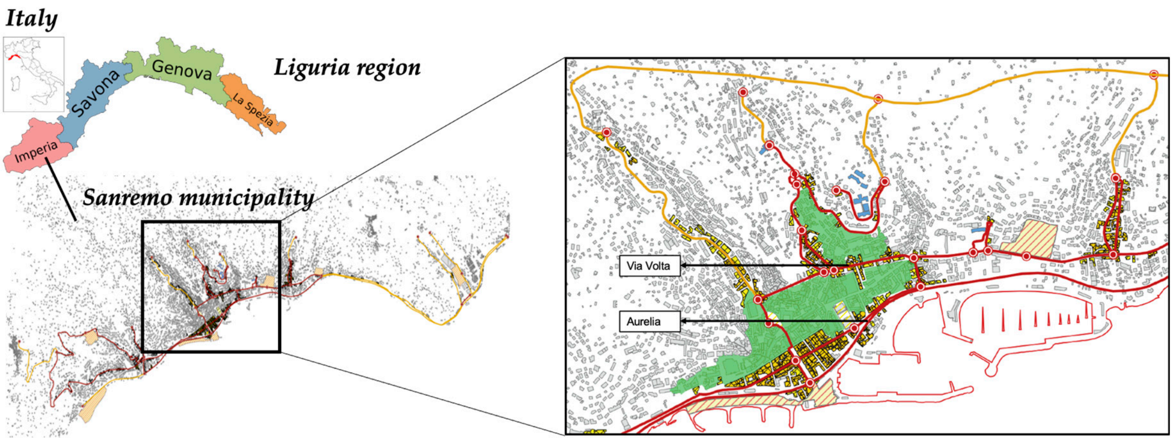



**Figure 7.** Overview of the location of Sanremo municipality in the Liguria Region and zoom-in on the ELC system (the green area identifies the part of the urban system where most of the significant components of ELC and $SLC_{MIN}$ are concentrated, in red the main connections are identified).

Its Mediterranean climate and attractive seacoast setting on the Italian Riviera make it a popular tourist destination. In addition to tourism, the city is engaged in the manufacture of extra virgin olive oil, which has a protected "designation of origin". The city is a significant agricultural center in the province of Imperia and in western Liguria. Sanremo is referred to as the "City of Flowers," and the flower industry plays a significant role in the city's economy. The Municipal Casino (Figure 8a), an example of an Art Nouveau structure established in 1905, and the Ariston Theatre (Figure 8b), which presents a yearly schedule of renowned concerts, operas, and stage productions, are additional significant landmarks in Sanremo. Accordingly, it is apparent that tourism is the crucial element for the various SUFs in this municipality and, consequently, that accommodation facilities represent one of the primary economic productive activities. Additional information regarding the data collection and methodology application is provided in the following sections, which illustrate the approach used in this case study in more detail. Figure 7 also provides a partial view of the ELC system where some of the most significant connections are indicated (i.e., Volta and the Aurelia roads); the green area identifies the part of Sanremo municipality where most of the significant components are concentrated and where, in fact, the $SLC_{MIN}$ is mainly located.


**Figure 8.** Some of the emblematic buildings that characterize the Sanremo municipality: (**a**) the casino; (**b**) the ARISTON theatre; (**c**) the Russian church; and (**d**) the foodstuff ("Annonario", in Italian) market.

### *4.2. Data Collection and Tools Adopted for Implementing the Analysis Phase in the Sanremo Municipality*

Stakeholder consultation resulted in the identification of five major SUFs, including schools, churches, historical buildings, hotels, and supermarkets. All data of the buildings belonging to these SUFs were collected by first referring to the archive and Google Street View and the in situ surveys performed in strict collaboration with local technicians [69]. Ad hoc forms were conceived to collect the data necessary to assign the scores, as detailed in the following.

As introduced in Section 3.1 (phase A2 of Figure 4), in the analysis phase, to apply Equation (1), appropriate weight factors (${w_s}^{SE}$ and ${w_m}^{SV}$) must be defined. The weights adopted for the Sanremo case study are shown in Table 1, which were obtained by taking into account the opinions of municipality staff. The weight factors vary based on the examined SUF. For instance, compared with churches, the socio-economic factor "heritage conservation and cultural identity" has much less weight in the case of schools and supermarkets.

**Table 1.** Phase A2: definition of the weights ${w_s}^{SE}$ (a) and ${w_m}^{SV}$ (b) for Sanremo.

| SUF | $w^{SE}$ | | | $w^{SV}$ | | |
|---|---|---|---|---|---|---|
| | ${w_1}^{SE}$ Occupancy | ${w_2}^{SE}$ Economy | ${w_3}^{SE}$ Heritage/Cultural | ${w_1}^{SV}$ Hazard Risk | ${w_2}^{SV}$ Relation with ELC | ${w_3}^{SV}$ Structural Response |
| Schools | 0.50 | 0.35 | 0.15 | 0.70 | 0.10 | 0.20 |
| Religious | 0.20 | 0.10 | 0.70 | 0.70 | 0.10 | 0.20 |
| Historical | 0.25 | 0.25 | 0.50 | 0.70 | 0.10 | 0.20 |
| Hotels | 0.20 | 0.70 | 0.10 | 0.70 | 0.10 | 0.20 |
| Supermarkets | 0.40 | 0.60 | 0.00 | 0.70 | 0.10 | 0.20 |

Then, the scoring of each building was assigned in light of two main aspects, including socio-economic (SE) significance and structural vulnerability (SV), as was already mentioned in Section 3.1. Distinct criteria were proposed for each SUF taking into account the heterogeneity in the analyzed functions in the case of Sanremo. Table 2 shows the various criteria that are used to assess the occupancy (s = 1) and economy (s = 2) categories as well as the scores that should be given to each building based on those criteria. Additionally, different criteria and scoring rationale are presented in Table 3 for the category of heritage conservation and cultural identity (s = 3) as well.

