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

Figure 5. Current cartography of the Baixa of Lisbon with the dating of the individual buildings (**a**); historical cartography of the post-earthquake reconstruction of 1755 (**b**).

The urban fabric corresponds to a set of different juxtaposed structures: the area that rises on the eastern and western slopes of the Colina do Castelo has characteristics that can bring it closer to those observed in the Moorish cities. For this reason, they appear as simple organisms and little differentiated on a functional level, with a very dense and irregular fabric. Being a city without continuity, in which the private space crosses the public space, the churches are seen as central and neuralgic points that generate the surrounding space.

The westernmost part of the historic city (Carmo and Chiado), on the other hand, has a regular urban structure. This change perhaps coincides with the genesis of a more organized municipal authority interested in the control and growth of the urban layout of the city.

With the earthquake of 1 November 1755, most of the existing buildings in Lisbon were destroyed or severely damaged. At the time of the earthquake, Lisbon had a population of around 100,000 and an area of 350 hectares. After the earthquake, about 17,000 of the existing 20,000 houses were destroyed or made uninhabitable, as well as palaces, convents and churches, many of which were demolished and later rebuilt in other places due to the Baixa reconstruction plan. The new urban fabric planning was one of the strategies implemented by the then prime minister, the Marquis of Pombal.

3.4. Typological Analysis

To establish a clear and concise evolution of building typologies, it can be said that masonry buildings constitute an important percentage of the building heritage of the city. Given the evolution over time of construction practices in masonry buildings, it is possible to detect variations in terms of architecture and construction types and structural design [41]. These differences determine significant variations in the seismic resistance of the different building types identified. Among the types of masonry buildings built after 1755, three phases can be distinguished: "Pombalino", "Gaioleiro" and "Placa" buildings. The differentiation between the building types mentioned is based not only on the time of construction but essentially on the presence or less of wooden structural elements [42]. It is, therefore, possible to establish a subdivision in terms of building types based on their structural characteristics directly related to the time of construction and the construction technologies used (Figure 6).

Figure 6. Construction typology of the buildings under study.

- Buildings with "Pre-Pombalina" type masonry structure (before 1775)

Buildings that have withstood the great earthquake of 1755 in whole or in part and have been preserved over time to this day are considered an integral part of this category. This category includes buildings of historical interest, although many are in poor condition. This type of building consisted of two, three or at most four floors, generally with very low ceilings, a high density of walls and few openings to the outside. The floors of ground floors were generally made of limestone slabs. As for the floors of the upper floors, the use of wooden floors was more common. The vertical structures could be of three types: regular stone masonry (*cantaria*), ordinary masonry (*alvenaria*) or partitions (*tabique*). The differentiation is based on the type of material used in its construction and the related construction process.

- "Pombalino" Buildings—masonry structure type (1775–1880)

The pombaline plan is characterized by coherence, homogeneity and balance based on a layout of the road axes with a reticulated and regular structure and in the uniformity of the buildings designed, both in terms of elevations and in terms of internal subdivision [43].

The Gaiola (Cage) is made up of a set of timber frames with masonry infill, called "frontais", connected at the corners by vertical bars that belong to the orthogonal walls. The connection between the orthogonal front walls through common vertical wooden bars and the timber floors forms a three-dimensional structure capable of resisting forces in any direction. In general, the space between the wooden bars of the front walls is filled with poor quality masonry and the surfaces are covered with finishing material, so the *gaiola* is generally not visible. Usually, the gaiola develops above the ground floor and in the internal walls.

The facades and walls between adjacent buildings are generally built with ordinary stone masonry, with some exceptions of better-quality masonry at the angles and in some columns and walls of the ground floor.

- "Gaioleiro" Buildings—masonry structure type (from 1880 to 1930)

The period between 1880 and 1930 was fundamentally characterized by a great expansion of the city, both for the creation of large urban areas, and for the increase in the height of the buildings: the name "Gaioleiro", is intended to translate the simplification and the enormous changes in terms of structural and constructive systems on the Pombalino buildings, which included the increase in the height of the buildings which quickly reached five or six floors, accompanied by the distortion of the original cage, in which some elements of solidarity have simply disappeared of the "frontais" walls. The observed changes have given rise to another type of building characterized by the absence of structural and three-dimensional continuity.

- "Placa" Buildings—mixed masonry-reinforced concrete type (since 1930)

Around 1930, concrete appeared, used in full attics, progressively replacing wooden floors in kitchens and bathrooms, and protruding elements such as balconies up to the entire attics (Placa).

Reinforced concrete beams begin to be used during this transition period at the ground floor ceiling level, mainly in situations where shops are installed or to facilitate the opening of larger spaces.

The so-called integral reinforced concrete structures only appeared between the 1930s and 1940s, but it was only in 1950 that they began to have a great expression.

3.5. Seismic Hazard

Identifying the seismic impact of the most significant earthquakes that occurred in Portugal was considered essential in the development of the research. As for the number of earthquakes recorded in Portugal, most of the events occurred in the 18th and 19th centuries.

