Pre-diagnosis Protocol for Large Residential Building Stock. The Case of Barcelona's Vulnerable Areas

C. Cornadó, S. Vima-Grau, and P. Garcia-Almirall

Abstract The large-scale evaluation of buildings is an important tool to guarantee that our cities are in good condition. This chapter presents the experience of a pre-diagnosis protocol applied to the most socially vulnerable neighborhoods in Barcelona. The protocol was specifically designed for this purpose and proposes a methodology in several elimination phases, in which attention is gradually focused on buildings that may be damaged and could lead to risk situations. The protocol was used to evaluate buildings in 16 neighborhoods of Barcelona. The original characteristics of the buildings varied widely, but all of them had suffered from a lack of building maintenance over decades. The results provide extensive information about the constructed reality of these neighborhoods and general and specific knowledge about the state of conservation of the buildings and their actual damage.

Keywords Refurbishment · Building assessment · Housing refurbishment · Pre-diagnosis protocol

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1 Introduction

Proper maintenance and updating of buildings are essential to maintain the building stock, and consequently cities, in good condition. One tool to guarantee good condition is the establishment of diagnostic protocols for existing buildings (Díaz et al. 1993). However, this is a challenge when it comes to evaluating large building stock, due to the extent of the work to be done and the mobilization of necessary resources. Diagnosis of large, privately-owned urban developments often entails management difficulties.

In recent years in Spain, building inspection protocols have been established that are mandatory for buildings over 50 years old. These are known as Technical Building Inspections (ITEs) (Ley 2013; Monjo et al. 2002; ITE 2005). ITEs transfer the responsibility for diagnosing buildings and subsequently carrying out refurbishments to private initiative. With this legislation, the preservation and improvement of safety, habitability, accessibility and sustainability of existing buildings are sought.

Unfortunately, in neighborhoods with the most vulnerable economic and social conditions (Castel 1990; Beck 2001; UN 2003), homeowners cannot afford the expense of carrying out inspections to diagnose their building or the subsequent refurbishment that may result from an inspection. It is precisely these neighborhoods that tend to have a greater need for refurbishment, as years have passed without any maintenance due to a lack of financial resources, leading to the progressive deterioration of buildings (Thomsen et al. 2015a, b).

In this context, Barcelona City Council observed that public aid for building refurbishments did not usually reach the most vulnerable sectors of society (Ajuntament de Barcelona 2016; Tapada and Arbaci 2011). There were several reasons for this, including a lack of knowledge of administrative processes, a lack of coordination among residents, situations of late payment and ignorance of the language. Therefore, in 2017, the City Council started a new line of refurbishment grants designed for these vulnerable communities (Ajuntament de Barcelona 2016; DOGC 2018). In this line, the city council had to take a proactive position, and identify buildings in poor condition in the most vulnerable areas of Barcelona, through a multidisciplinary team that communicates with the community and facilitates the procedures and resources required to complete the refurbishment of buildings as necessary.

To identify buildings that are a priority for refurbishment grant programs, Barcelona City Council commissioned the Universitat Politècnica de Catalunya (UPC) to design and apply a pre-diagnosis protocol for the buildings (Cornadó and Garcia-Almirall 2017). This protocol should be applied to areas that were previously identified as especially vulnerable within the residential fabric of the city (Garcia-Almirall et al. 2017), with a large building stock that has a range of technical characteristics and buildings constructed during different periods.

This chapter describes the pre-diagnosis protocol, explains the methodology used and provides the main results of the study to characterize the buildings, their general condition and the main damage observed.

2 Objectives

The main objective is to provide and validate a large-scale diagnostic protocol that can be applied to residential buildings.

The following objectives are established as secondary objectives within the scope of vulnerable residential stock in Barcelona:

- Provide a general understanding of the state of the buildings in relation to potential hazards to people, habitability and accessibility.
- Characterize the construction of vulnerable residential building stock in Barcelona and classify it into building types.
- Systematize the main damage and shortcomings observed in the buildings.
- Establish possible relationships between the construction characteristics of the buildings and the damage found in them.
- Establish priority levels in the need for refurbishment in the study areas.

3 Methodology

3.1 Selection of the Study Areas

A study was carried out in Barcelona in 2017 to create a map of residential vulnerability (Garcia-Almirall et al. 2017). Residential vulnerability is defined as a set of objective conditions in the residential space that indicate situations of social discrimination and structural disadvantage of the population, related to a specific time and context (Castel 1990; Beck 2001; UN 2003). The methodology followed in this study was based on a system of indicators drawn up through the use of statistical data, complemented with very specific data supplied by Barcelona City Council. Overall urban vulnerability within the city of Barcelona was studied in three areas: socio-economic, socio-demographic, and residential and socio-urban (Cornadó et al. 2017). As mentioned above, the result was a general vulnerability map with a vulnerability index on a scale.

It was agreed with the city council that to undertake the pre-diagnosis of buildings in vulnerable areas, three levels of vulnerability should be included in the sample: high, pronounced and extreme.

However, not all areas with these three levels of vulnerability were included in the pre-diagnosis study of buildings. The aim of the study was to start a proactive campaign of refurbishment grants (DOGC 2018) that was applicable to 16 of the neighborhoods included in the areas of maximum vulnerability in Barcelona. Some of the vulnerable areas were excluded. These 16 neighborhoods were included in Barcelona's Neighborhoods Plan (2017) (Ajuntament de Barcelona 2016), a municipal program to reverse inequalities between neighborhoods by promoting, among others, actions and grants for building conservation in complex communities (see Sect. 1, Introduction).

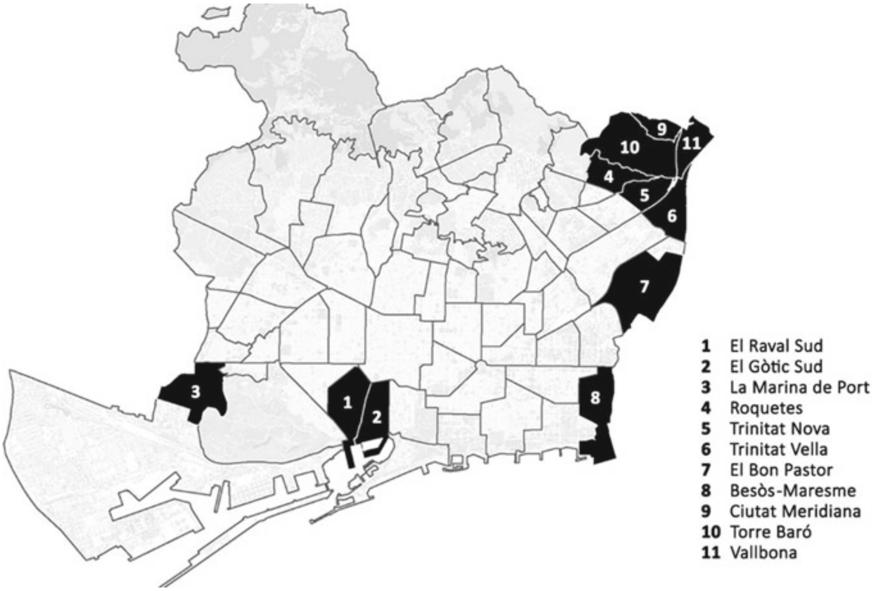

Fig. 1 Location of the studied areas

Figure 1 shows the areas selected for inclusion in the pre-diagnosis study, in which the pre-diagnosis protocol was applied to residential buildings. One of the main challenges was to apply the same protocol to buildings in different neighborhoods and times of construction. The study included areas of the historic center (El Raval Sud and Gotic Sud), large housing estates from the mid-20th century (Trinitat Nova, Besòs-Maresme, Ciutat Meridiana), areas with a combination of suburban growth of the mid-19th century and beginning of the 20th and urban fabrics in closed blocks of the mid-20th century (La Marina de Port, Roquetes, Trinitat Vella, El Bon Pastor) and buildings in originally informal urban developments (Torre Baró and Vallbona).