**Table 2.** Criteria assigned to the socio-economic fields—occupancy and economy.

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

**Table 3.** Criteria assigned to the socio-economic fields—heritage conservation and cultural identity.

| **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 |

Regarding the structural vulnerability, the safety index (SI) is the metric used for the first category, i.e., the structural response (m = 1); scores were assigned according to the range of variation summarized in Table 4. For determining the consequent hazard risk (m = 2), according to the score classes listed in Table 4, the results available from the study of Seismic Microzonation Level 1 [70] were employed. Table 5 shows that the only consequent risk considered was a landslide, and the score for this category was assigned based on four separate classes of susceptibility.

**Table 4.** Criteria assigned to the structural vulnerability fields—structural response and hazard.

| **Structural Response** | | **Presence of Hazard** | |
|---|---|---|---|
| **Criterion** | $P_{i,1}^{SV}$ | **Criteria** | $P_{i,2}^{SV}$ |
| IS $\leq$ 0.4 | 0.2 | Relation with MOPS *: building on unstable or liquefiable zone | Excluded from the list |
| 0.4 < IS $\leq$ 0.6 | 0.4 | Susceptibility to landslide failure high | 0.25 |
| 0.6 < IS $\leq$ 0.8 | 0.6 | Susceptibility to landslide failure medium | 0.50 |
| 0.4 < IS $\leq$ 1 | 0.8 | Susceptibility to landslide failure low | 0.75 |
| IS > 1 | 1 | Susceptibility to landslide failure very low | 1 |

* Maps of the homogeneous micro zones in seismic perspective.

**Table 5.** Vulnerability index $V_0$ adopted for unreinforced masonry (URM) and RC structures (from [56,58] for monumental buildings).

| **Structural Type** | | | | $V_0$ |
|---|---|---|---|---|
| Ordinary buildings | Masonry [55] | M3 | Simple stone | 0.74 |
| | | M4 | Massive stone | 0.616 |
| | Reinforced concrete [55] | RC1 | Frame in r.c. (without ERD) | 0.644 |
| Palaces [57] | | | | 0.62 |
| Churches [57] | | | | 0.89 |
| Theaters [57] | | | | 0.70 |

Regarding the SI, as aforementioned, the adopted methods need to balance the effort in acquiring the necessary data and executing the analyses with the capability of discriminating the seismic structural behavior. For the whole stock of school buildings in the Sanremo municipality, the results from the adoption of a mechanical–analytical approach combined with the use of detailed numerical models set through the equivalent frame approach were already available [71]; these data allowed for the direct evaluation of the SI. Although such a mechanical–analytical approach [72,73] is based on a limited number of geometrical and mechanical factors (as better illustrated in Section 4.3), the collection of all these data was unfeasible for the other eligible buildings in the SLC. This is why, for the other SUFs, the macroseismic model originally proposed in ([72,74]) was preferred.

The macroseismic model can be considered an empirical–heuristic method. It is directly derived from the concept of the European Macroseismic Scale (EMS98) [75], which defines six vulnerability classes (named from A to F). The macroseismic scales are not instrumental based, and they implicitly contain a vulnerability model. According to the original proposal of [74], the linguistic definitions of EMS98 were translated in quantitative terms by the fuzzy set theory, and the completion to Damage Probability Matrix (DPM) was carried out by using the binomial probability distribution. In this model, the vulnerability is synthetically expressed by a vulnerability curve, which gives the mean damage $\mu_D$ (=$\sum kp_{DSk}$) as a function of the macroseismic intensity (I) according to:

$$\mu_D = 2.5 + 3\,tanh\left(\frac{I + 6.25V - 12.7}{Q}\right) \quad (0 \leq \mu_D \leq 5) \tag{2}$$

where the vulnerability index $V$ and the ductility index $Q$ are parameters representative of the seismic behavior of a group of buildings characterized by a homogeneous seismic behavior. The vulnerability index was assigned according to the following expression:

$$V = V_0 + \Delta V_m \tag{3}$$

where $V_0$ is a typological vulnerability index defined by [74] based on the consistency with EMS-98 buildings typologies, while $\Delta V_m$ corresponds to vulnerability modifiers aimed to account for a possible worsening or improvement in the seismic response based on specific structural factors. Tables 5 and 6 show the values of $V_0$ and $V_{m,k}$ adopted in the present study. The values of $V_0$ associated with monumental buildings were assumed accordingly to [76]; these values highlight the higher vulnerability expected for such monumental structures than residential buildings due to their architectural features (e.g., high slenderness ratio of walls). They were attributed based on the information carried out from ad hoc expeditious in situ surveys made in collaboration with the technicians of Sanremo municipality.

