


## Article

# Failure Modes in Electricity and Telecommunication Facilities in Dwellings in Spain

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**Abstract:** The value of a house depends not only on the quality of the construction elements but also on the functionality of its installations. Making mistakes during the design and even execution phases of installations in newly built homes is common. This paper determines, catalogues, and quantifies faults in electrical and telecommunications installations in dwellings based on owners' complaints and using the 'learning from faults' philosophy. To this end, 154 complaints concerning these installations in all of Spain were analyzed and protocolized. The results show that, in all types of dwellings, the most common fault was 'alterations and malfunctions' (81%), followed by 'incorrect or lack of placement of elements' (14%). The pathological origin with the greatest presence in the research was 'shortcomings and omissions in the installation' (40%) and 'anomalies in the installation' (36%). Moreover, all functional deterioration processes as well as the type of dwelling where each of these parameters occurred most were defined and quantified (association between each fault and its cause). Finally, the 'probability factor' (PF) was determined, which numerically quantifies the probable existence of complaints according to four ranges. The results will pave the way for more precise inspections during the construction phase.

**Keywords:** facilities; construction faults; design faults; dwelling projects; fault modes; project engineering



**Citation:** Carretero-Ayuso, M.J.; Sánchez-Barroso, G.; González-Domínguez, J.; García-Sanz-Calcedo, J. Failure Modes in Electricity and Telecommunication Facilities in Dwellings in Spain. *Appl. Sci.* **2021**, *11*, 5274. <https://doi.org/10.3390/app11115274>

Academic Editor: Giuseppe Marco Tina

Received: 9 April 2021

Accepted: 3 June 2021

Published: 6 June 2021

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## 1. Introduction

The electrical facility of a dwelling is composed of all of the interior elements used for supply, control, and distribution of electricity from the general connection to each of the internal power take-offs and lighting, such as circuit breakers, thermal-magnetic circuit breakers, switches, and plugs [1]. A telecommunications installation is usually made up of various elements such as the equipment for capturing television and radio channels, a basic panel for connection to data and internet service, telephone channels, circuits and distribution conductors, connection points to power supply networks, and connection sockets for said installation in different rooms of the dwelling [2].

A series of installations (electricity, gas, fire, potable water, sewage, rain, and ventilation) play a vital role and, as such, must be optimized when designing a building, since without them, the building would not operate correctly [3]. Making mistakes during both the design and execution phases in building installations is common. Consequently, a high degree of discomfort is generated among users/owners [4].

Balaras et al. [5] audited 349 residential buildings in seven European countries to find out how building elements (architecture and installations) are degraded. The follow-up analysis revealed the most striking influencing factors on the deterioration of residential buildings across Europe. In addition, they estimated service lives of various architectural elements of buildings and electromechanical installations.

Georgiou [6] determined 536 faults in a sample of 100 dwellings in Australia (5.36 faults per household). There are precedents of studies of many years ago [7] that already valued

the importance of managing installations during the building phase, evaluating the surcharges of a poor design and mismanagement. They concluded that the owner's role is as much of a determinant since commissioning the project as during useful life. Furthermore, Waziri [8] studied faults during both the design and construction phases that influence the maintenance of residential buildings in Nigeria. The results of his 60 surveys revealed that the use of low-quality products in construction and for the manufacture of installations parts—non-compliance with specifications—and the weak quality control on site are the most significant factors contributing to poor maintenance.

Shirkavand et al. [9] studied faults related to the delivery of buildings in Norwegian construction projects. They found that the main fault in technical installations of a building was that it did not work, preventing the remaining systems from performing correctly.

The building process is broad and heterogeneous, so different regulations may make certain control items mandatory. The concepts and control points on site should be expanded and intensified for two reasons [10]: to minimize the risk of subsequent complaints by owners and to ensure compliance with the characteristics of what the developer sells. However, data on current faults are challenging to obtain and can be poorly structured due to the lack of uniformity in the classification systems used by contractors [11]. As a counterpoint, research has shown that prior revisions of project requirements can avoid between 70% and 80% of the common faults detected in buildings [12]. It has also been proven that refurbished residential buildings, after a certain period of fault-free operation, perform as well as new buildings [13].

Islam et al. [14] studied factors that influence the cost performance of real estate developments due to building re-processing [15]. Notwithstanding, they did not take into account the incidence of faults reported by building owners. The widespread occurrence of faults and errors leads to economic and time deviations in construction projects that must be reduced [16]. Therefore, experience-based learning can help to minimize faults and their consequences [17]. Learning from faults is a beneficial process in engineering and business environments [18,19] and can be leveraged to build knowledge.

Gamil and Abdul Rahman [20] studied the critical factors contributing to construction fault in Yemen. They ranked 62 factors including, among others, poor construction management and frequent changes in design. Qi et al. [21] conducted a questionnaire survey to evaluate the frequency of quality faults. The research revealed that quality faults are caused by defaults by workers, inadequate checking procedures, incomplete construction site surveys, inaccurate design work, fraud of construction companies, and inefficient cooperation between different departments.