3.2 Pre-diagnosis Protocol

Faced with the difficulty of covering such vast, diverse building stock, a specific methodology was designed for the pre-diagnosis, with various levels of approximation. The methodology consisted of two inspection phases and an intermediate phase to validate the results (Fig. 2). The first phase consisted of selecting buildings in the study areas (sample) and carrying out an initial pre-diagnosis from the outside. As a result of this first phase, buildings were prioritized according to their state of conservation and need for refurbishment. These results were then discussed with neighborhood and district technicians in various meetings to compare them with the experience of technicians who work every day in the field and thus verify

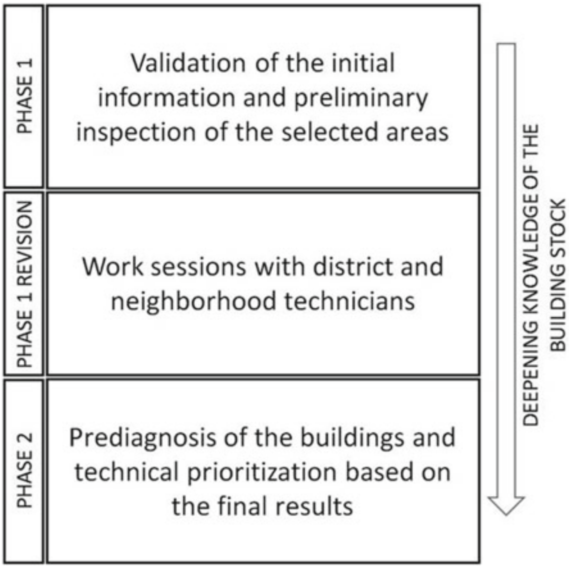

Fig. 2 Methodological phases of the pre-diagnosis process

them. In this review phase, consensus was reached on the buildings with the greatest need for refurbishment. Finally, in a second inspection phase, through contact with technicians and neighborhood entities that provided access to the buildings, interior inspections were carried out to further examine the level of severity of the damage in buildings. Figure 2 summarizes the methodological process for the pre-diagnosis protocol of the buildings that were studied. In the following paragraphs, the specific methodology of each of the protocol phases will be described.

3.2.1 Phase 1: Validation of the Information and Preliminary Inspection

As mentioned above, this phase consisted of two stages. A first stage of work with the available data and initial selection of the buildings to be studied (establishment of the sample), and a second stage of on-site inspection.

(a) ***Preliminary phase before the inspection***

To limit the study sample, residential buildings within the study areas were selected and the following were discarded:

- buildings that had been refurbished in the last 10 years
- buildings built after 1980

Table 1 List of the areas and number of residential buildings included in the study

District	Neigborhood	Studied buildings
1st district: Ciutat Vella	El Raval Sud	671
	El Gòtic Sud	328
3rd district: Sants Montjuic	La Marina de Port	124
8th district: Nou Barris	Roquetes	583
	Trinitat Nova	109
	Ciutat Meridiana	54
	Torre Baró	355
	Vallbona	94
9th district: Sant Andreu	Trinitat Vella	345
	Bon Pastor	254
10th district: Sant Martí	Besòs-Maresme	188

The final sample consisted of a total of 3633 buildings in 16 neighborhoods (Table 1). Although the protocol was applied to all buildings in the sample, it was decided to deliver the results separately by type of ownership, i.e. vertical or horizontal, as this affects the type of refurbishment policy to be applied.

(b) ***Inspection phase***

All the buildings in the sample were inspected from the outside. The inspections were carried out by technicians with experience in building assessment. The following actions were carried out:

- Data was collected on observed visible damage. The focus was points of the façades that could accumulate damage and could denote a poor state of conservation of the building. The indicators that were considered were: cracks in façade walls, façade buckling, unstable façade elements, presence of security nets, rusty metal elements, cracks in the facing, dampness, windows without frames and/or glass or bricked-up windows, degraded woodwork, lack of maintenance, stains and dirt, absence of elevator installation and height of the building.
- Assessment of the conservation state of each building and its need for refurbishment. Five indexes were established according to the state of conservation of the buildings. All buildings were given a rating according to their need for refurbishment on a scale of 5:1 urgent, 1.5 high, 2 necessary, 2.5 low and 3 very low. Buildings with urgent or high need for refurbishment have structural damage and/or risk of detachment of elements or materials from the façades, while buildings with a need for refurbishment have other non-risk evident damage. Buildings with low and very low need for refurbishment should only be maintained regularly. Figure 3 shows examples of buildings according to the need for refurbishment index. Indexing provides a sense of the urgency and need for refurbishment, to prioritize policy making.

Fig. 3 Need for refurbishment rating: 1 urgent, 1.5 high, 2 necessary, 2.5 low and 3 very low

The first exterior inspection phase also included the collection of data on the context of the neighborhood, its uses and activities.

The results of this phase are provided in georeferenced maps, building listings and databases.

3.2.2 Phase 1: Revision

After all the inspections that were carried out on the sample buildings, several meetings were scheduled with district technicians, neighborhood technicians and appropriate social agents in each case, some in the study areas directly, to:

- Verify the buildings to be included in the study areas.
- Compare the results of Phase 1 with local technicians' knowledge.
- Extend and complement the preliminary prioritization of buildings for the development of Phase 2 of the study.
- Facilitate contact with residents and entities and collect useful information for the development of Phase 2 of the study, which consisted of interior inspections of buildings.

In this phase, the detection of buildings that could be included in future refurbishment programs was communicated to the entities and the local government and consensus was reached on each case.

3.2.3 Phase 2: Pre-diagnosis and Technical Prioritization

This phase was based on a series of technical visits to the interior of buildings that were identified as having a higher index of need for refurbishment. To apply the protocol in the city of Barcelona, the study was limited to a total of 200 interior inspections. This did not include all buildings with the maximum level of need on the refurbishment index.

These buildings underwent an inspection similar to the Technical Building Inspections (ITE) that are mandatory in Spain and focus mainly on aspects of safety, accessibility and energy performance of buildings (Ley 2013). The information on the state of conservation and use of buildings was systematized on a card that was designed specifically for this research and reflected the characterization of the building from the perspective of structure, habitability, accessibility and energy consumption; its pathological state (conservation and maintenance); and the gathering of information from users about use and coexistence in the building. Such data had to pave the way for further refurbishment in these buildings. Physical information included in the inspection card was:

- Building technical description

  Description of the structural system (vertical structure, horizontal structure, roof structure, foundation)
  Building envelope description (façades and roofs)
  Installations
  Sketch of the building

- Diagnosis of the building:

  Visible damage to the structure, envelope and facilities
  Accessibility conditions
  Sustainability

As the pre-diagnosis protocol was applied to implement public refurbishment programs in buildings that house the most vulnerable communities in Barcelona, in this phase of the study, data of a social nature were collected from the buildings' neighborhood associations. This information focused on use and coexistence in the building: uses and activities, community, user profiles, usage habits, perception and satisfaction about the state of the building and the dwellings, etc.

4 Results

4.1 Characterization of Construction Building Types

A first distinction of building types can be established within the study areas according to their main morphological and construction characteristics.

Type 1: Historical buildings in closed blocks

Buildings of this group were built before 1940 using traditional techniques, with a structural system that consists of load bearing walls made from varying materials and with different widths depending on the date of construction and with unidirectional slabs (Giol et al. 1995; Arquitectura popular et al. 1988; Torres 2010; Busquets et al. 2004). We can find thick load bearing walls built with rubble masonry or rammed earth (pre-nineteenth century) and slender brick masonry walls (nineteenth and first half of the twentieth century). Floor slabs and deck slabs are usually unidirectional structures built with wood or metal beams, depending on the date of construction.

The façade of this type of buildings is a structural element with generally small openings, whether they are windows or balconies. Consequently, in terms of thermal behavior effects, façades are continuous walls without thermal bridges and without thermal insulation. These buildings are in historical urban fabrics, meaning they are usually included in the protected heritage catalogue (Catàleg del patrimoni arquitectònic històrico-artístic de la ciutat de Barcelona 1987). This protection usually affects façades and common elements to a greater or lesser extent. In addition, the urban configuration of very narrow parcels and considerable building depth tends to compromise the habitability of housing units, due to insufficient ventilation and illumination in some rooms (Spain 2008).