**Table 6.** Values of vulnerability modifiers $V_{m,k}$ adopted from [74].

| Behaviour Modifiers | Masonry | | Reinforced Concrete | | | |
|---|---|---|---|---|---|---|
| | | | ERD Level | Absent | Moderate | High |
| State of preservation | Good<br>Bad | −0.04<br>+0.04 | Good<br>Bad | -<br>+0.04 | -<br>+0.02 | -<br>0 |
| Number of floors | Low (1 ÷ 2)<br>Medium (3 ÷ 5)<br>High (>5) | −0.08<br>0<br>+0.08 | Low (1÷3)<br>Medium (4÷7)<br>High (>7) | −0.02<br>0<br>+0.04 | −0.02<br>0<br>+0.04 | −0.02<br>0<br>+0.04 |
| Plan irregularity | Geometry<br>Mass distribution | +0.04 | Geometry<br>Mass distribution | +0.04<br>+0.02 | +0.02<br>+0.01 | 0 |
| Vertical irregularity | Geometry<br>Mass distribution | +0.04 | Geometry<br>Mass distribution | +0.04 | +0.02 | 0 |
| Aggregate building position | Middle<br>Corner<br>Header | −0.04<br>+0.04<br>+0.06 | Insufficient aseismic joints | +0.04 | 0 | 0 |

In this work, Equation (2) was applied by assuming a ductility index equal to 2.3, as originally proposed in [74], for RC buildings and URM structures assimilable to residential building configurations, and equal to 3 for monumental buildings. Such a method has been recently validated against real observed damage data and further developed in [77,78]. The computation of the SI via the use of the macroseismic approach requires the introduction of the following assumptions: (1) the adoption of a reference damage level as a proxy for the attainment of the ultimate limit state (i.e., the Life Safety—LS) and (2) the adoption of an appropriate correlation law between the macroseismic intensity (I) and the peak ground acceleration (PGA), used as an intensity measure to characterize the seismic hazard in this study. As far as issue (1) is concerned, DL3 was assumed as a reference that corresponds to the value of the mean damage $\mu_D$ equal to 2.5; instead, for issue (2), the law proposed in [79] was selected. These two assumptions allow for the computation of $PGA_{C,LS}$, i.e., the maximum intensity measure corresponding to the fulfillment of the LS limit state. The safety index was then computed as the ratio of $PGA_{C,LS}$ to the corresponding seismic demand, i.e., $PGA_{D,LS}$. The latter was derived from the Seismic Microzonation study of Level 3 [80], developed by the research group coordinated by Prof. G. Ferretti from the Department of Earth, Environment and Life Sciences (DiSTAV) at the University of Genoa. The Microzonation of Level 3 studies take into account the specific amplification phenomena that are expected in the area and provide reference ground acceleration peak values that are higher than those suggested in the Italian Seismic Hazard Maps [81]; more specifically, the values estimated for the Sanremo municipality by this study vary from a reference value of 0.145 $m/s^2$ for soil A to a range of variation between 0.22 and 0.265 $m/s^2$ (excluded topographical effects).

Lastly, three separate factors were taken into account in determining the scores that are associated with the category relation with the ELC (m = 3) (see Table 7). The exact minimum distance from the ELC system was the first factor considered, and the scores were assigned in accordance, classifying the building into five groups. The second factor concerns the road connection between the building under examination and the ELC system and its landslide susceptibility, as can be seen in Table 7. The third factor, which is the density of the buildings along either side of the road connection between the building and the ELC system, was computed by dividing the sum of the width of buildings that are based along both sides of the connection by the overall length of the connection multiplied by 2. Therefore, the ratio would be 0 if the entire length of both sides of the road connection was occupied by buildings. The corresponding scores assigned to this factor are defined in Table 7 as well.

**Table 7.** 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 the ELC system | >500 m | 0 |
| | From 250 to 500 m | 0.25 |
| | From 100 to 250 m | 0.50 |
| | From 50 to 100 m | 0.75 |
| | From 0 to 50 m | 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 | 0 |
| | Susceptibility to landslide failure high | 0.25 |
| | Susceptibility to landslide failure medium | 0.5 |
| | Susceptibility to landslide failure low | 0.75 |
| | Susceptibility to landslide failure very low | 1 |
| Ratio of the front length and distance from ELC | From 1 to 2 | 0 |
| | From 0.6 to 1 | 0.3 |
| | From 0.3 to 0.6 | 0.6 |
| | From 0 to 0.3 | 1 |

### *4.3. Tools Adopted in the Sanremo Municipality for Implementing the Assessment Phase*

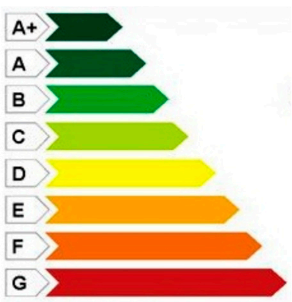
The assessment phase involves both the buildings of the $SLC_{MIN}$ and all the interfering buildings and, as aforementioned, usually requires the adoption of vulnerability models with a different computational/data collection effort for such two categories.

For the interfering buildings, which are usually higher in number than those selected for the $SCL_{MIN}$ system, the macroseismic model [74], already introduced in the description of how the analysis phase was implemented in Sanremo, was used. However, in this case, the primary goal is not a first estimate of the safety index but that of the probability of attaining a damage level (DL) incompatible with the adequate performance of connection (i.e., $P_{DL,lim}$). From the in situ survey, carried out by filling in the forms proposed in [41] for the ELC by the ICDP, integrated with the collection of some vulnerability factors, the data concerning the number of floors, type of construction, age, and position in the aggregate were acquired for every interfering building, which allowed for the computation of the vulnerability index (V). From Equation (2), it was then possible to compute $\mu_d$ and rebuild the damage probability distribution according to the binomial assumption, which is consistent with the main hypothesis of the mascroseismic approach. Finally, the reference DL equal to 4, for URM structures, and 3, for the RC ones, were adopted. The choice considers damage levels that could cause interference with the system by means of partial or total collapses. In the case of URM, this mainly refers to the complete activation of out-of-plane mechanisms [82–84], while, in the case of RC, it is mainly associated with the response of infills. As far as the last point is concerned, indeed, various works highlighted how the response of infills may strongly affect the first DLs in the response of RC structures [85–87].

