Extended abstract

Assessment and characterization of water damage in buildings

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December 2020

1. Introduction

Buildings and infrastructures deteriorate throughout their life cycle, which makes conservation, maintenance, repair, and rehabilitation tasks crucial to prevent their degradation. It is essential to identify both the causes for anomalies and the rehabilitation solutions that effectively contribute to increase durability. Lifespan evaluation of materials, components, installations, and buildings are recognized as being one of the most important factors to be considered in the construction sector (Rodrigues, 2008).

Within the scope of his activity of assessing property claims, carried out between 2008 and 2017, the author was confronted with a majority of claims involving water damage, which not only arise with a relatively high frequency, but also lead to significant impacts on the buildings themselves.

Water, under different states and as a natural agent for the degradation in buildings, has been a constant challenge in view of the need to preserve and satisfy basic living conditions. The assessment of the behavior of materials and elements used in construction, particularly in view of moisture, becomes essential for the characterization of their performance (Torres, 2014). Among the various ways in which anomalies caused by the presence of humidity can manifest themselves, the penetration of rainwater through cracks in the walls, as well as the situations that result from broken pipes from hydraulic networks stand out (Henriques, 1994).

Given that there are no reliable statistics in Portugal on the main causes of anomalies in buildings involving water damage, this dissertation will aim to create and analyze a database of claims on residential buildings. The existence of databases of this type, focusing on the phenomenon of humidity, allows to characterize statistically the origins and forms of the manifestation of these damages, leading to the definition of forms of prevention.

2. Methodology

2.1 Choice of input data

The first step in the database creation was choosing input data. The inspections carried out by the author during the analysis period (around 7500 cases) included documentation, photographic elements and detailed information about each occurrence, which covers the various types of problems that may occur in residential buildings. For the database construction, it was necessary to select the documentation to be used for data extraction. In this case, expert reports were used, since they contain fundamental data of each claim.

In a second phase, it was necessary to decide on the type of information and data to be extracted from the expert's report, considering the objective of the present work. To facilitate the selection process, the fields in the report were used as a reference.

Based on personal classification, the occurrences were analyzed, having obtained the distribution of causes shown in table 1, which confirms the importance of water as the most frequent cause of the damage that occurs during the buildings' exploration phase.

Table 1 – Main causes of damage to buildings

Main causes of occurrences	
Water	82.3%
Natural disaster	6.7%
Fire	3.8%
Stability	3.5%
Other	3.7%

It is important to point out that although water is present, in the form of precipitation, in storms normally associated with strong winds, and floods, resulting from water spills and torrential rains, these events are classified as natural phenomena and do not fall within the scope of the present study. On the other hand, given the predominance of humidity due to random causes and precipitation humidity on the water occurrences, other forms of manifestation - namely condensation, soil, construction, and hygroscopic humidity - were not considered.

In summary, the criteria underlying the choice of the sample were 2500 incidents from water damage carried out by the author within the scope of the Expert's activity in Lisbon Metropolitan Area, between the years 2008 to 2017 on occupied classic family accommodation.

2.2 Database parameters and criteria

Then, the parameters and respective criteria considered for the characterization of each occurrence in the database were selected. To facilitate storage, parameters were associated with different categories: occurrence, building and cost characterization, as shown in figure 1.

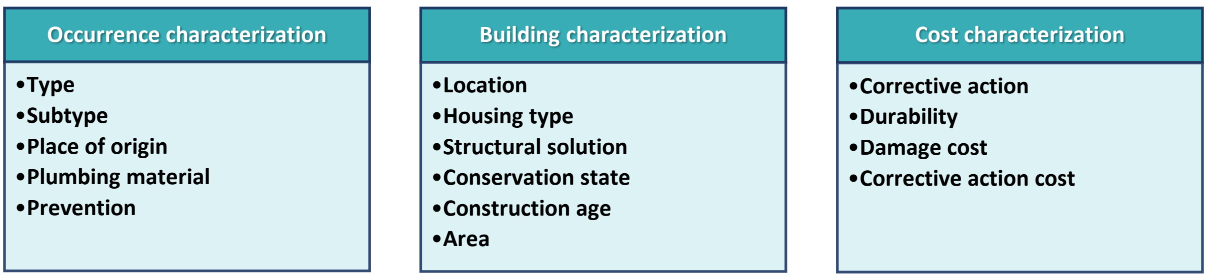

Figure 1 – Categories and parameters used in database

The origin of the occurrence is essential to the results analysis; therefore, the structure of the database was ordered according to the cause of the incident. Considering the relevance of hydraulic installations in this context, the type of occurrence was classified according to its association with the components of each network. The other occurrences without any relation to the hydraulic networks, consequence in their overall undue maintenance by the users of the building. Thus, incidences were divided into three different types: water distribution, sewage drainage and other causes.