Other authors applied different techniques to analyze the fault mode of building components. For example, Gonzalez-Dominguez et al. [22] applied Markov chains to determine the most appropriate maintenance period for roofs by analyzing a comprehensive fault database. El-Haram and Horner [23] analyzed construction projects of 18 houses drawn from Dundee City Council's housing stock by applying fault mode and effects analysis (FMEA) under a Reliability Centered Maintenance (RCM) approach. A comparative analysis of condition survey, FMEA, and RCM were provided to assess the benefits of applying RCM to an existing building stock. Benbachir et al. [24] determined the risks of structural faults by using fault mode effects and criticality analysis (FMECA) to establish a methodology for managing these faults. Lin and Fan [25] explored the relations between defect types and quality inspection grades of public construction projects in Taiwan using data mining and fuzzy logic. A classification of 499 defect types was created on the basis of 17,648 defects from a sample of 990 construction projects. Capozzoli et al. [26] conducted a fault detection analysis using data mining techniques for a set of smart office buildings using pattern recognition techniques together with outlier detection methods.

This paper studies the faults in electricity and telecommunications installations in dwellings based on complaints registered by their owners. No papers dealing with faults of these two domestic installations has been found after reviewing the international scientific references. Related investigations are focused on analyzing surveys and not events that

have taken place. This fact makes this research a novelty in the field of forensic engineering. This research aims to shed light on the most common faults in the electrical and telecommunications installations of dwellings that lead to owners filing court action and then reducing the costs due to these processes. However, research into construction faults usually analyses buildings that are dependent on each other (i.e., they belong to the same construction company or developer), which can lead to somewhat biased results. In our case, no parameter can link one work with another, ensuring independence.

The aim of this work is to identify the most common incidences in electricity and telecommunication facilities and to propose a methodology to identify the weak points in the building process that lead to user dissatisfaction, non-quality costs, complaints, and judicial filings during a building's service life. The results obtained from this research contribute to improving the quality of construction. Knowing the typology and probability of occurrence of this type of fault allows professionals in the sector to be aware of the most recurrent faults and to solve and/or prevent them at the design stage. Additionally, government decision-makers will be able to adapt legislation to avoid the most frequent faults.

## 2. Materials and Methods

The methodological process has been sequenced in the following subsections.

### 2.1. Data Collection

The sources of information used for this work were records belonging to the liability insurance company that covers the Official College of Technical Architects and Quantity Surveyors of Spain [27]. Data about fault modes in both electrical and telecommunications facilities between 2011 and 2013 were collected [28]. All of these faults led the owners to take legal action against companies that built their houses.

Judgments from the Administration of Justice do not distinguish between design faults and execution faults. A judge rules that the installation was inefficient but does not specify whether it was caused by a design or implementation fault, as they focus only on proving the existence of a fault.

Homeowners take action in court when a fault appears in a building, and the contractor fails to repair it. Once the judicial process begins, technical-specialist reporters (forensic engineers) conduct an assessment of faults. These forensic reports from the civil liability insurance company that covers the group of technical architects of Spain [29] are analyzed in this paper. To ensure the consistency of the sample, only information from complaints in which legal proceedings were final were taken into account. Consequently, no appeals can modify the results of our investigation. As a result, a comprehensive analysis was conducted for 100% of the judicial complaints with final judgements during this period in Spain. Therefore, it is not a partial sample in which there may be room for error. The sequence used by the authors for data collection is shown in Table 1.

**Table 1.** Phases in the data collection and reading processes.

Phase	Concept
1	Request for access to all current court records
2	Detailed reading of court records to identify faults
3	Characterization and grouping of the different faults according to their nature
4	Identification of the types of dwellings in which each fault occurs
5	General accounting of the cases for each of the installations
6	Determination of the total percentage of each of the fault groups
7	Distribution of fault groups by individual installations
8	Obtaining the values according to the pathological origin
9	Quantification of cases according to the type of dwelling and type of fault
10	Breakdown of cases by individual installations and types of faults
11	Analysis of functional impairment processes
12	Validation of the proposed interrelation matrix
13	Determination of the categories of the probability of complaints

## 2.2. Characterization

All complaints were analyzed and protocolized, totaling 154 cases. The facilities studied were electricity and telecommunications. The following descriptors were used to classify them: type of fault, pathological origin, and type of dwelling. Thus, the faults were classified into three groups of faults:

- Alterations and malfunctions (F1): inadequate or inefficient operation of an installation, such as part of the ducts are strangled or diminished, inefficient installation, the control panels do not function properly, communication between common and private branches of the dwellings, presence of faults in control elements, and alteration of the design parameters of the systems;
- Incorrect or lack of placement of elements (F2): elements are missing in the installation in question or are in an incorrect layout, parts have been installed in inaccessible places, pipelines not appropriately closed, inappropriate layouts or in unsuitable places, inadequate closure of the vertical service duct, moving parts, and ducts connected to the wrong location; and
- Water ingress through construction elements (F3): water gets inside the elements or channeling of the installation, the effect of water on the materials of these installations, filtrations to conduits due to the breakage of components, the entry of water through fracture points due to mechanical actions or due to the movement between parts and coupling elements, the loss of watertightness between poorly connected water pipes affecting the electricity or telecommunications conduits, and the presence of damp due to capillarity in the walls affecting boxes or couplings of this type of installation.