For the buildings of the $SLC_{MIN}$ system, the assessment phase implies the evaluation alternatively of the seismic risk class or that of the safety index. As stated in Section 3.1, the seismic risk class aims to combine safety needs with economic principles and was adopted in Sanremo applications for schools, historical buildings, hotels, and supermarkets; conversely, in the case of churches, only the SI was adopted as a reference.

The seismic risk class was attributed according to criteria proposed in [63], as briefly clarified in Table 8. The computation of EAL presupposes that the maximum intensity measure (usually the PGA) is compatible with the fulfillment of various limit states (see Figure 6a). The latter may be estimated from more or less accurate vulnerability approaches by varying the degree of accuracy of the available data. Also, the macroseismic approach may be used (as explicitly recommended in [63] for URM structures, according to the so-called "conventional approach") and, in such a case, it is recommended at least the use of modifier factors listed in Table 6 to better discriminate the seismic behavior of various buildings.

**Table 8.** Criteria adopted for assigning the seismic risk class (according to [46]).




| | **Risk Class from SI (LS LS)** | **Risk Class from EAL** |
|---|---|---|
| A+ | 100% ≥ SI | EAL ≤ 0.5% |
| A | 80% ≤ SI < 100% | 0.5% < EAL ≤ 1.0% |
| B | 60% ≤ SI < 80% | 1.0% < EAL ≤ 1.5% |
| C | 45% ≤ SI < 60% | 1.5% < EAL ≤ 2.5% |
| D | 30% ≤ SI < 45% | 2.5% < EAL ≤ 3.5% |
| E | 15% ≤ SI < 30% | 3.5% < EAL ≤ 4.5% |
| F | SI ≤ 15% | 4.5% < EAL ≤ 7.5% |
| G | | 7.5% ≤ EAL |

However, the limited number of buildings that compose the $SLC_{MIN}$ system, at least compared with the interfering buildings, makes it feasible to also apply mechanical–analytical approaches, which are based on a limited number of geometrical and mechanical parameters. This option, besides being a more accurate evaluation able to explicitly account for the various parameters that determine the structural response, also allows us to account for a more detailed seismic hazard characterization (e.g., instrumental IMs, seismic input in the spectral form) and exploit results of probabilistic seismic hazard analyses, when available. An interesting overview and discussion on the analogies and differences among different approaches, i.e., if empirical, mechanical–analytical, mechanical–numerical, or hybrid, is provided in [88,89], while in [90], a focus on analytical methodologies to derive vulnerability functions is presented. Among the mechanical–analytical approaches, some proposals specifically developed for RC structures are presented in [91–94], while those specifically for URM are developed in the works by [73,95–98].

In this work, by way of example, and given the availability of more detailed data from the archive, the mechanical–analytical Displacement-Based Vulnerability (DBV)-masonry method [73,98] was deployed for masonry buildings. The DBV-masonry method primarily refers to the global in-plane response of URM structures, starting from the shear-type idealization and evaluating the total base shear by assuming that all masonry piers fail simultaneously. This is true if the masonry piers are more or less the same size and the building has a regular floor plan. The vulnerability of actual structures that do not adhere to these hypothesis assumptions is calculated using the appropriate corrective factors. Through them, also weak spandrel-strong piers or intermediate behavior can be captured; moreover, in recent applications presented in [73], additional corrective factors have been introduced to account also for the possible activation of out-of-plane mechanisms. The model defines the capacity curve by the following three variables: the pseudo-elastic period of the structure $T_y$; the spectral acceleration at yielding $A_y$ (equal to the ultimate one $A_u$ because no hardening is assumed); and the ultimate displacement capacity $D_{DL4}$. In order to evaluate these variables, it is necessary to define a small number of mechanical and geometrical parameters, assume a basic modal shape, and assign specific correction factors that are intended to account for the impacts of a wide variety of constructive and morphological details (such as the presence of tie-rods, ring beams, etc.). The fundamental steps for using such a mechanical model are as follows: (1) analyzing the data that are available from archives or site surveys, (2) defining all necessary parameters and factors in two directions (X and Y), (3) assessing the capacity curves, (4) defining the seismic demand by an Acceleration–Displacement Response Spectrum (ADRS), and (5) evaluating the value $PGA_{LS}$ of the PGA that generates any LS threshold using overdamped spectra [98]. In that way, the EAL may be computed as well. A more detailed description of this method is out of the scope of this paper; thus, interested readers are invited to refer to [73,89,98].

For religious buildings, the vulnerability model proposed in the Italian G.U. no. 47 Guidelines [99] and inspired by the work of [100] was adopted. This allowed us to compute the vulnerability index (V) linked to the specific features (vulnerability indicators and earthquake-resistant details) of a church, in terms of possible collapse mechanisms of each macro element of the asset. This coefficient allowed us to quantify the seismic capacity that, compared with the demand PGA values obtained from microzonation studies, provides the safety index.

