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SYSTEM OF INSPECTION AND DIAGNOSIS OF EXTERIOR COATINGS OF PITCHED ROOFS

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EXTENDED ABSTRACT

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1. INTRODUCTION

The exterior coatings of roofs are one of the most relevant non-structural elements of a building, due to their function and to the pathologies associated to the loss of water tightness. The occurrence of anomalies in these coatings may originate structural problems in the roof and in the remainder of the building, as well as lead to losses related to furniture and goods inside the building.

The diversity of coating typologies that have been developed and may be found in the market is due to the necessity of improving the conditions of habitability beneath the roofs. With the evolution of Society, the preoccupations and demands related to roofs grew ever more rigorous and go far beyond the demand of water tightness to rain. The great vulnerability to flaws in the performance demands that are imposed on roofs, makes it so that the interventions on anomalies on exterior coatings of pitched roofs (RECI) are done with a character of urgency, for which reason regular inspections and a continuous maintenance are necessary, to avoid greater damage which can affect the whole of the building. In this work, tools are developed to assist the inspector in his activity, making it more efficient, contributing towards the reduction of costs in the use and maintenance stage.

This research work is further justified by the need to normalize the knowledge of anomalies that continue to emerge in RECI despite the growing focus on the quality of constructions. The emergence of anomalies is due to execution and maintenance errors, but also to the lack of systematization of knowledge of new materials - whose deepening is intended with this work. The ultimate goal consists of contributing to a greater durability and service life of coatings, and the delaying of signs of degradation.

2. TECHNOLOGY

The diversity of exterior coatings of pitched roofs is very great but, in the present work, only those with significant use (even if only in specific zones, such as slate) are considered. The studied RECI are slate, ceramic, micro-concrete, fiber-cement, metallic, plastic, and mixed (composite boards, sandwich panels, asphalt shingles and metallic tiles). All RECI pose advantages and disadvantages, for which the reason the adoption of a solution depends, mostly, on durability, economy, and the aesthetic demands associate to the type of use of the building. There are coatings which are more adequate for habitation and services buildings, while others apply mostly to buildings of lower demands or provisional constructions. In the first situation, smaller types of coating stand out (e.g., tiles) and, in the second case, coatings of greater dimensions (e.g., plates and boards).

The study of the functional demands to be met by coatings is important for the prescription of appropriate solutions for delaying the emergence of anomalies. The classification of requisites to be met by the RECI is divided into five main groups, among which are safety demands (which aim at ensuring the physical integrity of the occupants), habitability demands (destined to ensuring the living and comfort conditions of the users), durability demands (which aim at preserving the qualities of the coating), economy demands (which look to optimising the resources on the level of the constructive process, maintenance, and repair) and others (referring to geometric stability, constructive process and sustainability).

3. ANOMALIES

In the RECI, there is a set of more or less serious anomalies, of which it is important to have a deepened knowledge, namely of the causes that originated them. The determination of causes, and acting on them, allows for the elimination of anomalies. In order to optimize the inspection and diagnosis of the RECI's pathologies, a system of classification of anomalies is proposed (Table 1), based on the bibliographical review. It is also intended to normalise the designation and typification of anomalies and systematise the information in the scope of this theme. The grouping of anomalies by typology and visual aspect is proposed, 4 groups having been obtained, it being so that three divide into subgroups, totalling 19 main anomalies. Within each group, the anomalies were ordered based on the reach of their manifestations, which is to say, the anomalies that occur only on one element of the system appear first than those which manifest themselves in

all of the coating system. The identification with alphabetical and numerical characters enabled the production of correlation matrices.

Table 1 - Proposed classification of anomalies in RECI

A-C CONDENSATIONS
A-D DISPLACEMENTS / DEFORMATIONS
A-D1 severe deformations of the coating
A-D2 misalignment of coating elements
A-D3 release / detachment of coating elements
A-E DEGRADATION
A-E1 accumulation of debris
A-E2 corrosion
A-E3 peeling / scaling / exfoliation
A-E4 development of parasitic vegetation / biological colonization
A-E5 differences in tone / change color
A-E6 disintegration / oxidation (aging)
A-E7 cracking / fracture
A-O DESIGN / EXECUTION DEFECTS
A-O1 defects in connection systems
A-O2 defects in the finishing
A-O3 inexistence or deterioration of water tightness cords
A-O4 insufficient or excessive overlap
A-O5 defects in the thermal insulation system
A-O6 defects in the ventilation system
A-O7 insufficient or excessive slope
A-O8 incorrect or deficient interventions

