Resilience assessment of collective use buildings against natural and anthropological risks

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Abstract: Threatened by the global paradigm of climate change, infrastructures are rendered increasingly vulnerable by the frequency and intensity of natural phenomena. By 2050, it is projected that two thirds of the population will be established in urban areas, exacerbating their vulnerability.

The resilience of built assets has increasingly attracted the interest of various stakeholders, including engineering professionals from different areas, scientists, standardisation bodies, investors and financial institutions, regulatory agencies, different user groups, as well as national and regional administrative services. This growing attention has motivated the development of methods for classifying the resilience of built assets, to identify vulnerabilities and establish investment priorities, to increase their resilience when facing extreme events or other risks.

The present work builds on a previously developed system composed of dimensions, indicators and parameters that encompass the building envelope, as well as the building's exposure to natural and anthropologic related disasters, and its relationship with the community and its users. The outcomes of this development are the creation of more than 20 new parameters, 2 new indicators, and reformulation of existing evaluation criteria.

The assets analysed in this study are categorised as collective use. The sample is composed of 55 schools located in and owned by the Lisbon Municipality, dispersed throughout 24 of the 25 parishes. The results of the classification are analysed using SPSS software recurring to Pearson bivariate correlations, clustering, and regression techniques.

As is, the system poses as a great tool to identify vulnerabilities of assets, but not to propose solutions.

Keywords: Resilience; urban resilience; built assets; asset management; sustainability; disaster risk reduction.

1. Introduction

The undeniable rate of climate change is shown in a significant rise in the frequency and intensity of natural catastrophes, increasing the vulnerability of metropolitan areas by creating significant economic, physical, and social changes, culminating in enormous waves of human displacement. Due to rapid urbanisation, natural catastrophes, or armed conflict, these huge population shifts have notably damaging consequences, not only for infrastructure, but also for the urban environment, the labour market, and community cohesiveness. In order to avoid lengthy economic crises and social division, which result in the formation of vast and poorly structured metropolitan regions, it is increasingly vital to integrate the notion of urbanisation in the concept of sustainable development (UN Habitat, 2017; Satterthwaite, 2018).

The term resilience, which originated in the field of ecology, has been applied to literature within a broad range of sectors, but at its foundation, the academic consensus is that it symbolises a system's ability to resist a shock while staying functioning, changing to absorb that unexpected change (Davoudi et al., 2012a; Davoudi et al., 2012b). Uncertainty experienced nowadays, intensified by factors such as: i) extreme natural events, whose frequency is increasing due to climate change; ii) terrorist threats; iii) economic crises; iv) globalisation and the growing population density in urban centres; translate into risk factors that highlight the growing importance of the resilience issue (ISO/TR 22845:2020).

This dissertation focuses on the theme of resilience of the built environment as a philosophy of risk management in a disaster situation, focusing on the risks exacerbated by climate change and its impact on the intensity and frequency of catastrophic weather events, as well as anthropic risks associated with population growth and urban centres. In this sense, it aims to identify the degree to which the built environment is exposed to risks with the goal of mitigating them, keeping in mind that total eradication is unattainable.

The work developed is based on the resilience classification system proposed and developed in previous research (Duarte, 2021) and the international technical report ISO/TR 22845 (ISO 22845, 2020) that addresses the resilience of buildings and civil engineering works.

2. Natural and anthropological risks

According to the United Nations' Office for Disaster Risk Reduction (UNDRR), the term disaster can be defined as "*a serious disruption of the functioning of a community or society causing widespread human, material, economic or environmental losses that exceed the ability of that society or community to respond by its own means*." (UNDRR, 2021a). The entity similarly describes hazard as "*a potentially dangerous physical event, phenomenon, or human activity that has the possibility of causing loss of life or injury, property damage, social or economic disruption, or environmental degradation*." (UNDRR, 2021b). Disasters and hazards have a certain probability of occurring in a specific period, in a certain area, and at a certain intensity.