The pathological origins that caused these faults were categorized and classified into these four types:

- Shortcomings and omissions in the installation (O1): all or part of the constituent elements necessary for the operation of the installation have been dispensed or systems have been installed without their devices;
- Anomalies in the installation (O2): an element or set of elements has suffered damage;
- Deteriorated or misplaced couplings (O3): the union between parts has not been executed correctly due to a lack of connection or incorrect handling of couplings; and
- Deficient or inadequate materials (O4): disposal of elements and/or materials that are unsuitable, deteriorated, or unfit for the function they must perform.

The types of dwellings studied were as follows:

- Apartment blocks (T1): a building in which the height above the surface predominates and its primary use (excluding the ground floor) is to be inhabited by two or more families;
- Attached houses (T2): a building that is inhabited by a single family and, constructively, has direct contact with other houses forming a row, with the houses all having individual access from the street and being independent of each other; and
- Detached houses (T3): a building that is inhabited by a single family and, constructively, is not in direct contact with other houses or buildings, having specific access from the street, although they are usually surrounded by a plot of land with a private garden.

An interrelation matrix between the types of faults and the pathological origins that caused them was made based on the above classification and with regard to the entire set studied. This conceptual matrix was never intended to replace the knowledge of the people who carry out the inspections or their rational judgement on each situation. The objective was to have a support base for less seasoned engineers for consultation after the results of this research are validated.

Traditionally, other authors have used interrelation matrices in diverse fields for inspection and diagnosis of construction units, such as flat roofs [30], pitched roofs [31], masonry walls [32], etc. Besides marking whether there is (or can be) a technical interrelationship between a fault and its causal origin, these matrices try to assess the constructive

force that links them. In this research, such a linkage is represented in Table 2. The intersection of the columns (type of fault) and the rows (pathological origin) are symbolized as follows:

‘- -’ There is no interrelation between the type of fault and the type of pathological origin.

‘□’ There is an interrelation between the type of fault and the type of pathological origin, and this interrelation has a low numerical incidence (estimated at less than 1 in 3 times).

‘■’ There is an interrelationship between the type of fault and the type of pathological origin, and this interrelationship has a high numerical frequency (it is estimated that 1 in 3 times or more). This is usually the ‘predominant’ situation.

**Table 2.** Conceptual interrelation matrix between types of faults and pathological origins.

Type of Pathological Origin	Type of Fault Group		
	Alterations and Malfunctions	Incorrect or Lack of Placement of Elements	Water Ingress through Construction Elements
Shortcomings and omissions in the installation	■ #	□	□ #
Anomalies in the installation	■ #	□	--
Deteriorated or misplaced couplings	□	□ #	□
Deficient of inadequate materials	□	--	--

Legend: -- There is no interrelation between the type of fault and the type of pathological origin. □ There is an interrelation between the type of fault and the type of pathological origin, and this interrelation has a low numerical incidence. ■ There is an interrelation between the type of fault and the type of pathological origin, and this interrelation has a more intense numerical incidence. # Interrelationships that obtained a different consideration or a nuance of their incidence level during the validation process.

A data source with reliable information and a number of cases sufficient to establish the interrelationships, expressed in the form of a matrix, was necessary to validate and verify the interrelationships proposed in Table 2. This source of data is the set of types of faults obtained from the complaints made before the courts by the owners (which included an expert report attesting to the existence of such faults).

### 2.3. Assessment

In the second stage of the research, a group of eight expert consultants carries out an ‘inter-judge validation’ [33]. In order to quantify the possibility of filing complaints, a risk analysis was carried according to UNE-EN-31010 standard [34]. People with at least 20 years of experience in the field of anomalies or faults were asked, such as auditors of civil liability insurance companies, university professors, heads of companies, and quality control laboratories, etc.

The concept of ‘probability of occurrence of a fault’ was extracted from UNE 60812 standard [35] to assign two of the three descriptors (type of fault and type of pathological origin). This standard recognizes that there is no univocal definition to assign a ‘probability of occurrence of the fault’ and that specialized persons who conduct the analysis must define a common framework of action for each case. The following five procedural phases were carried out:

- Phase 1: The owners’ degree of annoyance or perception of dissatisfaction with the faults in their buildings was assigned individually by each of the expert consultants asked. This assessment was made according to the characteristics of these faults and the problems of use, which made the owners more or less inclined to file a legal complaint. The decision was to bijectivity assign a score to each of the fault types, which was determined to be 1, 3, and 5. Similarly, the group of expert consultants decided to assign to the types of pathological origins a bijective-type score representing the degree of constructive or technical importance that these origins represent. It was



determined to be 2, 4, 6, and 8. This valuation process was performed according to the following Equation (1) [36].

$$p(x) = \sum_{n=1}^q \frac{m(n, i(n, x))}{q} \quad (1)$$

where  $x$  = each of the types of fault to be scored;  $m$  = scores awarded;  $q$  = number of expert consultants consulted (8, in this case);  $n$  = expert-consultant ' $n$ ' (therefore:  $1 \leq n \leq q$ );  $p(x)$  = average score awarded by ' $q$ ' expert consultants for the fault ' $x$ '; and  $i(n, x)$  = bijective application associating the expert consultant ' $n$ ' with the types of faults.

