Table 1. Parameters adopted in the Vicente methodology, vulnerability classes and associated weights.

Vulnerability Parameters		Vulnerability Class				Weight
		A	**B**	**C**	**D**	
P1	Type of resisting system	0	5	20	50	0.75
P2	Quality of the resisting system	0	5	20	50	1
P3	Conventional strength	0	5	20	50	1.5
P4	Maximum distance between walls	0	5	20	50	0.5
P5	Number of floors	0	5	20	50	1.5
P6	Location of buildings and type of foundation	0	5	20	50	0.75
P7	Aggregate position and interaction	0	5	20	50	1.5
P8	Plan configuration	0	5	20	50	0.75
P9	Height regularity	0	5	20	50	0.75
P10	Wall façade openings and alignments	0	5	20	50	0.5
P11	Horizontal diaphragms	0	5	20	50	1
P12	Roof typology	0	5	20	50	1
P13	Fragilities and conservation state	0	5	20	50	1
P14	Nonstructural elements	0	5	20	50	0.5

Table 2. Vulnerability indices for different building typologies. Reprinted with permission from [35]. Copyright 2020, Polese et al.

	Vulnerability Parameters	Vulnerability Indices				
		V^{--}	V^{-}	V^{*}	V^{+}	V^{++}
M3	Unreinforced masonry bearing walls—simple stone	0.46	0.65	0.74	0.83	1.02
M4	Unreinforced masonry bearing walls–massive stone	0.3	0.49	0.616	0.793	0.86
RC1	RC frame (without ERD)	0.3	0.49	0.644	0.8	1.02
	RC frame (moderate ERD)	0.14	0.33	0.484	0.64	0.86

If more information is available, the characterization of the vulnerability can be improved by adopting the following equation:

$$V = V^{*} + \Delta V \tag{1}$$

In Equation (1), the score modifier score ΔV considers the effect of relevance to vulnerability factors. As can be seen in Table 3, the maximum variation ΔV for masonry buildings is due to the height of the buildings (from ME to LO or HI, function of the number of storeys), the presence of vaults or the presence/absence of retrofit interventions (±0.08).

Table 3. Vulnerability modifiers. Reprinted with permission from [35]. Copyright 2020, Polese et al.

Vulnerability Parameters	Masonry	ΔV
State of preservation	Good state Bad state	−0.04 +0.04
Number of stories	LO (1, 2) ME (3, 4, 5) HI (≥6)	−0.08 0.0 +0.08
Plan irregularity	RC frame (without ERD)	+0.04
Elevation irregularity	RC frame (moderate ERD)	+0.04
Retrofit intervention	Yes No	−0.08 +0.08
Horizontal structure	Steel slabs Wood slabs Vaults	−0.06 −0.02 +0.08

2.4. Definition of Damage Scenario

Once the vulnerability index relating to individual buildings was obtained, a methodology for calculating the expected average damage was applied. The correlation between the seismic input and the expected damage is expressed in terms of vulnerability curves as a function of the assessed vulnerability, described by a closed analytical function.

It is possible to predict the expected damage to buildings for a particular level of seismic intensity from the vulnerability index (I_V) acquired for each building and, if necessary, produce vulnerability and fragility curves, which are a function of the different degrees of seismic intensity. According to [14], Equation (2) defines the relationship between the vulnerability index (I_V) and the macroseismic vulnerability (V):

$$V = 0.0068 \times I_V + 0.521 \tag{2}$$

As a result, the vulnerability is stated as mean damage (μ_D), which is described by the equation:

$$\mu_D = 2.5 + 3\tanh\left(\frac{I_{EMS-98} + 6.25V - 12.7}{Q}\right) \tag{3}$$

The seismic intensity (EMS98) is calculated as a function of the PGA through the equation:

$$I_{EMS-98} = 5 + \frac{\ln(PGA) - \ln(0.03)}{\ln(1.8)} \tag{4}$$

The macroseismic intensity I and vulnerability V affect the mean damage $\mu_{D,I}$ which also depends on the ductility parameter. Depending on the type of construction, the Q parameter, which determines the slope of the curves, can have a variety of values. Masonry structures that aren't particularly intended to exhibit ductile behavior can have a representative value of Q = 2.3.