Built assets are subject to risks that expose their vulnerabilities. To reduce them, it is crucial to understand these risks. Natural hazards are, according to Hishan *et al.* (2021), "*geographic events that occur regularly at small scales* *throughout the world. If these result in disruptions to the functioning of a community or society involving widespread human, economic, material, or environmental losses or impacts that exceed their capacity to respond, it is called a disaster”*.

The higher the risk of the hazard, the greater the vulnerability to it, and thus the greater the chances of its potential occurrence (El-Atrash et al., 2008). To assess this risk, the same author stated that human preparedness is inversely proportional to human vulnerability to withstand such events (Ibid). Risk management should be conducted in advance to prevent disasters by applying mitigation and risk reduction measures, and by conducting (or synonym) residual risk management in order to decrease the losses caused in the event of a disaster. Depending on the risks, there are various strategic approaches to implement in order to reduce those that may prove disasterous (Satterthwaite, 2018).

2.1. Climate induced risks

The continuous degradation of climate has a very significant impact on natural hazards and, as such, it is possible to observe an increase in the frequency of associated phenomena. Extreme temperatures, droughts, extreme precipitation, floods, and storms are increasingly disaster risk factors (Seidler et al., 2018).

The deterioration of the environment can be pointed out as the factor that most contributes to the increase of the vulnerability of built assets. It is only possible to stop this trend through the implementation of measures that allow for the adaptation and mitigation of the harmful effects of climate variations (Dalezios, 2017).

Currently, the object of study of the scientific community, that is dedicated to the topic in question in this chapter, is the relationship between extreme weather phenomena with climate change, analysing their impacts in order to outline strategies for managing the associated risks. In this view, it is necessary to "*experiment with adopting a holistic and integrated approach using common methodologies such as risk analysis, which involves risk management and risk assessment"* (Dalezios, 2017).

The aforementioned approach allows for a more effective management of potential hazards by not only focusing on avoiding them, but also understanding that there are hazards that pose as inevitable. Several localised natural hazards are identified, such as: (i) cyclones; (ii) floods; (iii) earthquakes; (iv) landslides; (v) tsunamis (Dalezios, 2017). Only a correct risk assessment allows for the elaboration of the most suitable mechanisms and strategies for each situation, with the aim of achieving a reduction of vulnerability. The risk assessment framework of action can be divided into 3 components: (i) identification; (ii) estimation; (iii) assessment. As stated by Bosher (2014), *"this process should be carried out at a multidisciplinary level in order to tailor potential disaster reduction measures with regard to their compatibility with the context in which they are applied. In particular, the importance of knowing what is useful, and what is critical, to support the resilience of individuals, communities, and institutions. This perspective specifically highlights the importance of local solutions generated by local actors proactively addressing local problems”.*

The causes of climate-induced disasters are generally associated with slow processes that have an enormous influence on climate change such as: i) the degradation of forests; ii) acidification of water bodies; iii) decrease in biodiversity; iv) rise in water level; v) rise in global temperature; vi) degradation of the ozone layer. The impacts caused by these processes and phenomena in the urban environment, are aggravated by i) temporary, rapid, and informal industrialisations; ii) settlements with insufficient structural solutions and poor planning that contribute to an increased susceptibility to the impacts of climate change leading to hydrometeorological and geological threats (Iwama, I et al., 2021; Landsberg, 1970; Satterthwaite, 2009)

When compared to inherent natural hazards, we can state that human interventions regarding overexploitation of resources, poor land management, and insufficient technology are the causes behind crises in the agricultural, health, and water sectors. At times the risk of disasters have been aggravated by the need to respond to social risks such as poverty. Thus, by not considering the first risk (disasters), the result is a consequent aggravation of the second (social risks) in the long run (Yodmani, 2001; Wisner, 2004).

In this view, it becomes vital to have a wide concept and understanding of the conditions at risk in order to conduct coherent risk management. The most difficult problem this approach to management provides is the capacity to predict future hazards in order to lessen likelihood, allowing it to be associated with the notion of sustainable development (Hishan et al. 2021).