## 5. Results

The main results of the application of the EQ-DIRECTION procedure to Sanremo municipality are presented in this section, which is also supported by a graphic representation via the GIS platform. As partially depicted in Figure 9, in the zoom-in concentrated in the main historical area of the municipality, there are 184 eligible buildings in Sanremo (phase A1 of Figure 4) that correspond to the five identified SUFs and are potential candidates for the $SLC_{MIN.}$ The numbers for each category are as follows: schools (45), churches (24), historical structures (51), supermarkets (21), and hotels (43). The latter serve as Sanremo's primary productive function, as stated in the case study description.

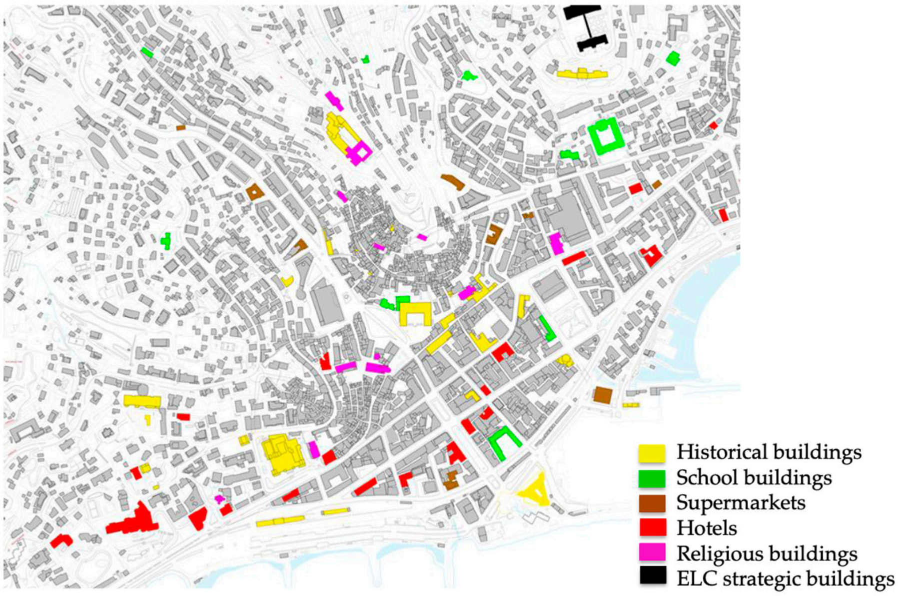



**Figure 9.** Analysis phase applied to Sanremo municipality (A1—identification of buildings belonging to the most important SUFs identified: the figure refers to a zoom-in on the urban system where the majority of buildings analyzed for the SLC are located).

Figure 10a illustrates, by way of example, the resulting scores for the hotels in Sanremo assigned at the end of the analysis phase implemented, as described in Section 4.2. Both scores are illustrated, i.e., the partial scores associated with the ES vs. factors and the final ones after their combination through the weight factors in Table 1 and renormalization to 1. In orange and yellow, two hotels are marked, for which quite different structural or socio-economic performance is expected; however, in the end, they belong to the same class (i.e., with $P_i$ ranging from 0.3 to 0.6). Although the result is sensitive to the weight factors assumed, the procedure allows us to account for various aspects that potentially contribute altogether to defining the overall resilience of the system. Instead, Figure 10b helps in identifying such hotels in the urban system; each hotel is colored in a shade of blue to clarify its corresponding final score value.

The scores assigned in the analysis phase were useful in addressing the selection of buildings for $SLC_{MIN}$ (Figure 11a), even if they were integrated with other factors. In particular, some crucial buildings for the recovery were determined after consultation with municipality staff regardless of the scores given to them. They consist of five buildings, i.e., the Annonario Market, the Russian Church, the Sanremo Casino, the San Siro Church, and the Ariston Theater (shown in purple in Figure 11a). Some streets were selected as the crucial network for connecting the most significant buildings to one another and to the ELC system; Figure 11a shows the additional streets, which are referred to as the SLC link and are shown as blue lines. According to the findings of the stakeholder interviews, the five most significant buildings and the corresponding road network should be regarded as the core system in SLC because, given the characteristics of Sanremo and its primary sources of income, preserving those elements is the most crucial issue for sustaining the socio-economic functionality and livelihood of the city. Because of this, identifying more buildings with regard to SLC should, to some extent, take into account their proximity to the most significant building and the networks that connect them, in addition to the scores they receive. More specifically, the $SLC_{MIN}$ includes 19 regular and monumental masonry structures constructed before 1919 with the number of floors ranging from three to seven; five buildings made of reinforced concrete constructed between 1945 and 1971 with the number of floors ranging from five to seven; one steel supermarket constructed in accordance with seismic regulations; and four churches.