2.5. Loss Evaluation

The risk maps integrate the damage map results to create indicators of impacts and losses based on predetermined formulas defined in [18]. Based on the agreement on methods to estimate the risk in terms of expected damage for residential buildings, the methodology employs a shared approach in the Italian scientific community operating in the seismic vulnerability and risk sector. The impact specifically lists the amount of buildings that can be used or not in the short and long term and those which have collapsed. Casualties, injuries, and economic losses are used to express losses.

Damage-risk matrices give instructions on how to convert damage levels into risk indicators. Each matrix indicates the percentage to which each level of damage adds to an impact or loss: in order to estimate losses, the research employed default percentages from the IRMA Platform [19]. The steps for risk assessment are shown in Figure 2. The percentage of damaged structures matching to the selected impact is provided by matrix 1 (Table 4). Matrices 2 and 3 provide the values to evaluate economic and human losses (Tables 5 and 6).

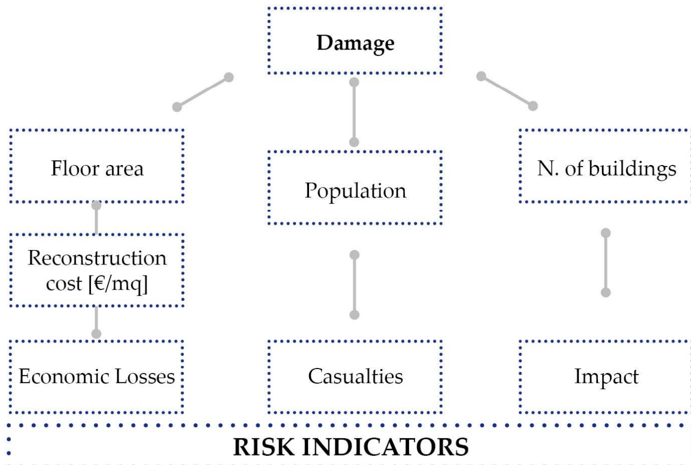

Figure 2. Framework for risk assessment.

Table 4. Matrix 1—Percentage of damaged buildings. Reprinted with permission from [19]. Copyright 2021, Borzi et al.

Damage Level	Usable (%)	Not Usable (%) (Short Time Span)	Not Usable (%) (Long Time Span)	Collapsed (%)
D1	100	0	0	0
D2	60	40	0	0
D3	0	40	60	0
D4	0	0	100	0
D5	0	0	0	100

Table 5. Matrix 2—Percentage of cost of repair or replacement. Reprinted with permission from [19]. Copyright 2020, Borzi et al.

Damage Level	Cost of Repair or Replacement (%)
D1	2
D2	10
D3	30
D4	60
D5	100

Table 6. Matrix 3—Percentage of fatalities or injuries. Reprinted with permission from [19]. Copyright 2020, Borzi et al.

Damage Level	Fatalities (%)	Injuries (%)
D1	0	0
D2	0	0
D3	0	0
D4	1	10
D5	5	30

In accordance with the formulation of [19], the values foresee, for example, that 60% of the buildings with D3 damage and all the buildings with D4 damage are to be considered unusable for a long period of time. The likelihood of injury or death to occupants is usually assessed based on the level of damage to the building. It is considered that only damage levels D4 and D5 have significant injury and fatality ratios relative to the population. The probability of occurrence of each level of harm can be multiplied to combine these partial results and create the risk map.

2.6. Resilience Scenario

The final strategy for the assessment of resilience is built through a matrix-type approach by combining the analysis data on the constructed data and those of systemic reading at a building scale for a temporal optimization of process management and preventive planning aimed at defining an order of priority of intervention.

The final strategy for the assessment of resilience takes up and re-adapts the method used by D'Amico and Currà [26], based on the so-called "tyranny of urgency", i.e., the overwhelming pressure to act quickly to the catastrophic event or to act in a preventive perspective to invest the available resources efficiently. Through a matrix-type approach, the data from the analysis of the built data and expected losses are combined with managing tangible and intangible values, for a temporal optimization of process management and preventive planning, aimed at defining an intervention priority order based not only on the intrinsic vulnerability of the artefacts but also on the potential loss of cultural heritage.