2.2. Seismic induced risks

Since the 1990s there has been a greater concern about disaster risk reduction. In 1999 the United Nations declared that period as the International Decade for Disaster Risk Reduction (IDNDR). Multiple projects were created that remain highly relevant today. One of them was the Global Seismic Hazard Assessment Program (Giardini, 1999). It was created as the first appropriate map to equate seismic risk as well as the first to incorporate numerous national and regional models to create the first global hazard map of peak ground acceleration for a 475-year return time in rock (Silva et al., 2020).

Earthquakes are the most unpredictable natural phenomena, which, when combined with their destructive capability, result in a very high catastrophe risk. The unrestricted rise of the world population has resulted in a surge of "megacities," which are frequently located in areas prone to natural catastrophes, notably earthquakes, which increases their vulnerability (Silva, 2013).

The rise in human casualties and asset devastation caused by seismic events reflects a negative paradigm. The severity of the problem is exacerbated by the fact that the primary cause of mortality related to such events is the incapacity to evacuate, emphasising the importance of developing building technology and seismic strengthening, as well as developing satisfaction thresholds (Zhou et al., 2020).

In order to standardise the seismic valences of structures, Eurocode 8 (EC8) was developed by the technical committee CEN/TC 250 aiming at structural Eurocodes. This European standard serves as a guideline for the quantification of seismic action and the creation of national standards that promote the seismic safety of buildings, ensuring that structures meet minimum safety requirements. Since its emergence in 2004, the EC8 has been subject to continuous development, in order to strengthen the seismic safety thresholds of structures (Carvalho, 2008; Romãozinho, 2008).

2.3. Human induced risks

Besides the risks that have natural origins, the risks caused by Mankind should also be considered. In the last two decades there has been a tenfold global increase in: i) terrorist attacks; ii) incidents involving kidnapping and murder; iii) attacks on facilities or infrastructures. Recognising the gravity of this paradigm, some countries are developing studies that intend to incorporate counterterrorist engineering in the design phase of infrastructures in order to reduce the impacts inherent to this type of incidents, through planning (ISO/TR 22370:2020).

Urbanisation is also a challenge to the resilience of urban areas and buildings. In 2007, 50% of the world's population was found to reside in urban areas. What is more, projections for population density growth indicate that by 2050, the world's population will be close to 10 billion and about 70% will reside in urban areas (Field et al., 2017).

In addition, it is projected by the Intergovernmental Panel on Climate Action that between 2000 and 2030 there will be an increase of 1.2 million square kilometres in the area occupied by urban areas. This expansion implies a very significant loss of green infrastructure for climate change adaptation. The projected scale of urban areas thus poses a challenge to vulnerability, especially due to the fact that they are the main front in combating climate change (UN Habitat, 2018b; ISO 22370:2020).

3. Resilience of collective use assets

The assets that express the greatest relevance to this study are the assets of collective use (EUC). In this view, all case studies analysed ahead can be inserted in this category. EUC is to be understood as any building or group of buildings and their associated unbuilt spaces (e.g., green spaces), which have commercial, service provision, hotel, educational, social, sports, cultural, health or other purposes, and are intended for collective use by people.

According to CARE (2014), assets are an essential part of disaster response, meaning adaptive capacity is distinguished by its reactive nature for survival, and adaptation requires a long-term vision that involves planning (Archer et al., 2020). The assets that identify with this typology have a high importance in society, and their purpose is to serve the community in various areas. The community dimension of these assets gives them a role that can be crucial in disaster and risk awareness. The latter can be achieved by incorporating strategies to disseminate information about disaster risks, making it easier for a large percentage of the population to access it. Moreover, the size of some of these buildings affects their ability to provide support in a disaster situation, either by providing housing or emergency services.

Thus, we can understand that an EUC managed with awareness of disaster risks allows for a decrease in vulnerabilities, resulting in an increase in resilience, mitigating possible adverse consequences. In parallel, the resilience of these buildings takes on a very high importance, so they can be considered as vital assets for the functioning and sustainability of society, especially in a disaster situation (Magis, 2010).