In view of the diversity of the hydraulic components, it was necessary to break up the occurrences into subtypes, using proper nomenclature. Considering the components of the water distribution there was a fragmentation of three subtypes: introduction pipes, distribution pipes and accessories. In the sewage drainage network, the elements were divided into five subtypes: discharge pipes, plumb pipes, rain pipes, collectors' pipes and devices. Regarding other causes, occurrences were divided according to the main parts: exterior surroundings and interior compartments.

The next parameter used was the place of origin of the occurrence, which provides relevant information on the incidence of water damage on the different building elements. In this parameter, the claims were grouped according to three distinct areas: private rooms, common areas and external area. It was also necessary to apply a fragmentation, to specify the divisions belonging to each area.

Regarding plumbing materials, they were grouped according to the following nomenclature: galvanized steel, PEX, PPR, HDPE, stainless, copper, lead, PVC, multilayer, connection brass, steel mesh, stoneware, concrete, and metal. Lastly on occurrence characterization, the data about incident prevention was logged into three classes: unforeseen, without maintenance and predictable.

In the building characterization category, starting with the location parameter, the registration was sorted out according to the municipalities belonging to Lisbon. The next step was to store the information concerning housing type, according to two kinds - single family and multifamily. The characterization of the structural solution of each building was carried out based on floor type, wood or concrete.

There was also a parameter about the general state of conservation of the dwelling, based on direct visual inspection, according to the needs for repair of the structure, roof, walls, and window frames. This information was documented according to two classes, good or bad. As last parameters in this category, information about the building's construction age and dwelling area were stored.

In the cost characterization category, starting with corrective action, information was grouped into three distinct types: repair, replacement and unclogging. Based on the element's age, data was stored on average durability of the element's parameter. Regarding occurrence global costs, parameters were created for anomaly damage cost, as well as the cost of the corrective action adopted to restore the proper functioning of the hydraulic network.

3. Results and discussion

3.1 Data sample validation

After the design and construction of the database and the respective storage of information, it was pertinent to carry out the validation of the sample using descriptive statistics concepts. In this work, numerical measures of central tendency and dispersion, as well as box & whiskers diagrams, which serve to visualize the trend of data distribution and detect discrepancies, were used.

Therefore, to carefully analyze the information used in the database, the sample was validated according to the type and subtype of occurrence in each year. On the other hand, all the parameters in the building characterization category were compared with the definitive 2011 Census results for the Lisbon region (INE 2012).

In general, it is possible to state that the data collected is convincing, and it is feasible to achieve conclusive results in the forecast of occurrences per year. Water distribution and inadequate maintenance types present a form of distribution and variability within the normal range. In sewage drainage an outlier was detected, as shown in the figure 2.