This type of buildings (Figs. 4 and 5) can be found in: the historical center of Barcelona (El Raval and El Barri Gòtic), areas of suburban growth of the mid-19th century and beginning of the 20th century (Busquets et al. 2004) and economic housing "Cases Barates" in the El Bon Pastor neighborhood (1929).

Type 2: Buildings from the second half of the twentieth century in closed urban blocks

The buildings in this group have concrete structures. Most of them are made from concrete slabs and columns. However, some load bearing brick masonry walls combined with concrete slabs can be found (Azpilicueta 1939; Planells et al. 1950).

Fig. 4 Examples of Type 1 buildings. Top row: El Raval and El Barri Gòtic. Middle row: Areas of suburban growth. Bottom row Cases Barates in El Bon Pastor neighborhood

Fig. 5 Type 1 buildings' façades

The façade wall is not usually load bearing and this results in higher flexibility and larger openings. In many cases, floor slabs interrupt the façade walls, which generates thermal bridges. Galleries, setbacks and irregularities in the façade plane are common. Galleries are usually built with very thin walls that are not insulated and contain large openings, which generate very big surfaces where heat losses are considerable. Façade cladding can be continuous or discontinuous (including many cases of brickwork façades and plating).

Building typologies included in this group are highly variable, according to each urban fabric and morphology, although interior ventilation, illumination and circulation are better than in the case of traditional constructions. However, it is common to find rooms with insufficient surface area, and very highly partitioned housing types that were created for the traditional family of the twentieth century.

This type of buildings (Figs. 6 and 7) can be found in: Roquetes, Trinitat Vella, La Marina de Port and El Bon Pastor.

Type 3: Buildings in originally informal urban developments

Buildings included in Type 3 were created with construction techniques that are very similar to those of Type 2 buildings because the period of construction is the same. However, the structural configurations are sometimes similar to Type 1 buildings, with masonry bearing walls and unidirectional slab structures. Type 3 buildings were originally constructed in marginal urbanization areas, and most of them were self-constructed. In this kind of buildings, the quality of the construction techniques and systems cannot be guaranteed, because construction took place outside of any regulation framework. This type of buildings (Fig. 8) can be found within the study areas: in Torre Baró, Vallbona and an area of Roquetes.

Fig. 6 Examples of Type 2 buildings. Top row: El Bon Pastor. Bottom row: Trinitat Vella

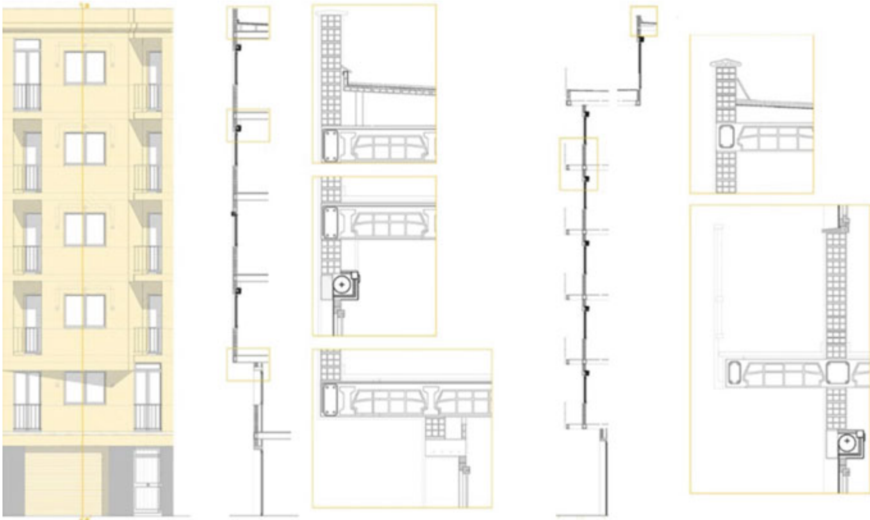

Fig. 7 Type 2 buildings' façades

Fig. 8 Examples of Type 3 buildings in Torre Baró and Vallbona

Type 4: Large housing estate buildings

This type of building is specific to open block urban fabrics, such as those of modern mass housing in large housing estates of the mid-20th century. These buildings are usually built with similar construction techniques to those of Type 2, usually in combination with the use of concrete in large complex systems and prefabricated panels for structural elements (Dutch tunnel system, prefabricated structures) and for the rest of construction systems (façade panels, balcony rails, cladding, etc.) (Díaz 1954; Ferrer 1996; Rosello 2011).

Type 4 buildings correspond to housing typologies that are specifically designed according to the needs of the conventional twentieth century family and are systematically repeated in large housing estates in linear block configuration. The functional layout of the housing units provides a systematic configuration for wet rooms and ventilation. The construction quality varies widely among the cases, depending on the urgency at the time of construction and the political economy that promoted the construction in each case.

This type of buildings (Figs. 9 and 10) can be found in: Ciutat Meridiana, El Sud-oest del Besòs, Trinitat Nova, and certain sectors of Roquetes, Trinitat Vella and La Marina de Port (Fig. 11).

Fig. 9 Examples of Type 4 buildings. From top to bottom: Ciutat Meridiana and Sud-oest del Besòs, Les Marines and Roquetes, Ciutat Meridiana and Trinitat Nova, and, finally Sud-oest del Besòs

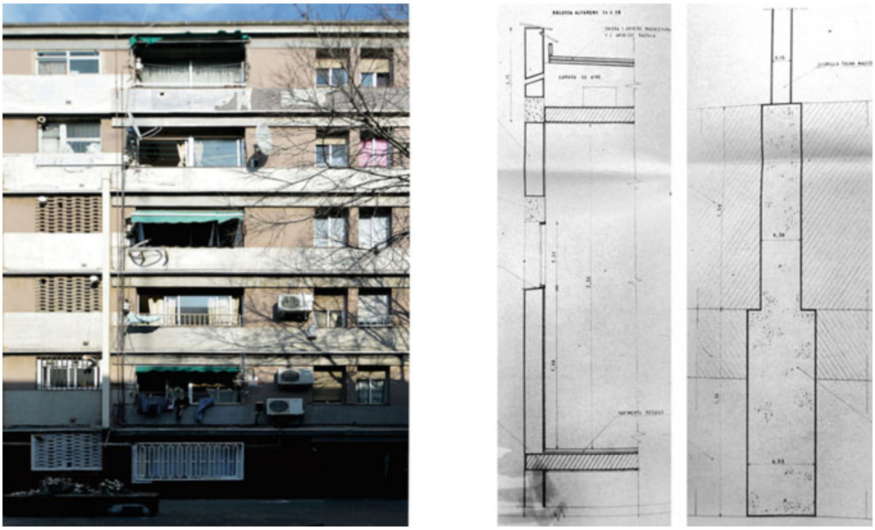

Fig. 10 Examples of Type 4 buildings' façade details (Rosello 2011)

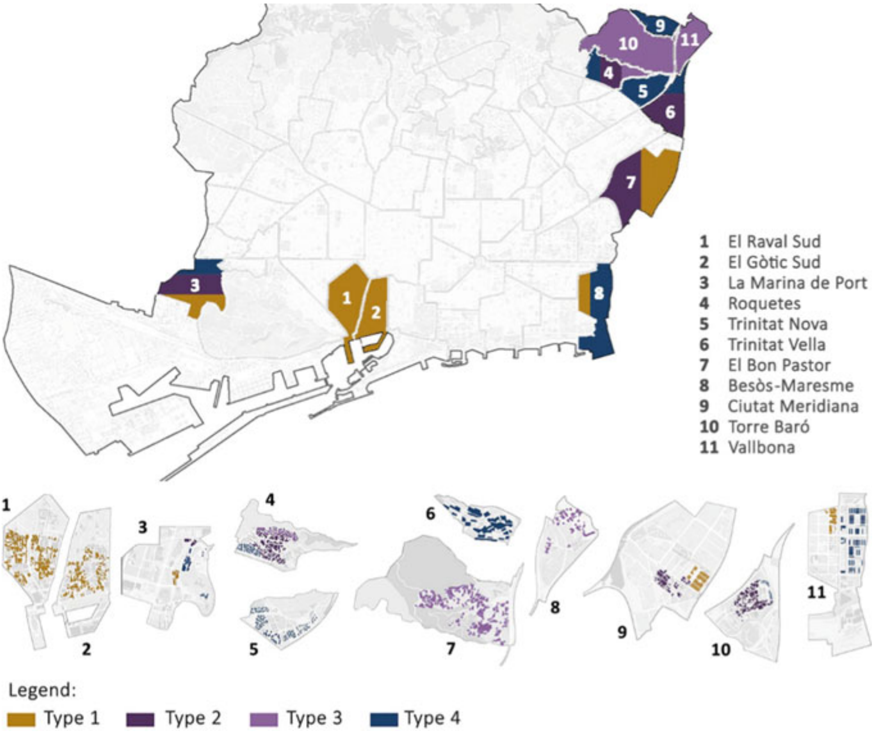

Fig. 11 Barcelona map where the different building types are indicated within the study areas