The concept of resilience is not new, having already been studied and applied to several areas, such as human psychology, ecology, and disaster risk management. Within the scientific community, the term resilience was first used in the first half of the 17th century. However, its origin is derived from the Latin term "Resilio" - whose meaning corresponds to "jump" or "bounce back", and the prefix "Re-" which translates as "again" and "Salire" which corresponds to "jump" in modern English. One of the first iterations of the term appeared in the field of materials physics. It was related to the theory of elasticity to represent the amount of energy stored in an elastically deformed body. In 1856, the famous physicist William J. M. Rankine applied the concept to describe the stiffness and ductility behaviour of steel beams (Alexander, 2013).

The idea of resilience has naturally expanded its scope of applicability as it has evolved through time. Its relevance to the built environment is significant. A resilient built environment must be designed, located, built, operated, and managed to maximise the ability of the built assets, associated support structures (physical and institutional), and those who frequent or inhabit it to withstand, recover from, and mitigate the effects of extreme human or natural hazards (Bosher, 2008). As a response, the study must go beyond the technical capabilities of the structure itself, taking into account a wide range of variables that impact it as thoroughly as the concept (Hynes et al., 2013).

Urban resilience is the ability of individuals, communities, institutions, businesses, and systems that make up the city to survive, adapt, and grow regardless of the chronic stresses and acute shocks they may experience. The UNDRR defines resilience in this context as the ability to absorb, adapt, transform, and recover from the effects of hazards quickly and effectively (The Rockefeller Foundation, 2015). In this sense, it is of the utmost relevance to keep the concept in mind in urban planning, in order to face this new paradigm, promoting a management that allows reducing disaster risks.

In light of this paradigm, multiple initiatives have been developed and idealised in name of resilience. This study focuses on several projects developed in an international context, as well as in Portugal, namely Nature-based Solutions for urban resilience (NbS).

4. Revision and expansion of SCRP

The work developed by Duarte (2021), allowed for the creation of a first iteration of a tool that may acquire a very significant importance at the national level. It allows for the standardisation of the classification of resilience of built assets, thus contributing, through satisfaction levels for the various parameters assessed, to the promotion of resilience. In order to characterise the assets in a complete way, the model is subdivided into 5 general themes, dimensions, which are subdivided into subthemes, indicators. Each of these corresponds to a number of parameters that are assessed through evaluation criteria. The resulting classification makes it possible to understand in detail the areas that need intervention in order to improve resilience, as well as those in which the asset performs better.

The Portuguese Resilience Rating System (SCRP) is organised into five main dimensions that define the concerns regarding the resilience of a building against natural disasters, namely environmental (D1), economic (D2), organisational (D3), social (D4), and technical (D5). Each of these divisions resulted from a research based on three reasons: the essential pillars for sustainable development defined by Agenda XXI; the literature review of the dimensions defined by Bruneau et al. (2003); and the dimensions present in the bibliographical references.

Understanding the significance of the political and legislative components in the major issue of this study, and academic research in the field of international relations that link specific political currents to tactics for generating resilience (Badarin, 2020). The creation of a new dimension that encompasses the factors related to governance was analysed. In parallel, the study of strategic decision analysis models such as the case of PESTEL (Issa et al., 2014) used in a business management context in which, in addition to the 5 dimensions already present in the SCRP, legal and political dimensions also appear, also contributed to this consideration. Likewise, the Global Risks Report 2022 conducted by the World Economic Forum (2022) includes a dimension alluding to the governance theme, which in this case appears as a geopolitical dimension. The impossibility of quantifying many of the issues studied presented itself as a difficulty in their integration into the system developed. The holistic approach of the system requires that its application can be made to assets in which the support and decisions of State organisations have less expression, without implications for their resilient capacities. Furthermore, the local character of some assets makes them independent from international and geopolitical relations. In this sense, governance parameters were included in the Organisational dimension (D3), instead of creating a new dimension, but recognising the relevance of the topic.