The generated matrix, called the "Matrix of Priorities", is structured on the decision-making principle underlying Covey's writings [37]. The economist configures the operational tool that takes the name of "Covey Quadrants" or "Eisenhower Matrix", starting from the assumption that "what is important is rarely urgent and what is urgent is rarely important" [37]. Therefore, the key words for understanding the model are two: "urgency" and "importance".

The analysis relating to the built environment that has an element of objectivity, based on data analysis, cartographies, and surveys, and therefore defined by the risk map, defines the element of "urgency", linked to conditions that require attention immediately and are those considered up to now with the methods applied for the definition of the damage and expected losses.

The parameters of the historic city related to the cultural heritage are instead linked to the definition of "importance", which is defined through the following categories [21]:

- historical value;
- aesthetic value;
- community value;
- economic value.

Each value category is assigned a V quality score based on the following criteria, which are derived from the National Trust of Australia [38]:

- exceptional value: the asset has characteristics of exceptional significance out of national borders (score: 20);
- considerable value: the asset has characteristics of national importance (score: 15);
- some value: the asset has characteristics of certain importance at a regional level (score: 10);
- limited value: the activity has characteristics of local relevance (score: 5);
- no value: the asset has no value (score: 0).

Therefore, the basic pre-disaster value of a specific building in the historic center I given by (5):

$$V = \sum_{i=1}^{4} V_i \quad (5)$$

where V_i is considered as the score of the i-th category of values.

The values proposed in Equation (5) have already been used in the 2011 Iorca earthquake (Spain) [21] and in two cases in two case studies in central Italy earthquake of 2016, for the city of Camerino and Vezzano [27].

The result of this elaboration, therefore, makes it possible to define the "urgency" and relative "importance" of intervention on a part of the historic center, trying to guide the preparation process in the preventive phase, or in the unfortunate case to serve as a basis for the reconstruction process in post-disaster phase.

The values thus obtained on the one hand of the damage and expected losses, and on the other hand, the basic value of the cultural assets was then normalized to a scale of 10 on the totals for each building's "urgency" and "importance" in the historic city under consideration, defining a pair of input values (x,y) for each building's priority matrix (Figure 3).

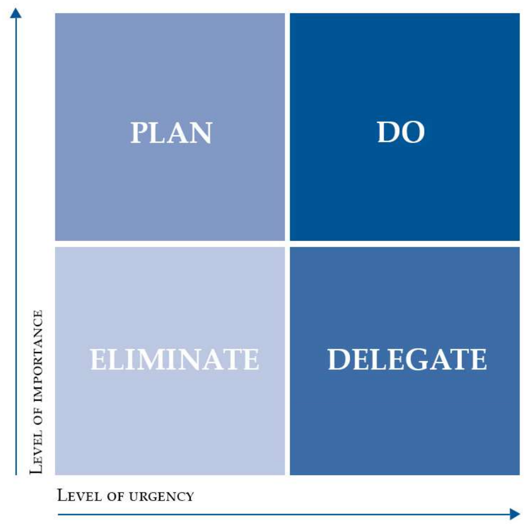

Figure 3. Eisenhower priority matrix.

3. Results

3.1. Lisbon Case Study

The presented framework is applied to the case study of Lisbon downtown, and it starts from former research started by [32]: the data present in the study carried out by Catulo et al. have been updated to 2022 and have been implemented by collecting information also on the other areas of the historic center.

The district has been regulated by a detailed heritage protection plan since 2011 (Plano de Pormenor de Salvaguarda da Baixa Pombalina—PPSBP). The data used in this study included:

- building footprints and street network provided by Lisbon Municipality (Shapefile). All the data were relative to the coordinate system Hayford-Gauss, datum 73;
- Plano de Pormenor de Salvaguarda da Baixa Pombalina—PPSBP)—Heritage protection plan;
- orthophoto maps from Google maps;
- building information retrieved from Lisbon Municipal Council archives, which regards geometrical properties, type of building, year of construction, retrofit interventions, and structural typology [39];
- all the data obtained has been verified and updated by on-site inspections: Lisbon downtown is quickly changing, and many building sites were ongoing during the surveys. From those analyses, from 2017 to 2022 at least four buildings have been rebuilt in reinforced concrete (RC). Therefore, the records of these recent transformations are still not completely available; for this reason, on-site surveys were necessary to have a complete dataset.