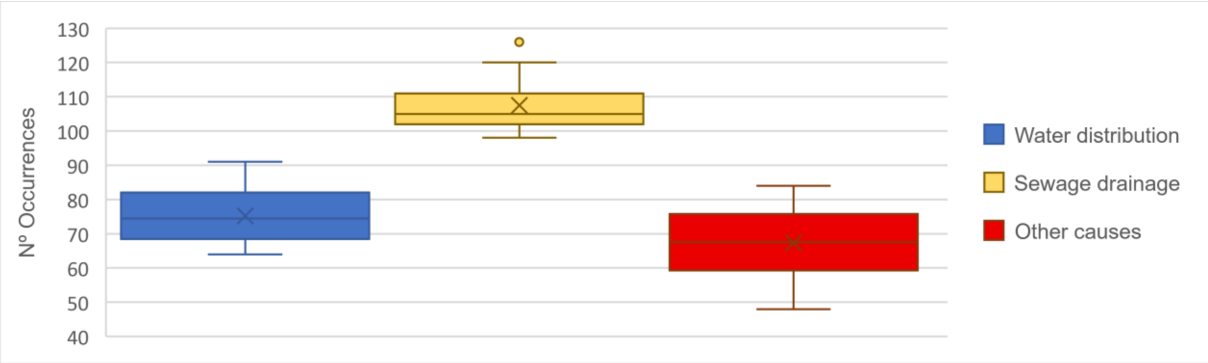

Figure 2 – Box & whiskers diagram by type of occurrence over the years

Since this outlier could compromise sample reliability, a second validation with a subtype parameter was carried out, as shown in figure 3. Although the accessories subtype shows a value considered an outlier, after a deep dive it was found to be a consistent value

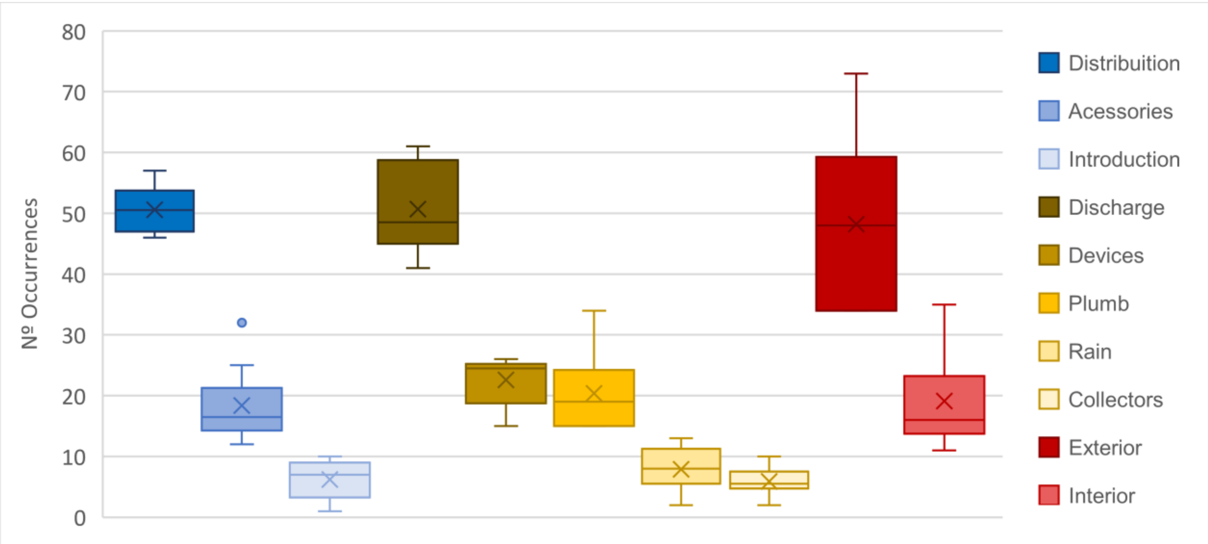

Figure 3 – Box & whiskers diagram related to occurrences by parameter subtype over the years

In summary, the consistency of the results obtained in the 10 years analyzed as well as its consistency with the data from the 2011 Census allows us to consider the sample to be reliable and a safe basis for analyzing claims involving hydraulic networks and other causes.

3.2 Occurrence characterization parameters results

Analyzing the main results, appears that the type of claim with the highest incidence rate occurs in drainage networks for domestic wastewater and rainwater in 43% of cases. The occurrences in the water distribution network correspond to 30.1% of the total and, finally, the claims due to other causes represent 26.9% of the total. Claims originating from hydraulic networks represent 73.1% of the total, which shows their importance during the buildings' exploration phase

Looking at the results in table 2, which shows the total occurrences organized by subtype, It is observed that claims in distribution and supply branches of water distribution networks, in discharge branches of wastewater drainage networks and in elements of the construction of the outer envelope are dominant, corresponding, each, to about 20 % of total occurrences. Claims on hydraulic network accessories, on fall plumb pipes from domestic sewage drainage networks and on interior construction elements, with incidence rates of 7.5 to 9.0% can be classified as medium incidence. It is interesting to note that claims involving accessories exhibit similar incidences for both hydraulic networks.