4.2 *Description of Main Damage Observed*

In this section, the main damage observed during the inspection campaigns in Phase 1 of the pre-diagnosis protocol is explained and grouped. These data were validated in the interior inspections. They can be grouped as follows:

(1) **Damage of mechanical, structural origin: cracks in façade walls and façade buckling**

This type of damage (Fig. 12) was observed in 13% of the cases, with different levels of risk according to its impact on the overall structural system or to the severity of rather localized damage.

A considerable percentage of cracks in façade walls were horizontal or slightly inclined and were found at the point of contact between the roof slabs and the façade. Thus, they can be attributed to the fact that the roof slab has different hygrothermal behavior, and expands more during the summer, which causes considerable thrusts to the façade's continuous wall. In cases in which façades are bearing walls subject to compressive stress, some vertical or 45° cracks were observed around window or door lintels. Another commonly observed type of damage was found in balcony slabs, where we observed cracks that could mostly be associated with corrosion of metal reinforcements. This very common damage, especially when it appears to be widespread in the building, was particularly severe in many cases. In only a very few cases, we could observe either a pattern of vertical continuous cracks in bearing façades subject to compression stress or a clear pattern of inclined cracks that can be associated with the wrong behavior of the foundations or the terrain causing differential settlements. In addition, the amount of observed buckling of façade bearing walls is very low, and in most cases some kind of repair had already taken place.

(2) **Unstable façade elements and risk of material detachment**

This group includes damage that could result in material detachment, with different levels of risk, although the severity is usually quite high, particularly in the case of

Fig. 12 Presence of damage of mechanical and structural origin and percentage within the total sample

high buildings that do not have any elements to prevent detachment. This damage was observed in 25% of the studied buildings and was one of the most typical types.

Some of the observed damage in these groups corresponded to unstable elements detaching from discontinuous cladding (especially ceramic tile cladding, vitreous coating and gresite, among others) located either in the ground floor cladding, on the entire façade surface, or in the frames of openings (parapets, jambs or less frequently lintels) and balcony flooring. In addition, observed damage included the risk of detachment of metal elements from 'brise soleils' or other metal elements attached to the façades, for instance, as protection for the fitting of installations. In another large group of cases, the risk of material detachment was associated with the presence of cracks or other damage caused mainly by humidity. Humidity can affect the main materials in façade walls (bricks, air-bricks, stone or mud, mortar or concrete), mortar or concrete in balcony slabs or continuous cladding materials, causing their deterioration and detachment.

Finally, the risk of material detachment has been observed in many cases in cornice elements affected by other damage such as dampness, cracks or even plant growth (Fig. 13).

In contrast with the high percentage of damage of considerable severity, prevention measures (Fig. 14) were only found in 5% of cases. Sometimes, they were associated with localized damage (a balcony, a part of the façade or the cornice), sometimes they were widespread and affected many elements of the building skin or even the

Fig. 13 Presence of unstable façade elements and risk of material detachment and percentage within the total sample

Fig. 14 Buildings with prevention measures applied

Fig. 15 Presence of dampness and percentage within the total sample

entire façade. An increase in the implementation of ITE inspections in Barcelona is leading to a rise in the percentage of prevention measures in buildings that need urgent refurbishment actions.

(3) **Presence of dampness**

Dampness is the most common type of damage that affected 30% of the studied buildings (Fig. 15) and is usually linked to corrosion of metal elements, stains and dirt, or even risks of material detachment and cracks, which generally damage elements or parts of the building.

A first group of dampness damage was observed in the base of the façade and interior walls as rising damp due to capillarity (Fig. 16). Basement continuous claddings usually have dirt, stains or detachments because of rising damp, and discontinuous claddings tend to detach. Wall materials such as mud, stone masonry or brick masonry are usually affected with considerable intensity up to 1 m, with salt crystallization and dissolution of joint material such as lime mortar.

In addition, some dampness damage was observed in locations that are exposed to rainwater leaking, such as cornices, balconies and elements in contact with openings (especially the walls of interior courtyards) (Fig. 17). In the case of cornices, the presence of discontinuous cladding or irregularities in material such as decorative elements, material alterations or cracks contributes to a greater impact in the presence of water leaks. Humidity is very common on the lower side of balcony slabs, while its severity increases to the degree that it affects metal reinforcements.

Fig. 16 Cases of rising damp due to capillarity

Fig. 17 Buildings with cornices, balconies and sills in poor condition

Fig. 18 Examples of water filtrations from interior services or water installations

Finally, some other types of dampness damage were observed at points of the façade in relation to possible water filtrations from interior services or water installations (rainwater or wastewater downspouts or water facilities) (Fig. 18).

(4) **Deficiencies in openings (glass enclosures and carpentry)**

Except for the few buildings that were not previously excluded from this study and that have been refurbished previously, all studied buildings were constructed prior to the first regulation that established the obligation of building with thermal insulation in Spain in 1979. Thus, energy efficiency shortfalls were found in all cases, which is why this section of damages includes more severe lacks of air and water tightness, usually due to damage of varying severity on windows, glass enclosures and carpentry that contributes to water filtration, lack of air tightness and thus very bad energy behavior. These kind of shortcomings were observed in 15% of cases.

A considerable number of buildings have severe observable deficiencies in the openings (Fig. 19). In some cases, the corresponding dwellings are empty. This was the case of bricked-up or blocked openings, and windows without any kind of glass or carpentry enclosure. There were also some cases of dwellings with signs of occupancy and serious damage too, such as windows with some broken glass, without glass enclosures, or very degraded woodwork. Nevertheless, in most cases it could be seen that the carpentry had not been renovated, the woodwork was degraded and the glass was single pane.

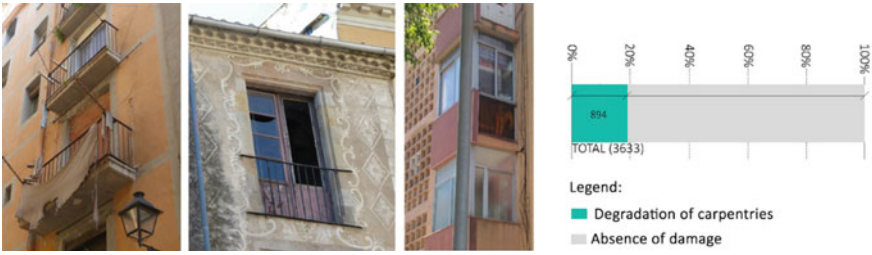

Fig. 19 Examples of deficiencies in the openings and percentage within the total sample

(5) **Deficiencies in accessibility**

As explained in the previous section, several deficiencies in accessibility (CTE 2018) within floors and accesses were widespread among the studied buildings (Fig. 20). Corridors and accesses to the dwellings as well as vestibules and access doors are not big enough. In addition, generally there are one or two steps at the exterior entrance to the building. In some cases, there are over five steps.