The proposal for expansion comprises more than 20 new parameters and 2 new indicators, as easily identifiable in green on **Table 1**, as well as expansion of parameters – adding one or two evaluation criteria, noted with (*) and (**), respectively – complete reformulation of the evaluation criteria or reformulation of the designation, marked with (1) and (2), respectively.

5. Implementation of the expanded system and statistical analysis

The studied objects are school buildings, including kindergartens and primary schools, owned by the municipality of Lisbon, and managed by the Camara Municipal de Lisboa (CML). The sample is made up of 55 schools in total. With the exception of the parish of Parque das Naçes, each of the remaining 24 parishes in the municipality has at least one EUC, resulting in a decent representation of the municipality. The study is based on the LNEC (2019) evaluation report on the state of conservation of schools in the municipality of Lisbon, and interaction with CML specialists responsible for their administration.

Only one school in the sample received an A+, whilst the others received an A, b ased on the comparability of the objects of study's total resilience ratings. The classifications generated from the examination of the school buildings in the sample showing asymmetries in D1 (Environmental) and D5 (Technical). The remaining aspects' scores show a uniformity that may be explained by the fact that they are all controlled and owned by the same entity, as well as their relatively close geographical proximity.

The SPSS analytic programme was used to conduct statistical analysis on the collected findings. Bivariate correlation analysis, cluster classifications, automated linear modelling, and linear regressions were used to get appropriate results. The analysis of Pearson correlation results allows us to understand the correlation between the variables, allowing us to identify positive variations that indicate an increasing correlation and negative variations that express a decreasing correlation in terms of resilience, based on the data obtained.

In terms of parameters the most significant correlations are shown between parameters P23 (Vegetation density) and P14 (Moveable objects), which is congruent with the fact that areas with higher vegetation density are less populated, so there is less presence of moveable objects such as cars, boats, or debris. The most distinguishable positive correlation identifies a direct or perfect correlation (equal to 1) between the number of floors (P89) referring to the safety of the building against flooding and the accessibility characteristics of the street (P67). Thus, it seems congruent to state that taller buildings house in theory more people and, for this reason, the density of inhabitants or users per unit area will be higher, which implies the need for more accessible streets, which provides in parallel greater safety against flooding.

As far as indicators are concerned, we can see that vulnerability to flooding (I3) has a parallel variation to vulnerability to tsunamis and tidal surge (I2), resulting from the fact that in coastal areas flood risk can be amplified by the occurrence of tsunamis and the tidal surge itself. The indicator that evaluates vulnerability to fire risk (I4) shows a negative correlation with accessibility (I13), which allows us to extrapolate that, of all the buildings analysed, those with the lowest fire risk are located in areas with more difficult access.

The automatic modulation enables us to understand that indicator I4 (Fire) allows to calculate the total score of the rating (T) with a probability of 24.7%, followed by I2 (Tsunami and tidal effect) with a probability of 15.1%, I14 (Seismic safety of the building) has an importance of 10. 4%, Accessibility (I13) has an importance of 9.5%, indicator I1 (Earthquake) corresponds to an importance of 8.3%, lastly the importance of I16 (Flood safety of building) and I5 (Landslide) is identical and translates into 6.9%.

The vulnerability of each asset was directly compared to the resilience capacities of said asset against that specific hazard, the sensitivity analysis performed as shown on Figure 1, Figure 2, Figure 3 e Figure 4. It provides for a thorough comprehension of critical situations. The other risks (Fire and Landslide) not contemplated in the figures didn't provide information about any critical situation. In that regard, four schools stood out as requiring quick intervention. In terms of seismic dangers, Esc 39 is in critical condition. It also demonstrates unsatisfactory flood and tsunami resilience. Esc24 would benefit substantially from budget allocation to improve its resilience to floods and tsunami hazards. Finally, schools Esc19 and Esc32 are in a poor conservation status and would require renovation actions. In contrast, it revealed that no structures were particularly vulnerable to fire.