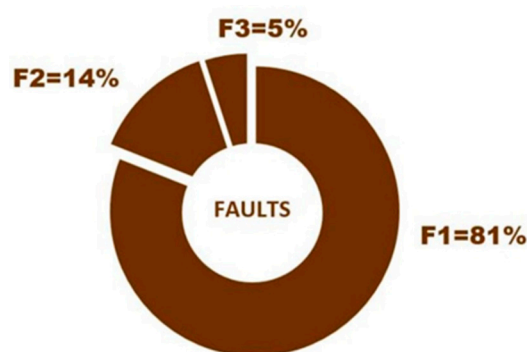
- Phase 2: level of joint severity, which is defined as the combination (multiplication of the scores) of the two scores defined in Phase 1.
- Phase 3: the 12 combinations resulting from correlating the 3 types of faults and the 4 types of pathological origins were quantified. An 'interrelation and intensity quadrant' was designed according to the degree of each interrelation.
- Phase 4: a 'weighted probability of complaints quadrant' was created, resulting from multiplying the level of joint severity (calculated in Phase 2) by the 'interrelation and intensity quadrant' (calculated in Phase 3). Each value of this quadrant is called 'probability factor' (PF). In this way, the value of PF numerically quantifies the chances of an owner filing a complaint in court, depending on the particular problem at hand.
- Phase 5: four 'probability categories' are established for the owners' complaints, based on the values obtained by PF in Phase 4, given that there is a wide spectrum of results. These categories make it easier to visualize and understand the results obtained. The categories are color-coded to make it easier to visualize their importance: white (W), green (G), yellow (Y) and red (R).

### 3. Results

The balance of complaints is uneven between the two domestic facilities. Electricity accounts for about 2/3 of the total (61.04%) data, while telecommunications accounts for just over a third of the total (38.96%).

#### 3.1. Values Depending on the Type of Fault

Each of the three types of faults that were the subject of owners' complaints was identified and quantified as indicated in Figure 1. 'Alterations and malfunctions' were the most common (F1 = 81%). Second was the 'incorrect or lack of placement of elements' (F2 = 14%). Finally, the remaining 5% corresponds to 'water ingress through construction elements' (F3).



**Figure 1.** General percentages of the types of faults detected in the research.

In order to go deeper into the weight of each of the faults, Figure 2 was drawn up, indicating the number of cases for each installation. No cases were detected about water ingress related to electrical installation.

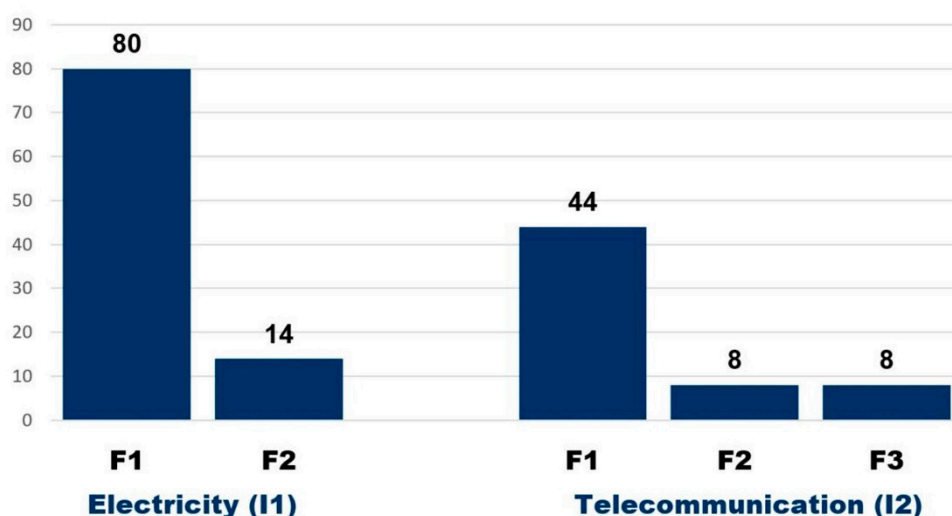


Figure 2. Distribution of the faults present in each of the facilities.

It is remarkable that, in both categories, the main fault accumulates approximately 3/4 of the cases for each one of them ( $F1 = 80$  for I1, which represents 85% of the situations with respect to the total of its own faults, and  $F1 = 44$  for I2, which represents 74% of its cases). Second, there are  $F2 = 14$  cases for I1 and  $F2 = 8$  cases for I2, which account for 15% and 13%, respectively.

### 3.2. Values According to Pathological Origins

Figure 3 shows the pathological origin of faults. O1 is more common, with 40%, followed by O2 with 36%. If these origins are broken down by the two installations, the following values are obtained:

- Electricity (I1) = O1 (39%) + O2 (37%) + O3 (15%) + O4 (9%);
- Telecommunications (I2) = O1 (40%) + O2 (34%) + O3 (13%) + O4 (13%).