These shortcomings are widespread and affect almost the entire sample. Figure 20 includes only cases of considerable height (buildings over four stories) in which a lack of vertical accessibility (no elevator installation) is combined with the rest of the accessibility deficiencies. With a percentage of over 45% of cases, the lack of an elevator when it is needed is by far the most common shortfall in the building stock. In some cases, when the inner dimensions of the staircase or the courtyards are big

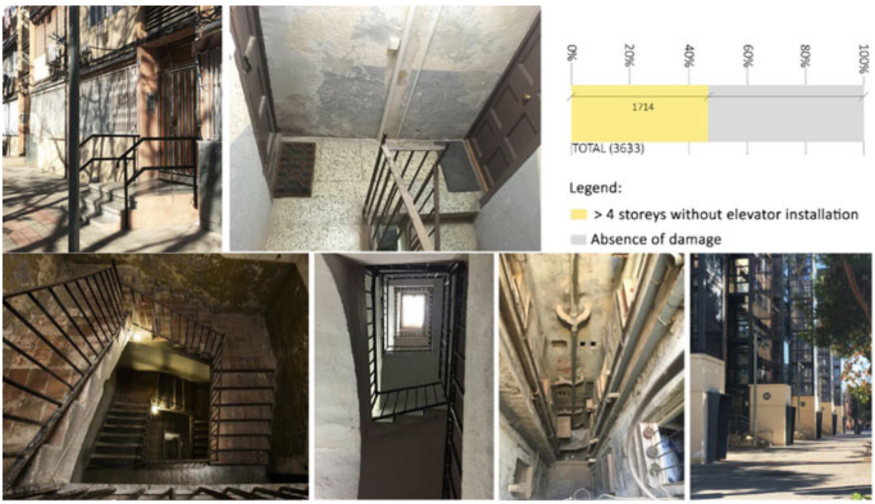

Fig. 20 Deficiencies in accessibility and percentage of 4 or more story buildings without elevator within the total sample

enough, an elevator could be installed. When these dimensions are too small (more commonly in Type 1 buildings) it is very complicated improve vertical accessibility.

4.3 State of Conservation and Need for Refurbishment

Observation of the state of conservation in the analyzed sample of cases (Fig. 21) shows how the proportion of cases in a reasonably good state (low or very low need of refurbishment) corresponded to 60% of cases. In contrast, the proportion of cases with urgent need of refurbishment (evidence of risk) corresponded to a fifth of the total sample.

The proportion of buildings that required refurbishment with some degree of urgency (urgent, high or necessary) was greater in the neighborhoods of El Bon Pastor, Torre Baró and La Marina de Port. This proportion was lower in the neighborhoods of Ciutat Meridiana and El Besòs.

However, if we focus on the highest level of urgency, the neighborhoods of El Bon Pastor, Torre Baró, El Raval (southern area), El Barri Gòtic (southern area), La Marina de Port and surprisingly Ciutat Meridiana had a higher percentage of cases, while the neighborhoods of Roquetes, Trinitat Vella, Vallbona and El Besòs had a lower proportion of cases in urgent need of refurbishment.

Taking into account that a quantitatively larger sample was analyzed in El Bon Pastor, Torre Baró and particularly El Raval and El Barri Gòtic, this high proportion of cases with an urgent need of refurbishment translates into a high number of affected buildings in those areas, particularly in El Bon Pastor.

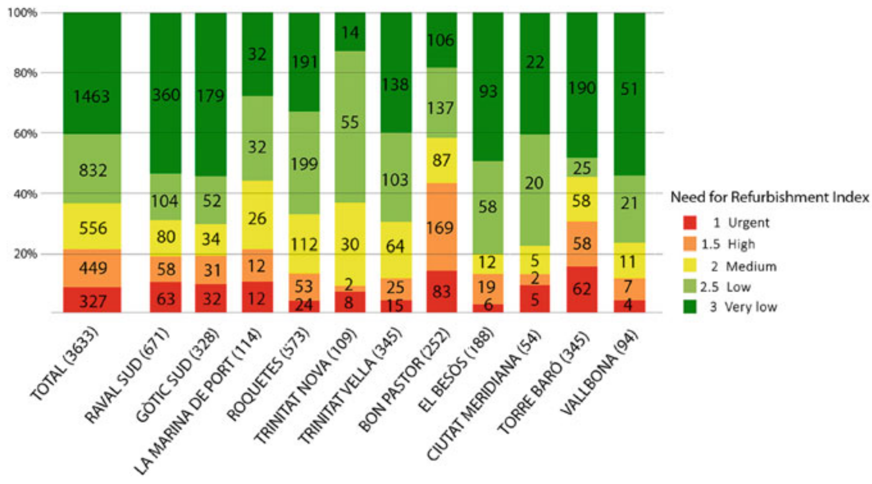

Fig. 21 Need of refurbishment index comparison between neighborhoods

In some neighborhoods, the proportion of cases that needed some refurbishment with a lower degree of urgency (no evident risk) was much higher than the proportion of cases in urgent need of refurbishment. This was the case of Trinitat Nova, Roquetes, La Marina de Port, Trinitat Vella and Vallbona.

Although the variability between neighborhoods in the percentage of buildings requiring some refurbishment measure at different levels was quite small (with few exceptions), the percentage of buildings in a very good state was much more variable. The areas with the highest proportion of buildings in such a state were El Raval, El Barri Gòtic, El Besòs, Torre Baró and Vallbona, while the neighborhoods of Trinitat Nova, El Bon Pastor, Roquetes and La Marina de Port had a much lower proportion. If we take into account the quantitative differentiation of the sample per neighborhood, the number of cases in a very good state of conservation according to an exterior inspection was higher in El Raval, Torre Baró, Roquetes, El Barri Gòtic, Trinitat Vella and El Besòs.

Finally, mapping of refurbishment need results shows how the observed variety in states of conservation within each of the neighborhoods translated into considerable geographic variability of results (Fig. 22). It was impossible to identify areas of a certain scale that were uniformly well-conserved, or areas of a certain scale that were uniformly deprived. In addition, it was common to observe how cases that required urgent refurbishment appeared to be adjacent to cases in a very good state of conservation.

4.4 Cross Analysis of Damage and Building Types Per Neighborhood

In this section, Figs. 23, 28, 30, 32 and 34 show how each of the previously described types of damage had a similar presence in the studied buildings. Close to 20% of mechanical structural damage, 25% risk of material detachments, 30% dampness, close to 20% degraded carpentry, and over 45% of severe deficiencies in accessibility. This balance, as well as the proportion of each kind of damage, varied widely depending on the neighborhood and therefore in relation to the construction building types that mainly characterized each neighborhood.

Firstly, mechanical structural damage appeared to be found quite uniformly in the neighborhoods, regardless of the construction building type, in 15–20% of cases (Fig. 23). The highest percentages were in El Bon Pastor, Torre Baró, El Besòs and El Barri Gòtic. In the first case, the observed damage corresponded mainly to cracks in cornices and lintels of mostly abandoned and very poorly maintained buildings (Fig. 24) in the area of 'Cases Barates' (economic housing) (Type 1). This repetition of the same kind of damage was generally quite unique to this area, although similar damage was observed in some cases of low Type 1 buildings, such as typologies of suburban growth of the nineteenth century in La Marina de Port.