Table 2 – Number of occurrences by subtype

Occurrence type	Subtype	Nº Occurrences	% of total	Total p/ type	% on type
Water distribution	Distribution	506	20.2%	752	67.3%
	Accessories	184	7.4%		24.5%
	Introduction	62	2.5%		8.2%
Sewage drainage	Discharge	507	20.3%	1075	47.2%
	Devices	226	9.0%		21.0%
	Plumb	204	8.2%		19.0%
	Rain	79	3.2%		7.4%
	Collectors	59	2.4%		5.5%
Other causes	Exterior	482	19.3%	673	71.6%
	Interior	191	7.6%		28.4%

Regarding the results for the place of origin shown on table 3, as expected most occurrences (77.0%) originate in the private area, and on the other hand, those originating in the unbuilding space have a very low value (3.2%). The common areas show a considerable result (19.8%), which is justified by the fact that the exterior walls and roof, driven by its inadequate maintenance, are included in this group. As expected, occurrences from the sanitary facilities, which account for about half of the claims (48%), stand out. Despite its lower incidence rate, the result recorded by occurrences whose cause is in kitchens (17.4%) is relevant. The third highest incidence rate (9.6% of the total) was observed on the exterior walls of the building (facades), which was also expected.

Table 3 – Number of occurrences in each area and place of origin

Area	Nº Occurrences	% per area	Place	Nº Occurrences	% per place
Private	1927	77.1%	Toilet	1200	48.0%
			Kitchen	435	17.4%
			Hall	119	4.8%
			Bedroom	45	1.8%
			Balcony	128	5.1%
Common	494	19.8%	Facade	240	9.6%
			Roof	128	5.1%
			Access	93	3.7%
			Parking	33	1.3%
External	79	3.2%	Outside	79	3.2%

Looking at the results for water distribution materials in table 4, the galvanized steel tubes were responsible for most incidents (55.5%). Bearing in mind that this material was frequently used in buildings constructed until the end of the 20th century, the high number of claims recorded is mainly down to the high number of existing pipes of this type than rather to any characteristic of the material. However, failures in galvanizing can cause corrosion that leads, over time, to pipe rupture. The remaining results seem to show a pattern for which the occurrences in each material depend more on the frequency of its use in buildings than on the physical and chemical characteristics. Lastly, regarding accessories materials, it appears that brass is responsible for most claims (13.8%), in comparison to accessories made of steel mesh (10.6%). It is not possible, however, to see if there is a greater probability of damage to these brass connections or if these connections exist only in greater numbers.

Table 4 - Number of occurrences for each material of the water distribution network

Occurrence type	Material	Nº Occurrences	%
Water distribution	Galvanized steel	417	55.5%
	Brass connection	104	13.8%
	Steel mesh	80	10.6%
	PEX	61	8.1%
	PPR	21	2.8%
	HDPE	15	2.0%
	Stainless	15	2.0%
	Copper	15	2.0%
	Lead	11	1.5%
	PVC	9	1.2%
	Multilayer	4	0.5%

The results for the sewage drainage network in table 5 show that polyvinyl chloride (PVC) pipes are responsible for most accidents (54.0%). As this material has been the preferred solution in this network since the 70s of the last century, it would be expected that most of the buildings surveyed would present this type of material. From the value obtained by low intensity polyethylene (PE) pipes (32.9%), given that it is a material regularly used in the 60s and 70s, it is possible to assume that tubes have not yet been renovated in a significant number of buildings. On the other hand, the replacement of plumb pipes can be an expensive and complex task, which can justify the considerable result recorded by stoneware pipes (6.1%), since it was a material used frequently in the first half of the 20th century.

Table 5 - Number of occurrences for each material of the sewage drainage network

Occurrence type	Material	Nº Occurrences	%
Sewage drainage	PVC	581	54.0%
	PE	354	32.9%
	Stoneware	66	6.1%
	Metal	41	3.8%
	Concrete	33	3.1%

The prevention of the accident is related to the behavior of the residents regarding the maintenance of the building elements. Through the main results in this parameter about half of the occurrences were sudden and unforeseen. It should be noted that preventive maintenance actions could, however, have prevented around 30% of claims and that postponed repair actions would have been responsible for about 15% of claims. Regarding only hydraulics networks claims, it should be noted that about three quarters are sudden and unforeseen.