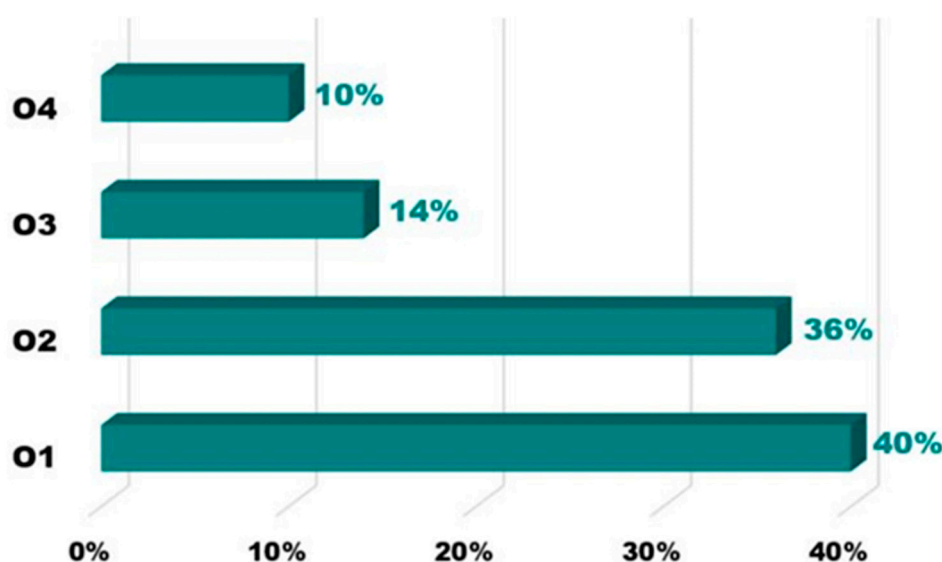


Figure 3. Values of the different pathological origins determined.

As can be seen, the two types of installations consist of all four types of pathological origins, and in both, O1 is the most recurrent, with very similar percentages. The rest of the pathological origins follow the same order either at I1 or I2 and with very similar percentages between them.

### 3.3. Values According to the Type of Dwelling and Type of Fault

The descriptor type of dwelling was also characterized, which constitutes where the faults occurred. Figure 4 shows that ‘apartment blocks’ (T1 = 51%) is where most faults are concentrated, followed second by ‘attached houses’ (T2 = 32%). In all types of dwellings, the most frequent fault was ‘alterations and malfunctions’ (F1 between 14% and 39%), followed by ‘incorrect or lack of placement of elements’ (F2 between 2% and 8%); fault F3, however, was not present in ‘detached houses’.

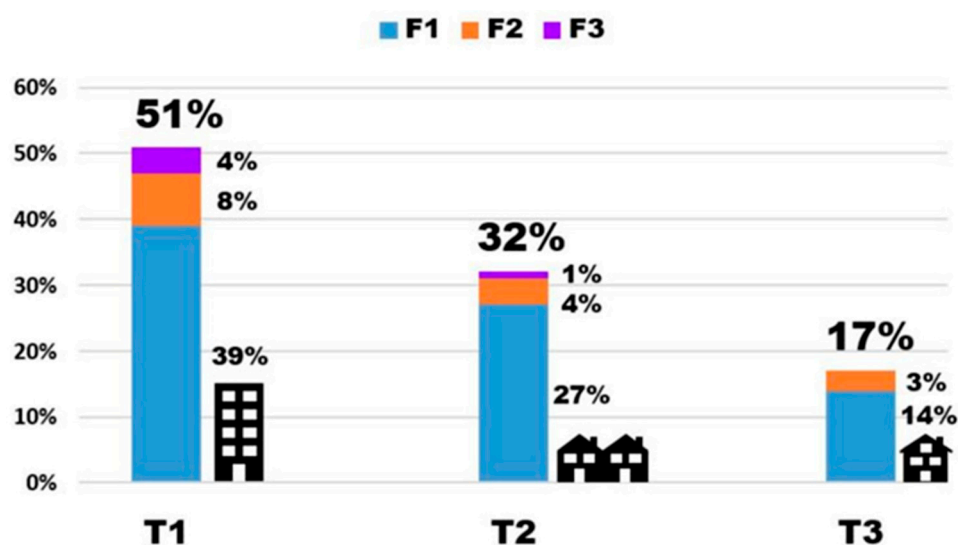


Figure 4. Association between the type of fault and the type of dwelling.

Table 3 breaks down the level of presence of faults by type of dwelling, according to each installation analyzed (Section 2.2). All of the values are expressed in percentages according to the number of cases determined in each type. For each of the rows, the upper value is expressed with respect to the computation of each installation and the lower value is expressed with respect to the total of the sample studied.

Table 3. Percentages according to each facility and type of dwelling according to the data set.