The A-C group concerns only condensations, which are one of the most critical forms of manifestation of humidity, towards the occurrence of anomalies in coatings. The A-D group concentrates the anomalies which consist of deformations of the coating and elements' movements, originating critical point of infiltration of rain waters. The A-E group is constituted by the anomalies which translate into aging and degradation, aesthetic alterations, loss of cohesion and wear of the coatings and accessories on the roofs. The A-O group refers to design / execution defects, such as insufficient or excessive slopes of the roofs, defects in the various elements of RECI (connections, joints, finishing, ventilation system, thermal insulation) and also inadequate interventions.

The vast majority of anomalies presented in this classification occur in all RECI; however, it is noted that some are specific to certain coatings. The A-C and A-D groups' anomalies and general, occurring in every type of RECI, while the A-E and A-O groups contain specific anomalies. Peeling / scaling / exfoliation is an anomaly which does not occur in plastics or fibre-cement coatings. On the other hand, disintegration / oxidation (aging) is a pathological process which only occurs in plastics and fibre-cement coatings. Corrosion is only observed in metallic and mixed coatings (with the exception of asphalt shingles) and the inexistence / deterioration of water tightness cords occurs only in fiber-cement, metallic, plastic, and mixed coatings.

3.1. CONDENSATIONS

Condensations translate into the formation of water droplets under the surface of the coatings. This anomaly occurs mostly in climactic regions with low air temperature or in interior areas with a high output of water vapour, added to deficient ventilation and thermal insulation systems, as well as to the inexistence or lack of continuity of the vapour-stopping barrier. Condensations contribute to the deterioration of the entire roof, to the formation of dark patches of dust retention and to the development of fungi and mold and provoke detachment of, formation of bubbles in, and cracking in asphalt shingles.

3.2. SEVERE DEFORMATIONS OF THE COATING

Deformations translate into the appearance of zones of convexity / concavity in the roofs' coatings, and are due mostly to the subsidence of the support structure. This anomaly may also be originated in the placing of heavy equipment over the coatings, in the impact of heavy objects, as a result of bad weather or vandalism, and also in the circulation of persons

and loads on the coatings. The occurrence of this anomaly may originate the opening of transversal and longitudinal joints in the coating, detachment of the water tightness cords and cracks / fractures of the elements. On the other hand, deformations originate zones of water accumulation, favouring the development of parasitic vegetation / biological colonization and the corrosion of connection parts and elements.

3.3. MISALIGNMENT OF COATING ELEMENTS

Misalignment is characterized by incorrect longitudinal and transversal placements, resulting in strings of elements with clearly irregular alignments. This anomaly is originated by the lack of rigour in the execution of the settlement and alignment of the elements and also by the substitution of elements by others with differing geometry or dimensions. Misalignment may also be originated in the action of strong winds in the case of roofs with great slopes or in the case of incorrectly fixed elements. The occurrence of misalignments results in the formation of joints in the coating, which are points favourable to the infiltration of humidity and precipitation.

3.4. RELEASE / DETACHMENT OF COATING ELEMENTS

Detaching is characterised by a total or partial separation of coating elements. In the case of total separation, the roof's structures are directly exposed to the entrance of rain waters. This anomaly occurs more frequently in roofs with high slopes and/or in incorrectly placed elements, by the action of strong winds. The absence of maintenance, both of the connection parts and of fractures or slightly detached elements may also originate this anomaly. In asphalt shingles, the concentration of water vapour in the inner surface of the coating may also result in their detachment.

3.5. ACCUMULATION OF DEBRIS

The accumulation of debris consists of the accumulation of vegetation, animal remains and other objects over the roofs, contributing to the appearance of parasitic vegetation and zones of accumulation of water. Infiltrations can occur in these areas, whenever the amount of stagnated water or the action of the winds exerts an influence in that sense. This anomaly is aggravated in roofs which present reduced slopes, inexistence / insufficiency or cleaning actions and also in finishing whose execution favours the accumulation of debris.