3.2. Location

The area of Lisbon downtown studied in this paper includes the Baixa area, or the lower part of the city, the districts of Bairro Alto and Chiado to the west and Alfama to the east (Figure 4).

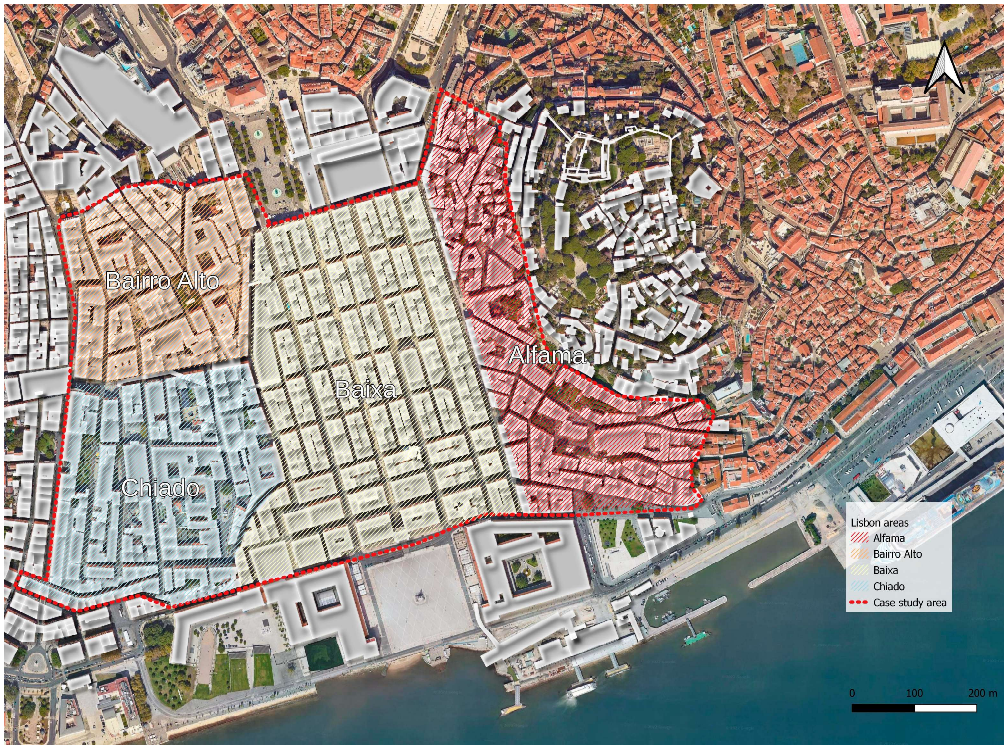

Figure 4. Case study area.

The part of the Baixa was completely rebuilt after the earthquake of 1755 [40] and is composed of buildings that include commercial activities on the ground floor and residential functions on the upper floors. In some cases, the historic family businesses and the interiors of the first shops are still preserved.

Although the residential component is decreasing, the city continues to be a center of culture and commerce. Chiado is one of the most traditional and characteristic neighborhoods of the city of Lisbon, and it is located between the Bairro Alto and the Baixa. On 25 August 1988, a fire that began in Rua do Carmo and quickly spread to Rua Garrett destroyed a total of 18 buildings in Chiado. In terms of the area of the city damaged and the number of buildings destroyed, the Chiado fire is considered the worst disaster that has hit the city since the 1755 earthquake.

Alfama is the oldest district of Lisbon and extends on the slope enclosed between the Castle of São Jorge and the Tagus River. Its name comes from the Arabic Al-hamma, which means “fountains” or “baths”.

3.3. Historical Evolution

The Portuguese building heritage, especially in Lisbon, has undergone great transformations over the centuries up to the present day.

Based on the observation of the available cartography and iconography (Figure 5) regarding Lisbon before the earthquake of 1755, the urban structure of the central part of the city has remained unchanged since the 16th century.