Type of Installation	Percentages of Cases by Type of Dwelling (%)			Total
	Apartments Blocks (T1)	Attached Houses (T2)	Detached Houses (T3)	
Electricity	64.10 (32.47)	64.00 (20.78)	46.15 (7.79)	— (61.04)
Telecommunications	35.90 (18.18)	36.00 (11.69)	53.85 (9.09)	— (38.96)
TOTAL	100 (50.65)	100 (32.47)	100 (16.88)	— (100)

Both apartment blocks (T1) and attached houses (T2) have rather high percentages of faults in electricity installations (64.10% and 64.00%, respectively). On the other hand, detached houses (T3) have a higher concentration of faults in telecommunications installations (53.85%).

### 3.4. Functional Deterioration Processes

‘Functional deterioration process’ (FDP) is defined as the joint and simultaneous linkage/association to a type of fault and its pathological origin, for the two installations studied. To this end, each of the existing faults in electricity and telecommunications installations was analyzed and their recurrence was quantified based on those that were



produced by one or another type of pathological origin. Table 4 identifies the 12 different FDPs, of which 6 are in each of the installations analyzed.

**Table 4.** Percentages of recurrence for each functional deterioration process.

Installation	Pathological Origin	Type of Fault	% of Installation	% of Total	Range
Electricity (I1)	O1	F1	30%	18.2%	VH
		F2	9%	5.2%	M
	O2	F1	32%	19.5%	VH
		F2	5%	3.9%	L
	O3	F1	15%	9.1%	M
	O4	F1	9%	5.2%	M
Telecommunications (I2)	O1	F1	30%	11.7%	H
		F2	10%	3.9%	L
	O2	F1	31%	11.6%	H
		F2	3%	1.3%	VL
	O3	F3	13%	5.2%	M
	O4	F1	13%	5.2%	M

The process at the top obtains 32% of the situations for electrical installations and is I1-O2-F1 (‘alterations and malfunctions’ caused by ‘anomalies in the installation’); second is I2-O2-F1 with 31%, with respect to the telecommunications installation (with the same type of fault and pathological origin). Finally, the third-highest percentage obtained for an installation co-occurred in I1 and I2 (I1-O1-F1 and I2-O1-F1; 30%, respectively): ‘alterations and malfunctions’ caused by ‘shortcomings and omissions in the installation’, both in electricity and in telecommunications.

For the percentages obtained for the general computation of the sample (154 cases), five ranges were typified according to the overall recurrence obtained (values indicated in the final column on the right of Table 4). They are the following (ranked from lowest to highest):

- VL range: those with ‘very low’ recurrence of association with FDP. It encompasses the percentages that have  $FDP \leq 3\%$ . There is only one case, I2.
- L range: those with ‘low’ recurrence of association with FDP. It encompasses the percentages with the ranges of  $3\% < FDP \leq 5\%$ . There are two cases, one in I1 and the other in I2.
- M range: those with ‘medium’ recurrence of association with FDP. It encompasses the percentages with the ranges of  $5\% < FDP \leq 10\%$ . There are five cases, three in I1 and two in I2.
- H range: those with ‘high’ recurrence of association with FDP. It encompasses the percentages with the ranges of  $10\% < FDP \leq 15\%$ . There are two cases, both in I2.
- VH range: those with ‘very high’ recurrence of association with FDP. It encompasses the percentages that have  $FDP > 15\%$ . There are 2 cases, both in I1.

A careful analysis of which types of pathological origins cause the different types of faults reveals the following:

- F1, which is presented in seven associations, is caused by four types of origins (twice for each pathological origin, except once for O3).
- F2, which is presented in four associations, twice for O1 and twice for O2.
- F3, which is presented in a single association, only caused by pathological origin O3.

O3 can also lead to two types of faults (F1 and F3), but O3 only produces F3. In analogy, O4 only causes one type of fault (F1), but F1 can be caused by O1, O2, O3, and O4.

### 3.5. Validation of the Proposed Interrelation Matrix

The breakdown of the functional deterioration processes (Table 4) shows the complete classification of the problems in these two installations. In addition, it also serves to verify

the starting hypothesis shown in the conceptual interrelation matrix expressed in the methodology (Table 2).

In general, there are grounds to say that there is a formal validation of the initial proposal, albeit with some appreciations and nuances, which explain why everything is not exactly the same. To compare Tables 2 and 4, we must first add the analogous functional deterioration processes to the latter (i.e., those that have the same type of fault and pathological origin). Then, the percentages (of the total studied) of the two occurrences of O1-F1 (18.2% + 11.7%), O1-F2 (5.2% + 3.9%), O2-F1 (19.5% + 11.6%), O2-F2 (3.9% + 1.3%), and O4-F1 (5.2% + 5.2%) are added.