3.2 Building characterization parameters results

Analyzing the results in figure 4, the municipalities that stand out are Lisbon (18.7%) and Sintra (17.1%). Among the rest, the municipalities of Cascais (9.6%) and Oeiras (8.8%) show slightly higher results. As can be seen, the municipalities of Greater Lisbon are responsible for most cases, while the highest incidence rate for the municipality of Setúbal Peninsula can be found in Almada (5.9%).

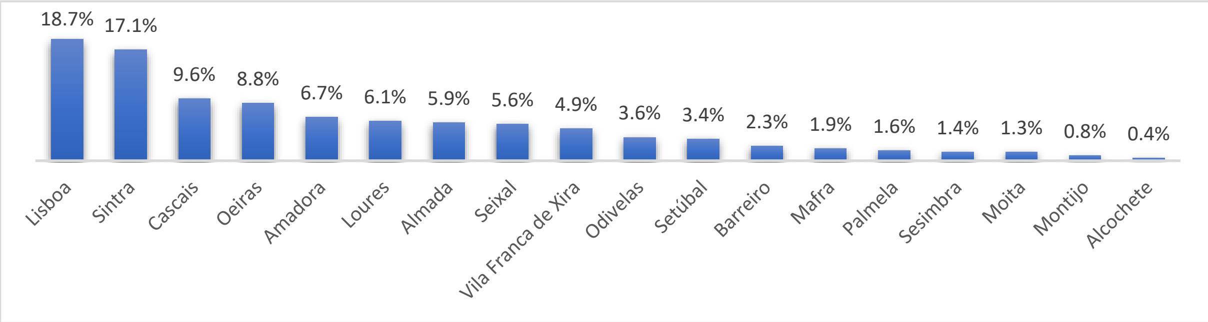

Figure 4 - Proportion as a percentage of the number of occurrences in each municipality

Evaluating the results of the sample for the housing type, most of the occurrences occur in multifamily dwellings (87.9%). Thus, in single family homes there is a small decrease in the weight of anomalies in sewage drainage networks, since in this housing type, in general, there is greater control over drainage systems, particularly in terms of rainwater pipes.

Analyzing the results for the type of construction structure parameter, most of the cases originate from buildings with concrete structure (90.3%). In buildings with older wooden floors, the proportion of claims in the drainage system is higher, which can be justified by the difficulty associated with interventions to replace this network, namely of components such as fall pipes or building collectors, often in stoneware.

Through the results about the general state of conservation of the dwelling, it appears that most claims occur in buildings in good condition (89%). In poor state of conservation buildings, claims external to the hydraulic networks are, as expected, preponderant, which mainly results from the general state of degradation of the building elements, particularly in old buildings.

Considering the age of the building's construction results, buildings of the 90s have a higher proportion of occurrences than the rest (25%). It turns out that older buildings, especially between 1946 and 1960, registered a lower incidence of occurrences, when compared to the proportion of buildings in the housing stock of those periods. It can also be concluded that the frequency of occurrences is higher when the buildings have a construction age between 20 and 30 years, which can be justified by the fact that several elements exceed the limit of their lifespan in this period.

Over the results regarding dwelling area, it appears that the accommodations with a useful area between 80 m² and 99 m² have a higher proportion of occurrences than others (31.6%), which motivates a significant difference in comparison with the Census data. It is also observed that the accommodations with a smaller living area show a lower number of incidences in claims, and the difference in relation to the Census is more evident in the dwellings with useful area between 40 m² and 59 m².

3.2 Cost characterization parameters results

Evaluating the results in figure 5, in most situations plumbing components do not exhibit an advanced state of deterioration that does not allow for temporary repair. The replacement actions, more expensive, were implemented in about 15% of the occurrences on both hydraulic networks. Lastly, simple unclogging in the sewage drainage, which can also be considered a punctual repair, was implemented in about 10% of cases.