3.6. CORROSION

Corrosion is the main process of degradation of metallic coatings of roofs and is manifested both via superficial and profound anomalies. The first consist of alterations of the aspect of the surface as well as superficial loss of the coating, and the second represent significant losses of metallic material and may put the functionality and safety of the coating into question. Corrosion may occur by the contact between two chemically incompatible metallic materials or due to the exposure conditions of a single metallic element. It greatly affects the aesthetics of metallic coatings and, in the more serious cases, may lead to the loss of their water tightness.

3.7. PEELING / SCALING / EXFOLIATION

This anomaly results in the detachment of small portions of the coating elements. In ceramic and micro-concrete coatings, peeling may be caused by icing-thawing cycles, associated to a deficient ventilation of the coatings. Scaling in slate coatings is related to the ease with which this material chips, due to its process of sedimentary formation, in nature. In metallic and composite coatings, exfoliations may occur due to the pressure exerted by the products of corrosion, resulting in the separation of the layers suffering the corrosive action. This anomaly originates the degradation of coatings and greatly affects their aesthetics, mainly in metallic and composite elements, related to corrosion.

3.8. DEVELOPMENT OF PARASITIC VEGETATION / BIOLOGICAL COLONIZATION

This anomaly consists in the development of microorganisms and plants in the surface of the coatings, due to the presence of humidity and solar radiation. It is directly related with the deficient flow of water and also with the insufficient ventilation of elements, which particular incidence in the more poorly ventilated and levelled areas of the roofs. This anomaly increases the retention of humidity in the coatings, favours the appearance of corrosion, provokes the alteration

of the tone of the elements and the deterioration of water tightness cords.

3.9. DIFFERENCES IN TONE / CHANGE OF COLOR

This anomaly results in coating elements whose original colour suffers changes, leading to roofs with no single tone. In ceramic coatings, the variations in tone may be connected to the manufacturing process while, in slate coatings, the spots of different colours are caused by the modification of the ferrous materials existent in them. In metallic coatings, this anomaly corresponds to the colour of the corrosion products. In plastics, the alteration in colour is manifested by the loss of translucid or transparent characteristics. This anomaly also occurs in roofs in which coating elements have been substituted by elements of a different tone.

3.10. DISINTEGRATION / OXIDATION (AGING)

The aging of fibre-cement consists of the deterioration and disintegration of the material by phenomena of carbonation, leaching and acid rains (sulphate attacks). The consequences are the reduction of the mechanical resistance of the coatings and damage to the environment and public health due to the release of asbestos fibers. In plastic coatings, aging occurs through chemical oxidation reactions which cause the loss of transparency of the elements and the increase of fragility and deformability.

3.11. CRACKING / FRACTURE

This anomaly results in the formation of cracks in the coating elements, both superficial and total (with separation of the elements in parts). The main causes for the occurrence of this anomaly are mechanical in nature, such as subsiding of the support structure, careless circulation of persons and impacts of heavy objects. In fiber-cement and plastic, aging can lead to cracking / fracturing, while in metallic elements, corrosion added to mechanical tensions (fatigue and traction), in favourable environmental conditions, can lead to rupture in certain points. In asphaltic tiles, the causes of cracking may be associated to thermal movements and the concentration of water vapour in the inner surface.

3.12. DEFECTS IN CONNECTION SYSTEMS

The defects in fixations consist of deformations, ruptures and detachment, not only of the coating elements, in those points, but also of the connection elements themselves, and also in their inadequate distribution. These result in errors in the execution stage, such as excessive or insufficient tightening, the application of excessive or insufficient quantities of connection elements and the placing of connection parts in the cavities of the coating elements. These errors result from resorting to inexperienced or unqualified labour for the task, and contribute to the loss of water tightness of the roof.

3.13. DEFECTS IN THE FINISHINGS

These defects are related to the use of inadequate materials and parts (mortars, asphalt panels and parts that do not meet the necessary requisites) and poorly executed works. They result from errors in the design and execution stages. The use of mortars and asphalt panels hampers the roof's ventilation and prolongs the elements' drying time. The execution of finishing with insufficient coverings and the deficient flow of water, allowing for its infiltration / accumulation in those points, are examples of frequent incorrect works.