- The O3-F1 interrelation only stands true for an electrical installation and the O3-F3 interrelation only stands true for the telecommunications installation.
- The interrelationships between ‘shortcomings and omissions in the installation’ (O1) and ‘alterations and malfunctions’ (F1), and between ‘anomalies in the installation’ (O2) and ‘alterations and malfunctions’ (F1) are certainly the most important for I1 and I2. From a numerical point of view, the initial hypothesis (1 out of 3 times or more = 33%) is not strictly fulfilled since they obtain the values for O1-F1 (29.90%) and O2-F1 (31.10%) together. However, the authors understand that they can be considered ‘predominant’ because the percentage difference with respect to the proposal is meagre, and the difference with the other percentages obtained is vast.
- The interrelations between ‘shortcomings and omissions in the installation’ (O1) and ‘water ingress through construction elements’ (F3) as well as between ‘deteriorated or misplaced couplings’ (O3) and ‘incorrect or lack of placement of elements’ (F2) have not been obtained among the ‘associations of functional deterioration processes’ found in the data source. This may have a double reading: first, that its frequency is very low and a much larger number of cases would be needed for them to appear; second, that they do exist but that their presence does not imply in practice a process of functional deterioration of the facility that is likely to be complained as a fault by the owners.

### 3.6. Determination of the Categories of the Probability of Complaints

The results of the assessment of the interrelationships between types of faults and types of pathological origin, based on the score obtained through the inter-judge validation process, are summarized in Table 5. This phase acquires its values from the percentage computation indicated in Table 4, and on which the sum of the ‘analogous functional deterioration’ processes has been carried out, as indicated in Section 3.6. The Phase 3 quadrant shown in Table 5 is the numerical expression resulting from the conceptual interrelation matrix (Table 2), once all of the percentages of the cases studied have been determined in practice.

As can be seen and as indicated in Phase 4, the values of O1-F1 and O2-F1 are those with the highest values and are included in the RED category (the equation is defined in Phase 5).

With these results in mind, designers and project managers must pay special attention to these two interrelationships, since if they occur in a dwelling, there is a high probability that, once the execution is complete, legal action may be taken by the owners of these dwellings.

**Table 5.** Determination of the probability of complaints by owners of dwellings.

PHASE	CONCEPT		VALUES			
PHASE 1: ‘Degree’ of seriousness of the problem	Type of score		Value according to each descriptor			
	Score according to how much of a nuisance it is to the user		F1	F2	F3	
			3	1	5	
	Score according to technical importance		O1	O2	O3	O4
			6	8	4	2
PHASE 2: ‘Level of joint severity’ of the type of fault and the pathologic origin	Combined score for each interrelationship		Type of fault			
	Type of Pathological Origin		F1	F2	F3	
		O1	18	6	30	
		O2	24	8	40	
		O3	12	4	20	
		O4	6	2	10	
PHASE 3: ‘Interrelation and intensity quadrant’ between the types of faults and the pathologic origin	Percentage presence of each interrelationship		Type of fault			
	Type of Pathological Origin		F1	F2	F3	
		O1	29.9	9.1	0.0	
		O2	31.2	5.2	0.0	
		O3	9.1	0.0	5.2	
		O4	10.3	0.0	0.0	
PHASE 4: ‘Weighted probability of complaints quadrant’ to determine the probability factor	Score of each interrelationship		Type of fault			
	Type of Pathological Origin		F1	F2	F3	
		O1	538.2	54.6	0.0	
		O2	748.8	41.6	0.0	
		O3	109.2	0.0	104.0	
		O4	61.8	0.0	0.0	
PHASE 5: ‘Probability categories’ of users’ complaints	Determination according to the values of the probability factor					
	Category	Code	Condition	No. of interrelationship	PF = Probability Factor according to Phase 4	
	WHITE	W	PF = 0	5 interrelationship		
	GREEN	G	$0 < RF \leq 100$	3 interrelationship		
	YELLOW	Y	$100 < RF \leq 300$	2 interrelationship		
	RED	R	PF > 300	2 interrelationship		

#### 4. Discussion

It has been shown that the information available in claims databases is powerful information for avoiding faults in housing construction. Moreover, processing this information systematically improves the quality of construction. The causes of faults can be identified as errors in building design and construction, or operations and maintenance [37]. The results of the study are in line with the latest dwelling fault strategies, which focus on avoiding the need for post-delivery remediation by dwelling developers, helping to increase owner confidence [38].

The ‘learning from faults’ philosophy was proven to be a suitable tool for increasing the quality of construction [39]. It has been shown that, by analyzing faults, it is possible to recognize their root causes, which are often the result of multiple factors. Case study publications on faults are an effective way to promote fault prevention based on lessons learned from previous faults [40].

A practical way of using this research is as a checklist to verify that the aspects identified as problematic do not occur. For this purpose, the items specified in Section 2.2 of this manuscript are broken down. Additionally, special attention should be paid to the interrelationships in Table 2 that have been marked with the symbol ■, considering that the review

of processes should be more intense in electrical installation than in telecommunications installation (especially in apartment blocks), as shown in Figures 2 and 4.

This article presents novel research as it involves previously unexplored data sources, a new proposed methodology, and the scoring of faults. No authors have studied or identified the knowledge about and the quantification of each of the functional developed deterioration processes presented here before. Therefore, this analysis can be considered a novelty to the field of scientific knowledge regarding this type of installation as well as an essential contribution to forensic engineering [41].