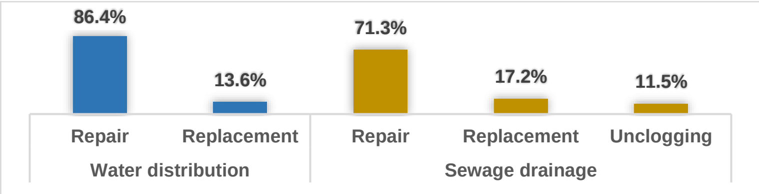

Figure 5 – Corrective action distribution in each hydraulic network

The results in table 6 show that the average durability of the elements responsible for water damage in buildings is 26 years. Sewage drainage components are the ones that exhibit greater durability (31 years), with plumb pipes being the ones with the highest lifetime value (40 years). The constituents of the water distribution have a lower durability (25 years) and in this network the introduction pipes have the highest value (30 years). The inadequate maintenance occurrences, on the other hand, show the lowest durability value among all types (21 years). The elements of the exterior have greater durability (23 years) compared to those located in the interior (15 years).

Table 6 - Average durability (in years) of the elements by type and subtype of occurrence

Occurrence type	Average durability	Subtype	Average durability
Water distribution	25	Distribution	25
		Accessories	22
		Introduction	30
Sewage drainage	31	Discharge	30
		Devices	25
		Plumb	40
		Rain	27
		Collectors	35
Other causes	21	Exterior	23
		Interior	15
Total	26	Total	26

Regarding average damage costs, results show that, in the case of hydraulic networks, the larger the diameter of the components, the greater the reduction in the average cost, so the conclusion is that, despite the reduced number of occurrences, anomalies in connection and introduction branches and distribution columns of water distribution networks, as well as building collectors and inspection chambers of drainage networks, can result in high losses. Taking in consideration the discrepancy and variability between the average damage costs arising in the sample by occurrence subtype, to assess the distribution of costs more affectively and obtain better results, it was necessary to remove outliers in each subtype. Through the results in table 7, it is obtained that the average damage expense is 13.19 €/m². Observing the results by type of occurrence, the values are very similar between each other (around 13,20 €/m²). On subtype results, occurrences originating from plumb pipes cause higher expenses than the other components of the hydraulic networks, and in contrast those resulting from collectors' pipes result in lower costs.

Table 7 – Average damage cost (€/m²) by type and subtype of occurrence (excluding *outliers*)

Type	Subtype	Nº Occurrences	Average damage cost (€/m²)	Average damage cost (€/m²)
Water distribution	Distribution	506	12.80	13.35
	Accessories	184	14.41	
	Introduction	62	14.64	
Sewage Drainage	Discharge	507	13.58	13.13
	Devices	226	11.71	
	Plumb	204	14.97	
	Rain	79	11.55	
	Collectors	59	10.54	
Other causes	Exterior	482	14.05	13.12
	Interior	191	10.78	
Total		2500	Average	13.19

Analyzing results in table 8, the sewer drainage network has a higher average repair cost (4,27 €/m²), compared to the water distribution network (3,67 €/m²). On the other hand, the average cost of repairing a hydraulic installation is 4,03 €/m². In the water distribution network, the introduction pipes have a higher repair cost (6,82 €/m²). In contrast, as would be expected, accessories have the lowest cost (2,17 €/m²). The distribution pipes, which represent most occurrences, have an average repair cost of 3,83 €/m². In the sewage drainage network, collectors' pipes have the highest average repair cost (6,55 €/m²). Conversely, evacuation accessories (devices) have the lowest cost (3,11 €/m²). Discharge pipes, responsible for most of the network's claims, have a repair cost of 3,92 €/m².

Table 8 - Average repair cost (€/m²) by type and subtype of occurrence

Type	Subtype	Nº Occurrences	Average repair cost (€/m²)	Average repair cost (€/m²)
Water distribution	Distribution	506	3.83	3.67
	Accessories	184	2.17	
	Introduction	62	6.82	
Sewage Drainage	Discharge	507	3.92	4.27
	Devices	226	3.11	
	Plumb	204	5.62	
	Rain	79	4.67	
	Collectors	59	6.55	
Total		4.03	Average	4.03

Through damage cost distribution results in figure 6, it can be observed that about half of the claims are in the range from 4,00 to 12,00 €/m², corresponding to about a quarter of claims with losses between 12.00 and 20.00 €/m² and about 10% of claims with losses above 28.00 €/m².