From an interpretation of the national historical record, the Lisbon earthquake of 1755, the Benavente earthquake of 1909, the Algarve earthquake of 1969 and the Azores earthquake of the 1980s, despite their different circumstances, are considered the most relevant events, which are supported by the quantity the available documentation. The year 1909 stands out with great evidence, but equally significant values are recorded in the years 1983 and 1984, respectively, with 115 and 143 earthquakes, and in 1975 (116 events). In 1969, 75 earthquakes were recorded; in 1978, there were 71 tremors. In 1931, 1951, 1954, 1964 and 1969 earthquakes were recorded with a maximum intensity level higher than 7. The Benavente earthquake, despite its dramatic consequences, recorded a much lower intensity (6.2).

When dealing with the consequences, the information that mentions these phenomena focuses mainly on the recorded human victims. The exception is the earthquake of 1755 [44]. Following the disaster, all Portuguese parishes had to send the prime minister a written report of all the damage.

The Lisbon region and the Algarve region are located in the area with the highest seismic risk on the Portuguese continent; noteworthy are the regions of Tagus Lezíria and the Setúbal peninsula, located in the "Lower Tagus Valley Fault", which also have a high seismic vulnerability. In addition, the coastal region of Alentejo has a medium-high impact index, along with a significant frequency of seismic events (Figure 7).

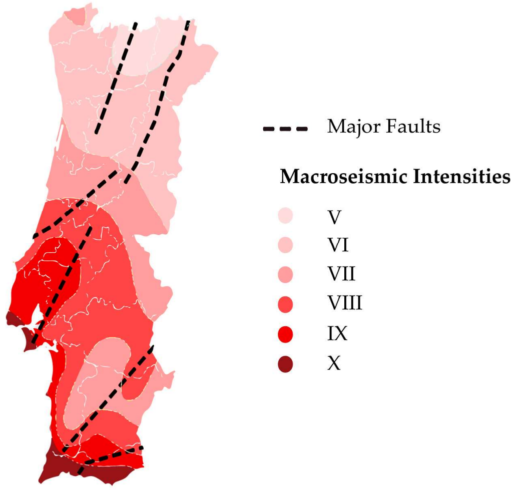

Figure 7. Map of macroseismic intensities and major faults in Portugal. Adapted from [45].

3.6. Exposure

The elements that characterize the Lisbon exposure have been catalogued according to the methodology described. In general, existing studies have been used [46,47] and the data collected from Lisbon municipality and from on-site surveys necessary to verify, update and gather all the information needed for the GIS platform.

The collected data are:

- data on listed heritage and/or historical-artistic interest;
- archaeological sites;
- museums;
- average floor area;
- the number of stories (Figure 8);
- exposure to the building heritage of the Baixa Pombalina [46];
- the state of conservation (Figure 9).

Figure 8. Number of floors for buildings in the historic center of Lisbon (adapted from Camara Municipal de Lisboa).

Figure 9. State of conservation of the buildings in the historic center of Lisbon (Camara Municipal de Lisboa, revised through on-site surveys in 2022 by the authors).

The data obtained were then used for the application of the framework.

3.7. Vulnerability Assessment for the Historic Center of Lisbon

From all the information obtained from the research data implemented above, it was possible to obtain all the information necessary to assess the seismic vulnerability of the buildings in the historic center of Lisbon. Two simplified assessments were performed: the first takes up the study done by Catulo [32] on the *Baixa* area, which is based on the Vicente method (2011) based on vulnerability index (VI). Figure 10 shows the mapping of the vulnerability index VI obtained.

Figure 10. Vulnerability index calculated according to the Vicente method (2011).

The second method applied for the definition of vulnerability V is the one proposed by Polese et al. [35] (Figure 11), which adapted the method applied by Lagomarsino and Giovinazzi [8] based on the damage probability matrix (DPM). This method needs less data than the previous one.

Figure 11. Vulnerability calculated based on the Polese et al. method (2011).

These two different methods were applied for the definition of the vulnerability to verify, which is the most reliable and therefore choosing one for the development of the risk map and the resilience matrix.

From the results obtained from the two vulnerability maps and comparing them with the constructive information collected, it can be seen that the method experimented by Polese et al. is much more severe; however, it does not always reflect the vulnerability that one would expect from a specific construction typology and past vulnerability studies, while the method developed by Vicente et al. turns out to be more consistent. For this reason, the vulnerability index experienced by the latter was used for subsequent analysis.

3.8. Definition of Damage Scenarios

The expected damage for buildings given a level of seismic intensity can therefore be calculated from the vulnerability index (VI) and vulnerability (V) obtained for each building. If desired, vulnerability and fragility curves that depend on the various levels of seismic intensity can also be generated.

The mean damage based on the Vicente method (VI) is shown in Figure 12.

The mean expected damage calculated based on the Polese et al. method is also reported (Figure 13).