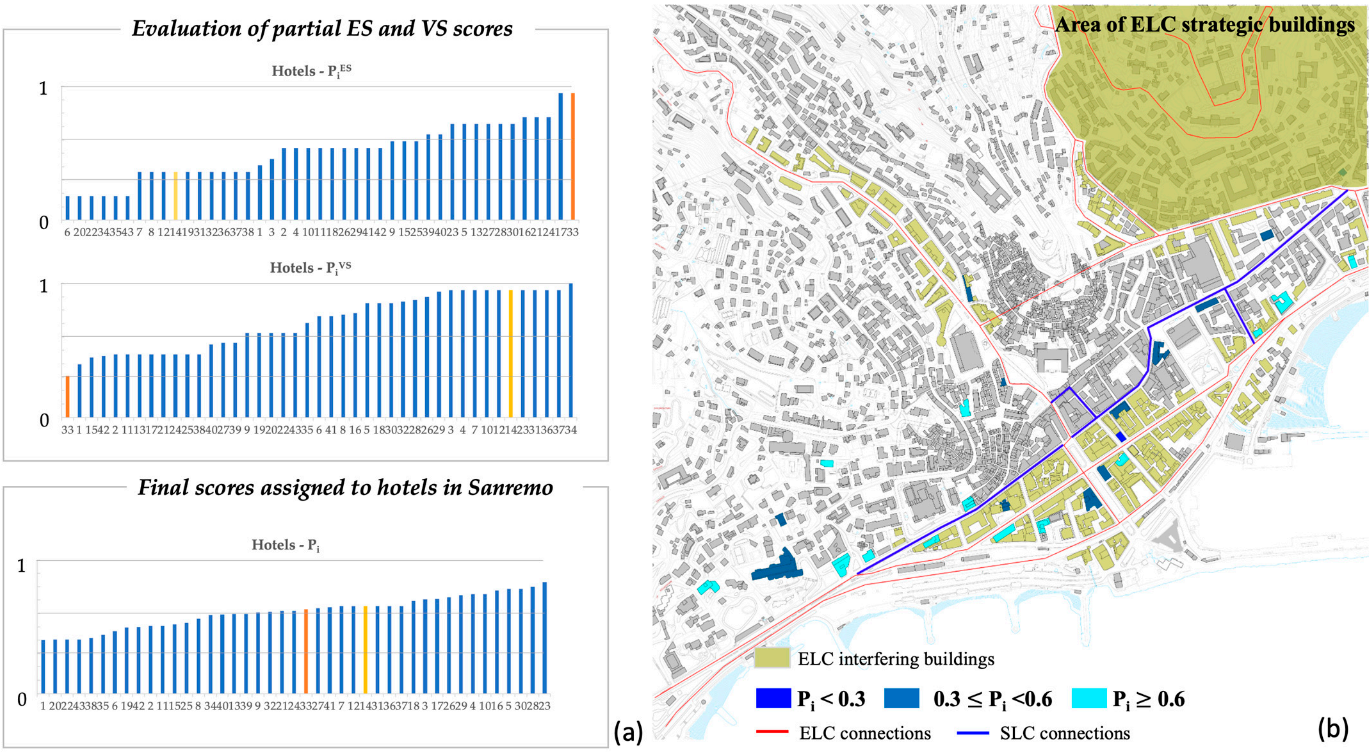



**Figure 10.** (**a**) Resulting scores for hotels in Sanremo from the analysis phase. (**b**) Localization of the hotels on the Sanremo map together with a graphic representation of the score Pi assigned to each eligible building.

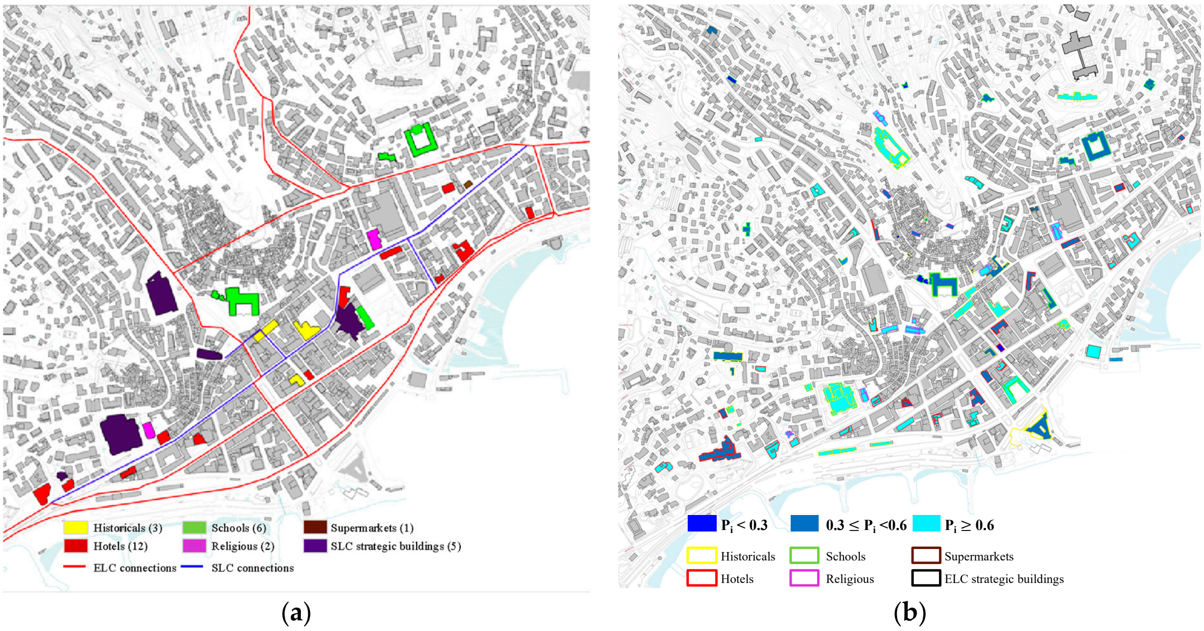
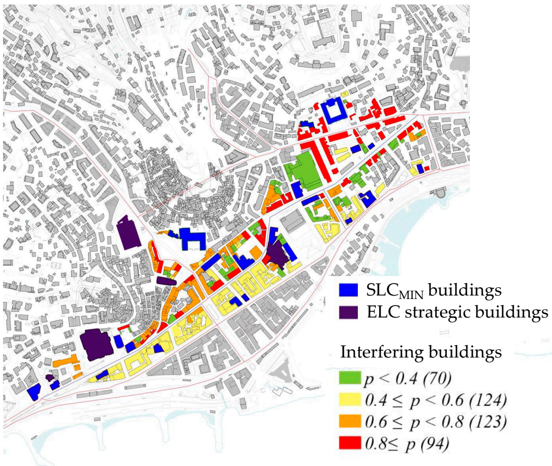