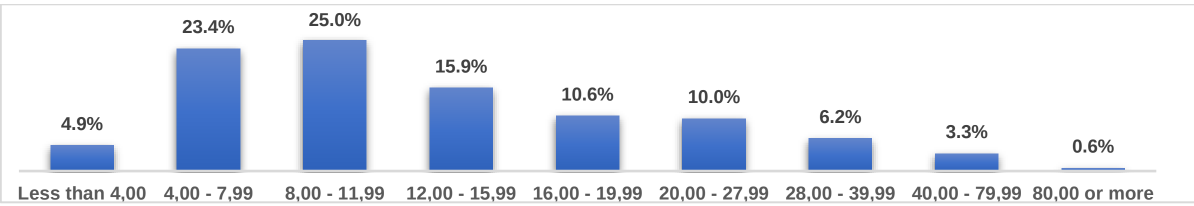

Figure 6 – Damage cost per gross construction area (€/m²)

Regarding repair cost distribution results in figure 7, it can be noted that network repairing costs in about 37% of the claims are between 0.80 and 2.40 €/m². Around the same number of claims occur in the interval between 2.40 and 4.00 €/m². Lastly, for the range between 4.00 and 5.60 €/m² in about 15% of cases.

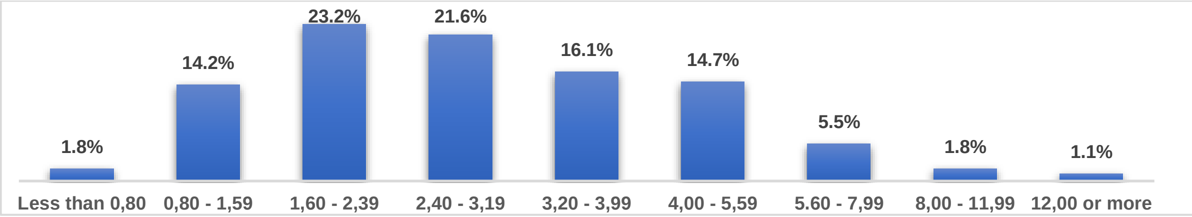

Figure 7 – Repair cost per gross construction area (€/m²)

4. Conclusions

In general, claims in water distribution networks have a durability of around 25 years and correspond to about 30% of claims involving water damage in buildings in the Lisbon metropolitan area. On the other hand, claims in wastewater drainage networks have a durability of 25 years or more and correspond to about 45% of overall total. Lastly, anomalies in construction elements external to the building's hydraulic networks correspond to about a quarter of the claims in buildings, being the most frequent type of claim in buildings in poor state of conservation.

Since about 80% of the existing buildings were built between 1919 and 2000, the vast majority have galvanized steel water distribution networks, which are responsible for about half of the claims. More than a third of older buildings (around 100 years old), are likely to still have lead plumbing, causing health risks. On the other hand, since more than 60% of existing buildings were built after 1960, PVC drainage networks are common, which are responsible for about 60% of claims. It is also possible to find materials such as stoneware in fall pipes and building collectors' pipes in older buildings.

In water distribution networks, about two-thirds of claims occur in distribution branches, mostly located in sanitary facilities and kitchens. About a third of the occurrences happen in other divisions, particularly in dwellings with a larger area, with more extensive networks. The incidence rate of claims is reduced with the ease of access to the building network and with the increase in the diameter of the pipes, as is the case of the introduction branches, often installed in sight or on easily accessible walls.

In sewage drainage networks, approximately 45% of claims occur at discharge branches, mostly located in sanitary facilities and kitchens, where damage to accessories and devices is also relevant. The occurrences in other divisions are unlikely, which increases the importance of these claims in houses of smaller areas. The incidence rate of claims is reduced with the ease of access to the building network and with the increase in the diameter of the pipes, as is the case of collector's pipes, often installed in sight in basements.

The other occurrences without any relation to the hydraulic networks, most claims occur in elements of the outer envelope, such as current façade areas, roofs and balconies. About a quarter of claims occur in sanitary facilities, due to deficiencies in the waterproofing of coatings and joint filling materials.

5. References

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