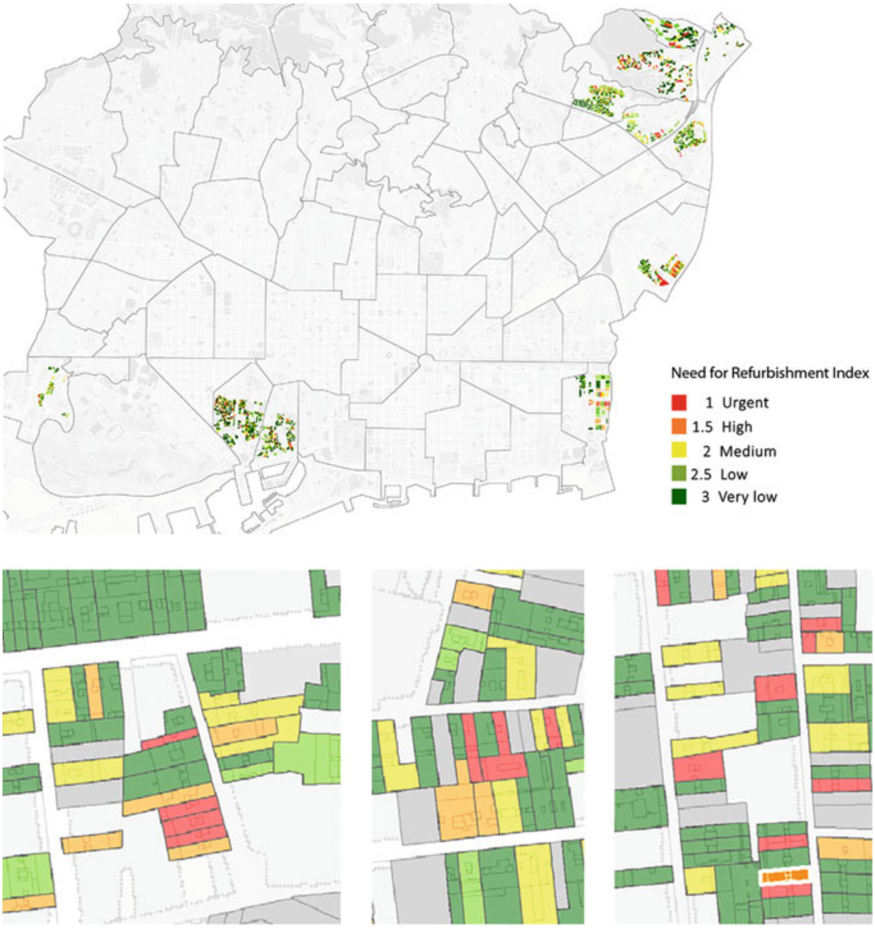

Fig. 22 Need for refurbishment index in the studied areas (top) and close up views in different neighborhoods (bottom)

In the case of Torre Baró (Type 3), the observed deficiencies were much more varied, and differed between considerable structural deficits in precarious self-constructions to other less relevant cracks in bearing walls around window or door lintels (Fig. 25). This combination of damage characterized, to a lesser extent, other areas with the same construction building types (Roquetes and Vallbona, Type 3).

Cracks observed in high linear block buildings in El Besòs (Type 4) were associated with old, mostly repaired serious damage in bearing walls with insufficient foundations (Díaz 1954), and other currently ongoing problems associated with deterioration in balconies and other slab elements built with aluminous cement (Fig. 26). Even though El Besòs was very specific for this problem, similar concrete pathology and damage associated with the deterioration of balcony slabs were observed in both

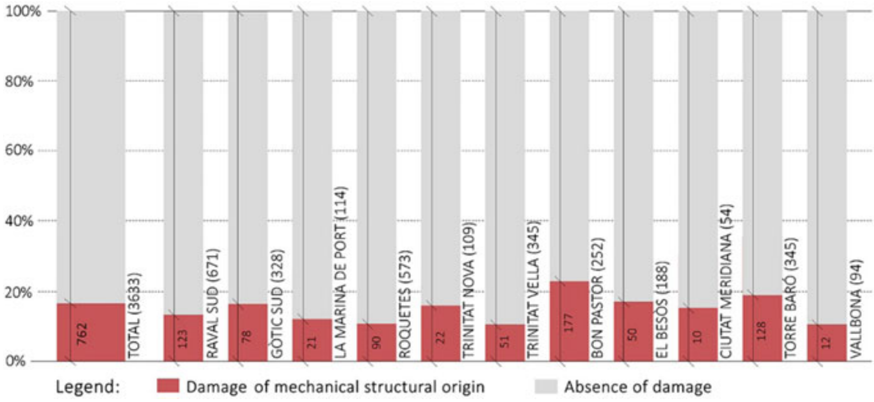

Fig. 23 Percentage of damage of mechanical structural origin and risk of material detachment within the sample

Fig. 24 Cracks in cornices and lintels in type 1 buildings

Fig. 25 Damage in type 3 buildings

neighborhoods with buildings of Type 2, Type 3 and particularly Type 4 (Ciutat Meridiana and Trinitat Nova).

Finally, observed damage in El Barri Gòtic (Type 1) (Fig. 27) differed from processes of buckling of load bearing façade walls that had mostly been repaired, cracks around window and door lintels, cracks in balcony slabs due to the corrosion

Fig. 26 Damage in balcony slabs

Fig. 27 Cracks and damage in load bearing façades

of metal elements and, in occasional cases, widespread structural damage observable with cracks that affected the whole length of the façade. Similar damage was observed in El Raval and other construction buildings of Type 1, with the exception of façade buckling that was more specific to El Barri Gotic, where buildings are older.

Notably, Types 2 and 3 buildings, with the exception of Torre Baró, had a lower percentage of damage of mechanical structural origin, as observed in the exterior inspection.

Secondly, unstable elements (Figs. 28 and 29) were observed in much more variable proportions among the neighborhoods (between 20 and 60%). Trinitat Nova was a distinctive case in which there was a very high percentage of buildings with unstable elements in the façade. This damage was greater in neighborhoods where Type 1 and Type 2 are predominant. In the first (Type 1), damage was mainly observed in balconies, cornices and continuous cladding, while in buildings from Type 2, these types of damage mostly appeared in façade plating and other elements besides balconies, and was similar to the observed damage in Trinitat Nova and linear blocks in El Besòs (Type 4). Curiously, in neighborhoods where Type 3 buildings are predominant, the amount of damage was considerably lower (Roquetes, Vallbona, and relatively low in Torre Baró).

Figure 30 presents damage related to bad hygrothermal behavior of the envelope due to the presence of humidity. These percentages were quite variable among neighborhoods. The percentage of buildings affected by dampness varied from just under

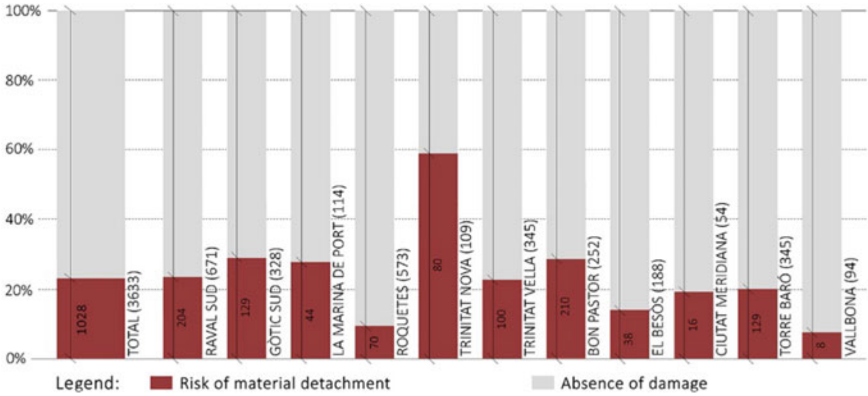

Fig. 28 Percentage of risk of material detachment

Fig. 29 Material detachment in façades

20% in Trinitat Vella, El Raval and El Barri Gòtic, and Vallbona and slightly over 20% in Torre Baró, to around 40% in La Marina de Port, Roquetes, Trinitat Nova, El Besòs and Ciutat Meridiana, and 60% in El Bon Pastor. Since the presence of dampness is associated with other observed types of damage, it is indicative of the general state of maintenance of the façade.

As mentioned above, it can be assumed that some of the single family buildings in Torre Baró and Vallbona have carried out refurbishment and maintenance actions, while the public programs to improve building façades in the historical center may have contributed to a lower percentage of damage in El Raval and El Barri Gòtic.

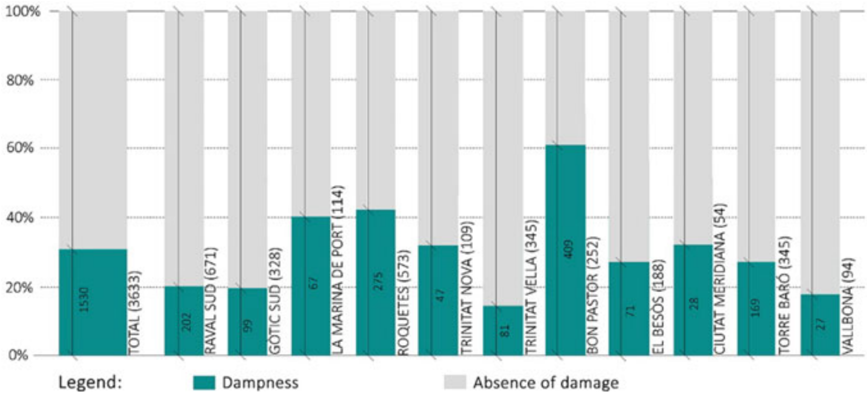

Fig. 30 Percentage of buildings with damage due to dampness

Other neighborhoods have significant percentages of damage, at around 40%, regardless of the building construction type (Types 1, 2 and 4) (Fig. 31). The concentration of damage in El Bon Pastor was, once again, specific to the 'Cases Barates' area.