No precedent was found of research employing data on electricity and telecommunications facilities in new dwellings faults. In view of the difficulty of accessing such records and of collecting and analyzing all cases in a country occurring over several years, this research provides forensic engineering with a new methodology of study.

FMEA and FMECA have been widely used and allow for risk analysis in abnormal situations of building installations. This systematic method makes it possible to design an assessment sheet in order to identify the degree of priority of the building's risk [42]. These can be used by project teams to assess and control how an item can fail, to check the feasibility of design prior to build, to ensure correct selection of material prior to build, to understand risks in assembly prior to build, and to understand potential operational failures prior to use.

The study of a large number of real faults makes it possible to move forward and to define checklists to minimize future errors, preventing them from reaching the use stage of building [43]. This is compatible with the Construction 4.0 approach, which is a unique opportunity to reconvert a sector that has always been burdened by deficient levels of productivity, caused by overly artisanal ways of doing things and anachronistic business management [44].

It has been observed that electrical and telecommunications engineers involved in housing do not usually take into account the concept of pathology as a primary consideration in their actions. This is due to the fact that these pathologies have a lower incidence than in other installations such as roofs, façades, and structures, among others [45]. However, the research has shown that many of these incidents generate complaints from users that go all the way to the courts of justice. It also became clear that it is necessary for the operators involved to be sufficiently trained. They should also carry out a final check of the operation and commissioning of this type of installation [46]. This final check of the functioning of the installations should always be carried out, as it has been proven in this research that 52.38% of faults appear in the first three years of the building's life.

This research focuses on newly constructed dwellings, excluding refurbishment and extension works, which represent most works carried out in Spain. In contrast to other countries, refurbishment in Spain has traditionally been smaller in volume [47]. However, in housing refurbishments, electricity and telecommunications installations are usually completely replaced [48]. Therefore, the findings of this research can be extrapolated to refurbished dwellings.

Measures and policies to maintain or upgrade the system are necessary to prevent any installation from degrading over time [49]. Findings provide construction stakeholders and researchers with a tool to improve the maintenance of these types of installations and to minimize errors, which reduce repair costs during their lifetime [50]. In addition, the results can be incorporated into the maintenance plans to optimize the periodicity of the preventive maintenance spectrums, and they may be of interest to other countries to know the probability in which the owners of buildings file complaints. This is possible because the values obtained correspond to a significant number of buildings and not just a partial or localized sample. In addition, this information can help reduce project faults and to minimize the impact of repair costs [51] due to non-quality processes [52]. Moreover, categorization of the different parameters under study can serve as a basis for implementing a procedure to deal with the problems that occur in dwellings in other countries. Specifically,

its extrapolation to the European Union environment is guaranteed since there are common basic regulations as well as freedom of transit of goods and professionals.

These results can be extrapolated to other building typologies. The main limitations of this work focus on the fact that the electrical and telecommunication installations of the buildings analyzed in the sample belong to residential buildings and are therefore less complex than in other buildings.

Future work should focus on quantifying the economic savings that could be generated by using the procedures defined in this research.

## 5. Conclusions

Faults in electricity and telecommunications facilities in dwellings have been studied based on the complaints made by their owners. It has been proven that the installation of electricity (61%) is where the highest concentration of faults occurs. It was observed that apartment blocks are where most faults arise (51%), followed by attached houses (32%).

The results also showed that, in all types of dwellings, the most common fault was ‘alterations and malfunctions’ (81%), followed by ‘incorrect or lack of placement of elements’ (14%). For its part, the pathological origins with the greatest presence in the research were ‘shortcomings and omissions in the installation’ (40%) and ‘anomalies in the installation’ (36%). For functional deterioration processes, 12 different possible combinations were observed; of these, the process that repeats most is ‘alterations and malfunctions in electricity caused by the existence of anomalies in the installation’ (30%).

Four categories of probability have been obtained for owners’ complaints. The highest probability factor ( $PF > 300$ ) contains two associations between the type of fault and the pathological origin, where there is the greatest probability of problems appearing on-site, and therefore, owners file complaints before courts.

The results allow for a more precise inspection work during construction. In addition, the concretion of different faults serves to draw up a checklist on the theoretically most conflictive points, which increases the quality of construction.

**Author Contributions:** Conceptualization, M.J.C.-A. and J.G.-S.-C.; data curation, M.J.C.-A.; formal analysis, G.S.-B. and J.G.-S.-C.; investigation, M.J.C.-A. and J.G.-S.-C.; methodology, M.J.C.-A. and J.G.-S.-C.; resources, M.J.C.-A. and J.G.-D.; software, J.G.-D.; supervision, J.G.-S.-C.; validation, J.G.-S.-C.; visualization, G.S.-B.; writing—review and editing, G.S.-B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the MUSAAT Foundation’s Action Plan, wherein it was agreed upon to carry out research nationally on buildings titled “National statistical analysis on construction pathologies”. Also was funded by European Regional Development Fund through Research Projects linked to the VI Regional Plan for Research, Technical Development and Innovation from the Regional Government of Extremadura (2017–2020), grant number GR18029.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data available on request due to privacy restrictions.

**Conflicts of Interest:** The authors declare no conflict of interest.

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