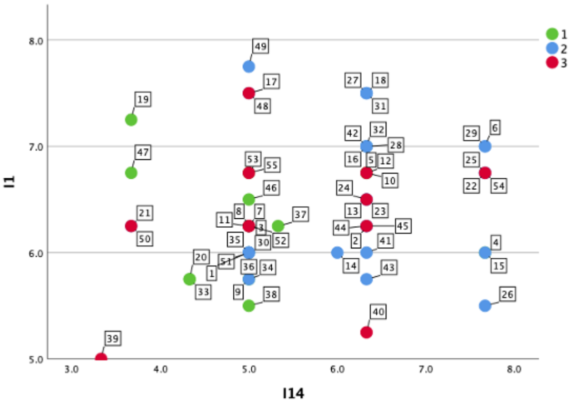

Figure 1 - Results of the classification of the indicators related to seismic vulnerability (I1) and safety (I14).

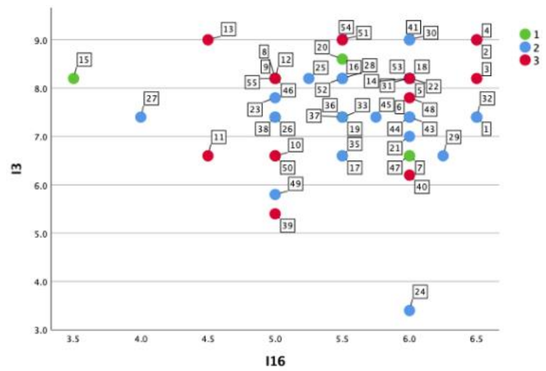

Figure 2 - Results of the classification of the indicators related to flooding vulnerability (I3) and safety (16).

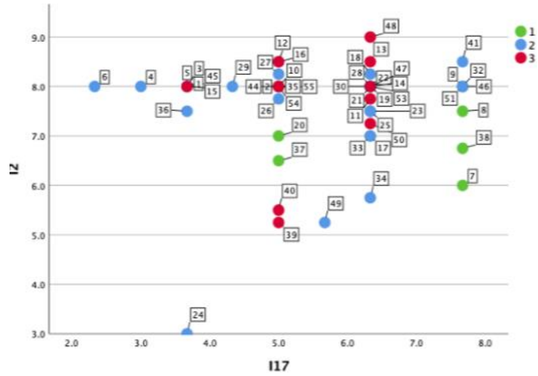

Figure 3 - Results of the classification of the indicators related to tsunami vulnerability (I2)and safety (I17).

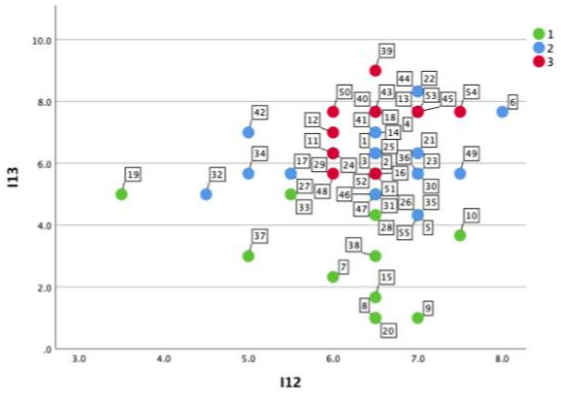

Figure 4 - Results of the classification of the indicators related Acescsibility (I13) and Conservation state (I12).

6. Conclusion

This research allowed for the construction and validation of the current system, as well as contributions to the growth of the concern with the establishment of initiatives to increase urban resilience and therefore the built assets, particularly in the face of natural disasters.

At this point, we may state that the system is a highly useful instrument for promoting asset resilience in the face of natural catastrophe events, allowing inadequacies to be identified. As a result, as of now, it is not feasible to provide instructions for solution implementation; only further development will allow such a feature.