3.14. INEXISTENCE OR DETERIORATION OF WATER TIGHTNESS CORDS

This anomaly refers to the absence of mastic in situations where it is necessary and, when it is applied, it results in cracking, discoloration, erosion, dissolution, swelling or loss of adherence. The precocious deterioration of mastic may be related to the use of mastic non standardized or incompatible with the RECI or even to incorrect application by inexperienced or unqualified labour. This anomaly may also be due to the action of temperature, water, pollution, microorganisms and mechanical actions, originating points of infiltration for water.

3.15. INSUFFICIENT OR EXCESSIVE OVERLAP

This anomaly translates in the opening of undesirable joints in the coating, which compromises the water tightness of the roofs. Its main causes are connected to design and execution: excessive slopes, allied to strong winds, incorrect spacing of the supporting panels, and improper placing of the coating elements. The careless circulation of persons and loads over the roof and the substitution of elements for others of different geometry and/or dimensions also stand as causes for the occurrence of this anomaly.

3.16. DEFECTS IN THE THERMAL INSULATION SYSTEM

This anomaly is characterised in some cases by the absence of a layer of thermal insulation and in others by the degradation of the existing insulation, leading to thermal bridges in the roof and the possibility of occurrence of condensations. The precocious deterioration of the insulation layer may be due to errors in the application stage, such as the use of non standardized materials, the loss of thickness of the insulation panels and dimensional changes dued to the temperature. The insulation's degradation, in the usage stage, may be provoked by the action of infiltration humidity and by unforeseen mechanical compression stress derived from deficient interventions in the roof.

3.17. DEFECTS IN THE VENTILATION SYSTEM

The anomaly generally corresponds to the insufficiency and/or incorrect placing of ventilation elements. In the design stage, the omission or incorrect detailing of the ventilation systems is recurring. As such, in the execution stage, the ventilation elements are not placed at all, are incorrectly distributed, or are insufficient in number. The placing of materials over the coating (in repair works) and the inexistence of cleaning actions on the ventilation elements lead to a deficient ventilation of the roof. This anomaly results in the slow drying of the coating elements and in the worsening of the salubrity conditions of the underlying spaces.

3.18. INSUFFICIENT OR EXCESSIVE SLOPE

This anomaly consists of roof slopes which do not abide by the minimum or maximum values established for each type of RECI - the cases of excessive inclination with elements which are adequately fixed to the support structure stand as exception. The causes are associated to design / detailing errors, or the roof's slope, and errors of execution of the support structure. This anomaly may lead to the detachment and fall of coating elements, areas of accumulation of debris, as well as the infiltration of water and the premature development of parasitic vegetation / biological colonization.

3.19. INCORRECT OR DEFICIENT INTERVENTIONS

Incorrect or deficient interventions correspond to the application of RECI elements of shapes or dimensions incompatible with those already present and / or the application of asphalt panels over the coatings. The first type of action results in incorrect connections, misalignment of the elements and points of infiltration of water. The second makes ventilation and the flow of rain waters more difficult and, in some cases, represents a significant increase of the overload in the support structure.

In the present work, it is not intended to describe in detailed manner each of the causes of the pathology, but to establish a typification according to groups of human responsibility of natural phenomena, which intervene in the pathological processes as their most frequent causes. As such, a proposal for a system of classification of the causes of anomalies in RECI is presented, organising the causes according to the chronological order of occurrence, as indicated in Table 2. This system is constituted by two main groups of causes: the direct or following ones, and the indirect or first ones. The first group is formed by actions of mechanical origin and environmental actions and the second by design, execution, and usage / maintenance errors.

The anomalies and causes which, directly or indirectly, are associated with the RECI having been characterised, the correlation matrices are presented, which have the objective of relating the anomalies observed *in situ* with their likely causes, and the anomalies between themselves, thus facilitating the diagnosis for future repairs. The anomalies/causes

relation is given by the following indices: 0 - no relation; 1 - small correlation and 2 - great correlation. In a first stage, the matrices were elaborated via information obtained during the literature review and, in a second stage, evaluated and validated after the inspection programme. Anomaly sheets were also created, in this work, wherein all of the information pertaining to each anomaly is gathered, as can be seen in the example of Table 3.