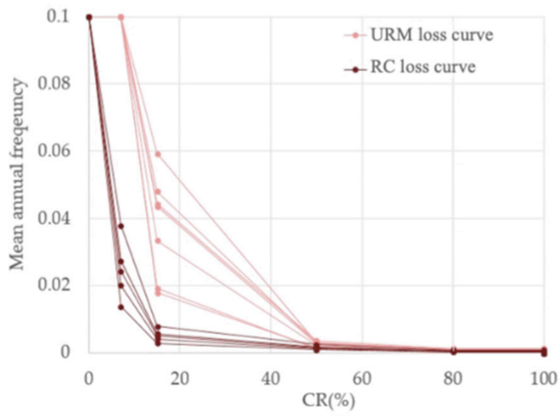

**Figure 11.** (**a**) Identification of buildings belonging to the $SLC_{MIN}$ system including SLC and ELC connections (step A3 of the analysis phase). (**b**) Graphic representation of the Pi score assigned to each eligible building and relative SUF for Sanremo (step A2 of the analysis phase).

Figure 11b shows the buildings of $SLC_{MIN}$ with a graphic representation of their score. Each eligible building is identified by a thicker outline color, which matches the relevant SUF according to the legend, and an internal color that indicates which range of the final score (>0.3, 0.3–0.6, >0.6) the building falls into. The 29 $SLC_{MIN}$-eligible buildings were optimally chosen from those with the highest scores (e.g., greater than 0.3), preferring those close to the ELC strategic buildings and SLC's most significant buildings or easily accessible from them through the established connections (e.g., red and blue road networks) (Figure 11a).

Figure 12 illustrates the main intermediate results of the assessment phase, namely, (a) the estimate of $P_{DL,lim}$ for the interfering buildings (the strategic buildings of the ELC and SLC system are highlighted in dark and light blue, while the other colors identify the probability of attaining the selected reference DL) and (b) the loss curves evaluated for URM and RC buildings.




(**a**)




(**b**)

**Figure 12.** Assessment phase: (**a**) assessment of the performance of interfering buildings and (**b**) loss curves for the URM and RC buildings of $SLC_{MIN.}$

The main geometric characteristics necessary for the application of the DBV-masonry method and the evaluation of EAL are the inter-story height, the number of floors, and the resistant area compared to the floor area. These data were obtained by conducting a documentary study of the municipal archive. In more detail, the geometrical parameters were considered as random variables, while for the mechanical properties of the masonry and floors, where unknown, reference was made to studies carried out on site on the construction typologies common in Sanremo; these studies were carried out according to the CARTIS approach [101]. In particular, the URM buildings analyzed are considered to be made of cleft stone masonry with good texture and square stone block masonry with tie rods and wooden-flexible and semi-flexible floors. Figure 12b shows how the Damage Limit State (SLD) value has the greatest influence on the value of the Average Annual Loss. Contrary to performance-based assessment strictly focused on safety aspects, where the Life Safety Limit State is typically the most important, the lower limit states are also crucial when evaluating structures from an economic perspective.

Finally, Figure 13 provides an overall overview of the final result of the assessment phase in terms of risk class or safety index (only for religious structures) of SLCMIN buildings as well as the likelihood that the damage level of reference will occur for each interfering building.