Table 1- Expanded resilience system

D1 ENVIRONMENTAL
I1 Earthquake
P1 – Seismic zoning - type 1 EC8
P2 – Seismic zoning - type 2 EC8
P3 – Seismic of soils PDM
P4 – Slope (1,2)
P5 – Soil type EC8 (1)
P6 – Distance to cliffs
P7 – Distance to faults
P8 – Population density
I2 Tsunami e tidal effect
P9 – Altitude
P10 – Distance to shore
P11 – Distance to the river
P12 – Natural barriers in the surroundings
P13 – Man made barriers in the surroundings
P14 – Movable objects
P15 – Rows built between the shore and the building
P16 – Susceptibility to direct tidal effect PDM
I3 Flooding
P17 – Relative location
P18 – Distance to the river
P19 – Natural barriers in the surroundings
P20 – Man made barriers in the surroundings
P21 – Flooding vulnerability PDM
I4 Fire
P22 – Distance to vegetation
P23 – Vegetation density
P24 – Maintenance status of the vegetation
P25 – Type of vegetation
P26 – Adjacent buildings
P27 – Proximity to industrial area
I5 Landslides
P28 – Slope (1,2)
P29 – Precipitation
P30 – Ground water level
P31 – Susceptibility to the occurrence of landslides PDM
P32 – Soil permeability
D2 FINANCIAL AND ECONOMIC
I6 Insurance
P33 – Insurance against natural disasters
I7 Strategic and financial implications
P34 – Financial plan
P35 – Economic evaluation of inactivity
P36 – Disaster funds
P37 – Access to external/internal credit
P38 – Access to bons
D3 ORGANISATIONAL
I8 Internal organisation
P39 – Continuity plan
P40 – Risk analysis a management
P41 – Post disaster recovery plan
P42 – Routine
P43 – Simulacrum
P44 – Learning and actualisation
P45 – Destructive event data
P46 – Responsible person
I9 External organisation
P47 – Conformity with current legislation
P48 – External norms of resilient construction
P49 – Responsible entity
P50 – Relationship between community and stakeholders
P51 - Monitorisation

D4 SOCIAL
I10 Emergency infrastructure
P52 – Access to police stations
P53 – Access to fire departments
P54 - Accesso to shelters
P55 – Access to medical infrastructure
I11 Social responsibility
P56 – Occupants
P57 – Dissemination of information
P58 – Social vulnerability
P59 – Existence of mutual help programs between neighbours
P60 – Number of social defence organizations
D5 TECHNICAL
I12 Conservation
P61 – Year of construction (1)
P62 – Structural system (**)
P63 – Conservation status
P64 – Record of maintenance, failures, and improvements
I13 Accessibility
P65 – Building density (1)
P66 – Alternative routes (*)
P67 – Street characteristics
I14 Seismic safety of the building
P68 – Floorplan irregularities
P69 – Height irregularities
P70 – Interaction with adjacent buildings
P71 – Uneven slabs
P72 – Soft storeys
P73 – Dilation joints
I15 Fire safety of the building
P74 – Conservation state of the electrical installations (2)
P75 – Gas installations
P76 – Overlapping spans
P77 – Firebreaks (*2)
P78 – Fire detection and alarm system (*)
P79 – Emergency lights and signalling (2)
P80 – Safety team (2)
P81 – Escape routes
P82 – Smoke control system (*2)
P83 – Intrinsic combat equipment (*2)
P84 – Extinguishers (**2)
P85 – Fire hydrants (2)
I16 Building safety against flooding
P86 – Existence of barriers (2)
P87 – Pumping systems against flooding (*2)
P88 – Façade vulnerability (2)
P89 – Number of floors
P90 – Street characteristics
P91 – Underground floors vulnerability
P92 – Impermeabilization solutions
P93 – Wastewater systems
I17 Building safety against tsunami
P94 – Number of floors
P95 – Orientation
P96 – Ground floor hydrodynamics (*)
I18 Building safety against landslides
P97 – Slope stability

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