Regarding damage to carpentry and woodwork (Figs. 32 and 33), the percentages were considerably higher in Type 1 buildings (El Raval, El Barri Gòtic and La Marina de Port), mostly due to aging and deformation of woodwork. Percentages were also high in some neighborhoods characterized by Type 2 buildings (Trinitat Vella) and 4 (Ciutat Meridiana), where the carpentry is mostly old aluminum frames, sometimes with deteriorated sliding windows containing single-pane or non-transparent glass.

Finally, severe deficiencies in accessibility was the type of damage that varied most widely by neighborhood and was greater in many neighborhoods (Fig. 34). Logically, the variation can be explained by the fact that high buildings with no elevator installation depended strictly on building type and urban morphology.

The highest percentages were observed in the historical neighborhoods of El Raval and El Gòtic, with Type 1 buildings in which the installation of elevators is extremely complex due to the small dimension of inner courtyards and staircases (Fig. 35), but the buildings are higher than 4 stories.

This problem is also common in large housing estates (Type 4), although in these cases it usually affects only linear block buildings, while tower blocks and other higher buildings usually have elevators installed at the time of construction. This explains the small percentage of deficiencies in El Besòs, where the coexistence of different typologies (higher blocks with elevators, lower blocks with no elevators and single family houses) distorts the relevance of the number of dwellings with no elevator access (a percentage that would be more similar to that of Ciutat Meridiana) (Fig. 36).

Neighborhoods in which this damage is less significant usually consist of lower buildings, as in the case of urbanization areas that were originally marginal (Type 3) or the unique typology of 'Cases barates' in El Bon Pastor.

Fig. 31 Damage due to dampness observed in façades. Buildings of Type 1, Type 2 and Type 4

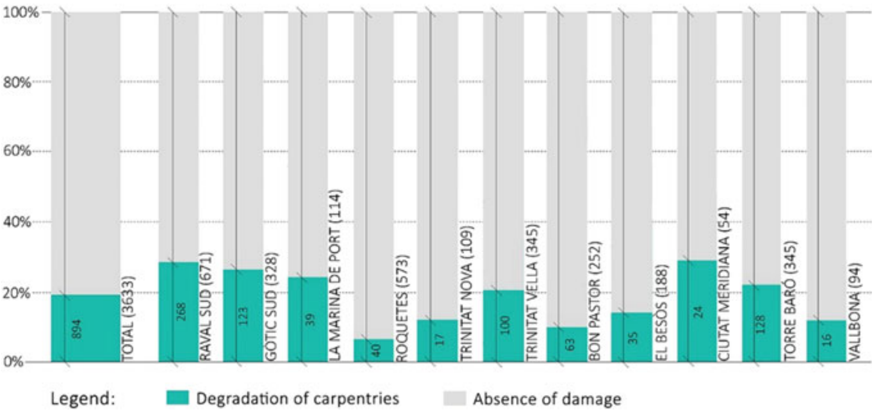

Fig. 32 Percentage of buildings with damage to carpentry and woodwork

Fig. 33 Damage to carpentry and woodwork in buildings of Type 1 and Type 2 and 4

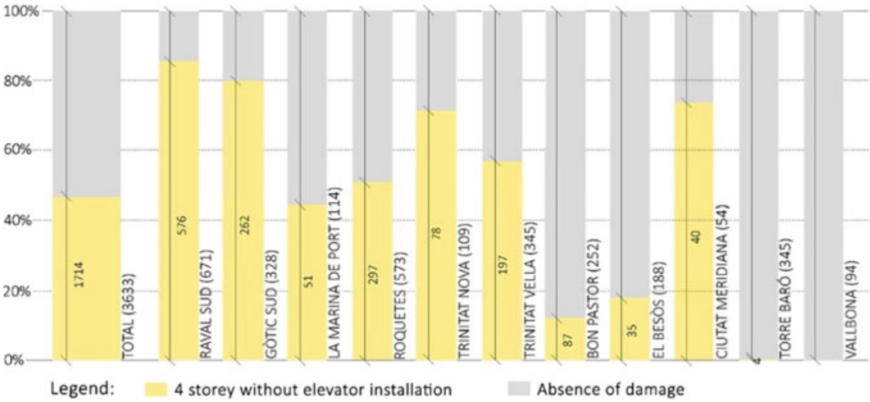

Fig. 34 Percentage of 4 or more story buildings without elevator

Fig. 35 Accessibility deficiencies in buildings of Type 1, in El Raval neighborhood

Fig. 36 Accessibility deficiencies in linear blocks of Type 4, in El Besòs neighborhood

Regarding the state of conservation (Fig. 21), the highest proportion of cases in urgent need of refurbishment correspond to the area of 'Cases barates' in El Bon Pastor (Type 1), followed by the neighborhood of Torre Baró (Type 3), and the neighborhoods of the historical center of the city, El Raval and El Barri Gòtic (Type 1).

El Bon Pastor and Torre Baró have particularly high percentages of cases with an urgent need of refurbishment, both quantitatively and in proportion. El Bon Pastor has a very large area that is affected by ongoing urban transformation that prevents some buildings from being refurbished, while the second corresponds to an urban development that was originally marginal and consists of mostly self-constructed buildings.

The proportion of cases in a very bad state of conservation was much lower in neighborhoods characterized by construction and building types 2 and 4. Surprisingly, 50% of buildings were in a very good state in the two neighborhoods of the historical center (Type 1), and in the two neighborhoods that were originally marginal and self-constructed (Type 3), while it was much lower in neighborhoods with buildings that were constructed between the 1950s and 1970s (Types 2, 3 and 4). This may be related with the public façade refurbishment programs carried out particularly in the historical neighborhoods of Ciutat Vella in Barcelona (Giol et al. 1995; Ripoll 1988), which had an impact on the good state of the building envelopes. In the case of buildings in a very good state in areas of originally marginal urbanization, their uniqueness in terms of property and typology (single family housing owned by tenants in building types that are usually not higher than two floors) may have made it more feasible to carry out improvements in many cases.

Finally, regarding the mapping and forms of aggregation of cases with a need for refurbishment, the aforementioned variation was, logically, common to all neighborhoods regardless of the building types and characteristics.

In neighborhoods comprised of clearly differentiated areas in terms of urban form and building types, the mapping showed remarkably different results according to building type. For example, the north-western area of El Besòs, comprised of Type 1 buildings, clearly had a higher concentration of buildings in a very good state, and cases with considerable evidence of risk were nonexistent. Similarly, the area of 'Cases barates' in El Bon Pastor (type 1) had the highest concentration of cases with

Fig. 37 Need for refurbishment index in El Bon Pastor (left) and Roquetes (right)

an urgent, high need for refurbishment, and could clearly be distinguished from other areas in El Bon Pastor with 3 and 4 type buildings. Finally, the south-western area of Roquetes, comprised of linear blocks and tower blocks built between the 1950s and 1970s (Type 4) was uniformly in a very good state of conservation according to the exterior inspection, while the northern part of the neighborhood comprised of an originally marginal urbanization of mostly self-constructed buildings had the highest concentration of buildings that need refurbishment with some degree of urgency, and the highest number of cases with evidence of risk in the neighborhood. Figure 37 shows the need of refurbishment index in El Bon Pastor and Roquetes.

Despite the differentiation in the mapping results in specific zones, it clear that on a smaller scale, per zone and within the same construction and building type, there was wide variety in the results and a dispersion of cases that had an urgent need for refurbishment. The most evident cases were probably those mapped in El Besòs and Ciutat Meridiana (Type 4) (Fig. 38), in which one building type of a linear block had cases in a very good state of conservation and cases with urgent need of refurbishment.

5 Conclusions

Once the pre-diagnosis protocol had been applied to residential buildings in the most vulnerable areas of Barcelona, the following conclusions were drawn on aspects of the characterization and assessment of the buildings.