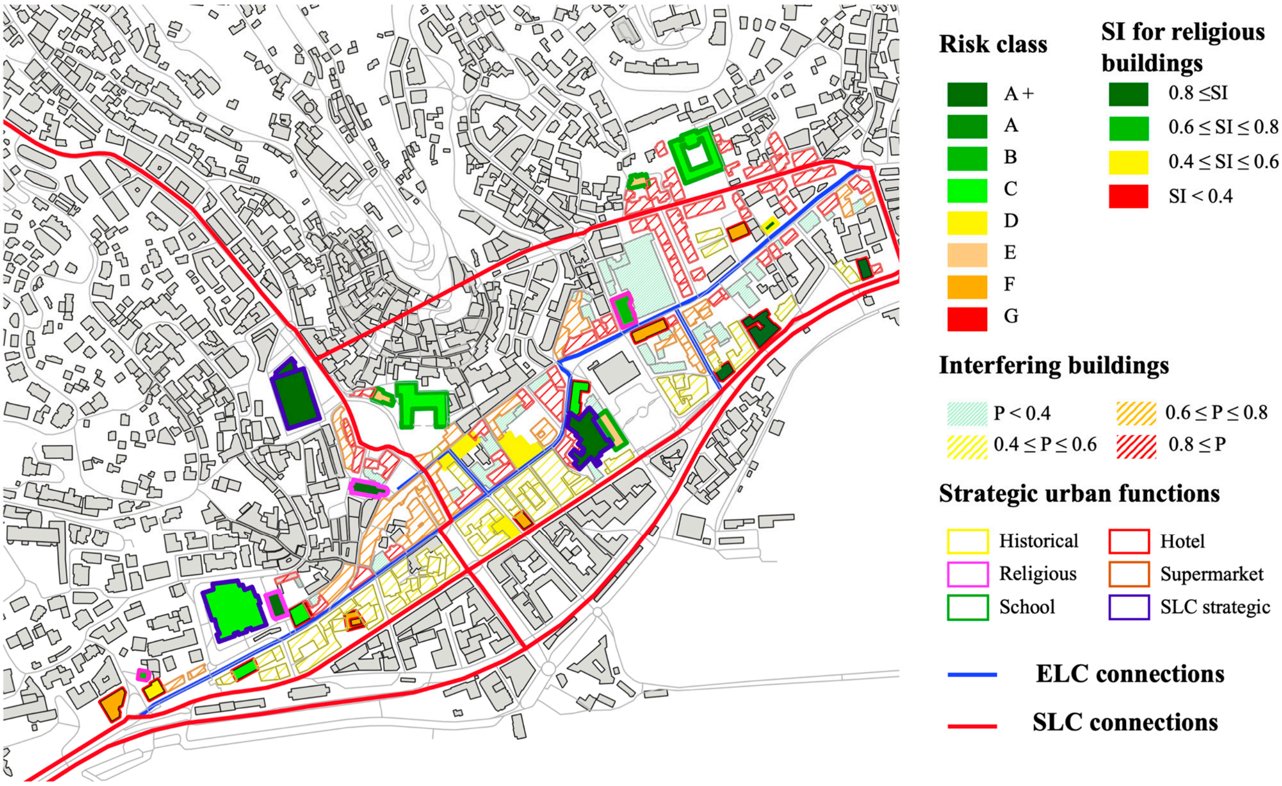



**Figure 13.** Overall representation of the final results of the EQ-DIRECTION procedure in Sanremo municipality.

## 6. Conclusions

The procedure proposed in this paper represents a pioneering effort to operationalize some general principles articulated by the Italian Civil Protection Department (ICPD), which seek to establish the desired targets of specific Limit Conditions on an urban settlements scale, in contrast to the prevalent focus in the literature on performance-based seismic assessment at the individual building level. The primary focus is on ensuring the safety and resilience of the urban system. This involves introducing a novel procedure named EQ-DIRECTON, designed to serve as a tool supporting risk mitigation policies enacted by local authorities at the urban scale. Specifically, EQ-DIRECTON can be employed to prioritize mitigation actions on selected buildings identified during peaceful times. This proactive approach aims to expedite and enhance the recovery phase following a potentially hazardous event, making it more efficient and effective.

The proposed approach highlights some key aspects including the following:

- Recognizing the paramount importance of actively involving local stakeholders in defining factors that significantly influence the decision-making process of the proposed procedure. This feature also enables the procedure to be adaptable to various urban contexts.
- Introducing tools aimed at striking a balance between the necessity for an assessment capable of discerning the performance of diverse buildings and the challenges associated with data collection and computation efforts.
- Taking into account a comprehensive set of factors crucial for recovery. This not only involves safety and structural considerations but also extends to socio-economic needs.

This paper tentatively demonstrates the feasibility of the proposed approach by applying it to the pilot case study of Sanremo. The visualization of results in a GIS environment proves to be highly effective. Moreover, once the collected data are implemented in such a tool, it may help the administration to monitor and continuously update the status of the urban settlements. For instance, it facilitates the updating of information on strengthening interventions carried out in the assets.

While this approach has yet to be implemented in any real-world case study to validate its applicability, numerous studies suggest that failing to adopt this approach results in inefficient and prolonged recovery following a disaster [102]. For instance, the aftermath of the L'Aquila earthquake and subsequent reconstruction efforts, which led to the displacement of the population from the city's central historic area, underscored the detrimental effects of lacking $SLC_{MIN}$. These effects include the loss of community identity [103], depopulation of the area, social fragmentation, and isolation [104,105], heightened social and economic vulnerability post-reconstruction [104], decreased spatial connectivity [106], limited community participation in recovery efforts [107,108], decreasing resilience of the community after reconstruction [107], and protracted recovery processes [31].

In addition, it is worth noting that the Italian Civil Protection's introduction of the concepts of SLC and the minimum urban system underscores the importance of moving towards implementing these concepts in real-world scenarios.

Certainly, the potential for enhancing the procedure is extensive and primarily includes the following:

- Testing more structured methods to promote stakeholder involvement, thereby addressing the definition of SUFs and the calibration of the weight factors $w$. Ongoing efforts in this direction involve the testing of fuzzy cognitive maps and other participatory approaches.
- Extending the approach beyond a single hazard perspective, which currently focuses solely on seismic risk, to encompass a multi-risk perspective [109]. This expansion aligns with the increasing need for mitigation policies, as recently explored in-depth in [110].

**Author Contributions:** Conceptualization/methodology/supervision/visualization/resources: S.C.; data curation/methodology/formal analysis: D.O.; writing—original draft preparation: S.C. and D.O.; writing—original draft preparation of Section 1 and review of the overall paper: S.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** The authors express their gratitude to the staff of Sanremo municipality that made the application presented in this paper possible, in particular Geol. Fulvio Franco (technical Responsible of this activity for the Municipality of Sanremo), Eng. Tommaso Buschiazzo, Geol. Valerio Vivaldi and Geol. Andrea Guardiani. The staff of Sanremo municipality contributes to collecting all the necessary data for the EQ-DIRECTION application and defining the buildings composing the $SLC_{MIN}$ system. The Sanremo municipality provided the financial support of this research activity. Moreover, the authors thankfully acknowledge the Liguria Region and, in particular, Geol. D. Bottero for the technical support and the contribution given to the development of the procedure, particularly related to the implications for public administrations. Note that the opinions and conclusions presented by the authors do not necessarily reflect those of the Italian Department of Civil Protection, even if the SLC general principles were established by such an institution.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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