The characterization of the buildings' construction was consistent with the year of construction and the urban context. Four building types were differentiated considering their morphological and construction characteristics. One type corresponds to historical buildings built with historical construction techniques, while three types built with modern construction techniques were distinguished: buildings from the

Fig. 38 Need for refurbishment index in El Besòs (left) and Ciutat Meridiana (right)

second half of the twentieth century in closed urban blocks, buildings that were originally in informal urban developments and buildings in large housing estates.

In terms of the general state of conservation of the buildings and their need for refurbishment, a low percentage of buildings urgently required refurbishment to guarantee safety (between 5 and 10%). The highest percentages of buildings with urgent need of refurbishment correspond to historical buildings (Type 1) or self-constructed buildings (Type 3). However, in construction types built with modern construction techniques (Types 2, 3 and 4), the percentage of buildings that need some type of refurbishment, regardless of severity, was greater than in types built with historical techniques (Type 1). No correlation was found between the amount of damage observed and its severity. In other words, there was no correspondence between the amount or diversity of damage in a building and its need for refurbishment. This contributes to validating the methodology that was used, and proves the need for the use of a global qualitative index to assess the need for refurbishment, in addition to the damage quantitative analysis.

Regarding the geographical distribution of the state of conservation of the buildings, wide variation was observed in all neighborhoods in the sample, regardless of building type. It was not possible to delimit areas on a large scale where the results were uniform. This makes it difficult to establish perimeters in which specific measures could be implemented. The design of refurbishment programs needs to incorporate tools that consider the existing variation, to achieve interventions that are flexible enough to address the very different nature of small delimitated areas while, at the same time, attempting to reach an extensive scope that can address the large dispersion of damage and degraded cases.

In general, the pathological states of the buildings studied can be associated with a prolonged lack of maintenance for years, which reflects the vulnerable social situation of the inhabitants. However, a relationship can be established between the type of damage present and the building types. In traditional construction building types (Type 1), the damage observed in façades was concentrated in cornices and balconies, while more modern buildings had more damage related to unstable façade elements such as plating. In contrast, the presence of cracks or other damage of mechanical structural origin, and the presence of dampness, were common types of damages that appeared uniformly in all building types, regardless of their age and construction techniques.

In terms of accessibility, the building types with the most deficiencies were historical buildings (Type 1) and mid-rise buildings on large housing estates (Type 4).

Finally, some conclusions should be made about the methodology used in the pre-diagnosis protocol. It is confirmed that the methodology used in Phase 1 is consistent with the results obtained in Phase 2, thereby validating the results of Phase 1 on the total sample. It is also verified that the accompaniment and support of neighborhood technicians and entities is very important to obtain higher quality results. Likewise, contact with neighborhood agents and technicians facilitates access to the buildings for a second phase and paves the way with neighbors for the implementation of future refurbishment programs. Likewise, it is verified that large building stock can be assessed using a protocol of this type, with the methodology in several phases to deepen knowledge of the buildings.

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References

Ajuntament de Barcelona (2016) Pla pel Dret a l'Habitatge de Barcelona 2016–2025. Resum executiu

Ajuntament de Barcelona: Pla de Barris. https://pladebarris.barcelona/ca

Azpilicueta E (2004) La construcción de la arquitectura de postguerra en España (1939–1962). Doctoral Thesis, Universidad Politécnica de Madrid

Beck U (2001) The society of risk. On the road to another modernity. Aubier, Paris, France

Busquets J et at (2004) The old town of Barcelona: a past with a future. Ajuntament de Barcelona ed., Barcelona, Spain

Castel R (1990) Disaffiliation: work and relational vulnerability. Hébergeur, Paris, France

Catàleg del patrimoni arquitectònic històrico-artístic de la ciutat de Barcelona. Ajuntament de Barcelona (1987). http://hdl.handle.net/11703/101775

Código Técnico de la Edificación (CTE) (2018) Documento Básico de Seguridad de utilización y accesibilidad (SUA). DB-SUA/2: Adecuación efectiva de las condiciones de accesibilidad en edificios existentes

Cornadó C, Garcia-Almirall P, Vima-Grau S (2017) Prediagnosi de l'edificació residencial en els àmbits de vulnerabilitat de la ciutat de Barcelona. Ajuntament de Barcelona

Cornadó C, Garcia-Almirall P, Vima-Grau S, Vila G, Uzqueda A (2017) Methodology for the detection of residential vulnerable areas—the case of Barcelona. In: IOP conference series materials science and engineering, vol 245. https://doi.org/10.1088/1757-899x/245/4/042062
Diari Oficial de la Generalitat de Catalunya (DOGC): Anunci de la Convocatòria del Programa de Finques d'Alta Complexitat. Núm 7642-14.6.2018. CVE-DOGC-A-18157071-2018 (2018)
Díaz C (1986) Aproximación a la evolución y el comportamiento derivado de las técnicas constructivas utilizadas en los tipos edificatorios exentos destinados a la vivienda económica en Cataluña (período 1954–1976). Doctoral thesis, Universitat Politècnica de Catalunya
Díaz C, Ferrer A, García R, Ulla A (1993) Els teixits edificats: transformació i permanencia. PAPERS. Regió Metropolitana de Barcelona 15
Ferrer A (1996) Els polígons a Barcelona. Edicions UPC, Barcelona, Spain
Garcia-Almirall P, Vila G, Vima-Grau S, Uzqueda A (2017) Estudi i detecció a la ciutat de Barcelona d'àmbits de vulnerabilitat residencial. Ajuntament de Barcelona
Giol P (1995) La casa de veins del segle XIX a Barcelona. Doctoral thesis, Universitat Politècnica de Catalunya, Barcelona, Spain
ITE (2005) Protocolo de Inspección Técnica de Edificios. Colegio Oficial de Arquitectos de Sevilla, Fundación FIDAS, Sevilla, Spain
Ley 8/2013, de 26 de junio, de rehabilitación, regeneración y renovaciones urbanas. Gobierno de España (2013)
Monjo J (2002) Manual para la inspección técnica de edificios. Ed. Munilla-Leria, Madrid, Spain
Planells A, Cornadó C, Díaz C (2013) Housing Typology in Santa Coloma de Gramanet (Barcelona) 1950–75. A methodology for analysis and further improvement of common housing. In: XXXIX IAHS World Congress on Housing. Milano, Italy. https://doi.org/10.13140/2.1.2855.9684
Ripoll R (1988) Arquitectura popular, reflexions vers una nova lectura. Quaderns de la Selva 2. Centre d'estudis selvatans **2**, 217–223. Santa Coloma de Farners, Barcelona, Spain
Rosello M (2011) Las técnicas de construcción utilizadas en la construcción del polígono residencial del Sud-Oest del Besós. Barcelona 1959–1961. In: Séptimo congreso nacional de historia de la construcción. Santiago de Compostela, Spain, pp 1233–1245 http://hdl.handle.net/2117/81450
Tapada MT, Arbaci S (2011) Proyectos de regeneración urbana en Barcelona contra la segregación socioespacial (1986-2009): solución o mito? ACE Archit City Environ 6(17):187–222. https://doi.org/10.5821/ace.v6i17.2534
Tarragó S, Barrionuevo A, Martí C (2008) Exigencias de la Habitabilidad de los Centros Históricos. In: Habitabilidad y Ciudad. Escuela Técnica Superior de Arquitectura de Sevilla ed., Sevilla, Spain, pp 31–34
Thomsen A, Van der Flier K, Nieboer N (2015a) Analyising obsolescence, an elaborated model for residential buildings. Struct Surv 33(3):210–227. https://doi.org/10.1108/SS-12-2014-0040
Thomsen A, Nieboer N, Van der Flier K (2015) Obsolescence—understanding the underlying processes. In: ENHR 2015 conference Lisbon
Torres C, Díaz C (2010) Técnicas de Intervención para la recuperación de los sistemas constructivos en los edificios del centro Histórico de Barcelona. In: CINPAR-2010 VI Congreso Internacional sobre Patología y Recuperación de Estructuras
UN (2003) Report on the social situation of the world 2003. Social vulnerability: sources and challenges. United Nations Publications, New York, US