Table 2 - Proposed classification of the causes of anomalies in RECI

C-P - DESIGN ERRORS	
C-P1 incorrect design / calculation of the support structure	
C-P2 incorrect design / detailing of the roof's slope	
C-P3 omitted or incorrect design / detailing of the ventilation systems	
C-P4 omitted or incorrect design / detailing of the thermal insulation system	
C-P5 omitted or incorrect design / detailing of the vapour-stop barrier	
C-P6 omitted or incorrect design / detailing of the circulation accessories on the roofs	
C-P7 incorrect design / detailing of the elements' overlap	
C-P8 incorrect design / detailing of the finishing areas	
C-P9 specification of inadequate or mutually incompatible materials	
C-E - EXECUTION ERRORS	
C-E1 incorrect interpretation of the execution project	
C-E2 use of inexperienced or unqualified labour	
C-E3 incorrect placing of the ventilation elements	
C-E4 incorrect application of the elements of thermal insulation	
C-E5 incorrect placement of the vapour-stop barrier	
C-E6 lack of rigour in the execution of the support panels and the alignment of the elements	
C-E7 incorrect handling of the materials or use of inadequate tools	
C-E8 application of excessive quantities of mortar	
C-E9 use of non prescribed, inadequate, or mutually incompatible materials	
C-E10 excessively rigid fixations or insufficient / excessive quantity of the connection elements	
C-E11 incorrect placement of water tightness cords	
C-E12 incorrect finishing of the tops of the polycarbonate boards	
C-E13 use of materials of low quality and or non certified / standardized materials	
C-E14 use of materials with heterogeneities dued to the manufacturing process	
C-M - ACTIONS OF MECHANICAL ORIGIN	
C-M1 deformation of the roof's support structure	C-M4 impacts of heavy objects, resulting from bad weather
C-M2 circulation of persons and loads over the coatings	C-M5 vandalism
C-M3 placement of heavy equipment over the roofs	
C-A - ENVIRONMENTAL ACTIONS	
C-A1 strong winds	C-A6 icing / thawing cycles
C-A2 solar radiation	C-A7 pollution
C-A3 chemical action of pigeons	C-A8 temperature
C-A4 biological action	C-A9 inside humidity
C-A5 presence of water (water / snow)	
C-U - USE / MAINTENANCE ERRORS	
C-U1 inadequate or non-existent maintenance	
C-U2 placing of mortar over the coatings, in repair works	
C-U3 placing of asphalt panels over the coatings, in repair works	
C-U4 alteration of the coating material or addition of new layers in the roof's structure	
C-U5 substitution of elements by others of different geometry	
C-U6 substitution of elements by others of different tonality	
C-U7 alteration of the conditions of use initially predicted	

4. DIAGNOSIS TECHNIQUES

In this work, a system of classification of the diagnosis techniques associated to the characterization of anomalies / causes in RECI is proposed. As can be seen in Table 4, the system is comprised of four groups, according to the type of execution and functioning of the equipment used in each of the techniques. Only those techniques suitable for *in situ* execution were considered, since laboratory testing demands specialized personnel and materials, implying costs, complexity, and high execution times. In this work, it is intended to present only simple, fast, and non destructive tests, since these usually bear a lower cost than the destructive techniques. In the classification table, each technique's identifying designation is once again presented, due to being necessary to the elaboration of the matrix of correlation between the anomalies and the diagnosis techniques, as presented in **§5**.

4.1. VISUAL INSPECTION

Visual inspection is one of the most used methods in the diagnosis of roof coatings, due to being simple, entailing low costs, and not requiring any special equipment. This inspection technique only requires a highly experienced profes-

sional, with knowledge in the field of RECI and some auxiliary equipment. The diagnosis of some anomalies may be performed resorting only to this technique, for which reason, in the remaining anomalies, visual inspection is applied as a complement to another technique and always in first place.

Table 3 - Anomaly sheet

A-C ANOMALY SHEET	
	
DESIGNATION:	
Condensations	
DESCRIPTION:	
They correspond to the formation of water droplets under the coatings' surfaces, as a consequence of the passage of the interior water vapour from the gaseous to the liquid state.	
PROBABLE CAUSES:	
- inexistence or incorrect application of elements of thermal insulation (C-P4, C-E4, C-E2)	
- inexistence or incorrect application of ventilation elements (C-P3, C-E3)	
- inexistence or incorrect application of elements of the vapour-stop barrier (C-P5, C-E5)	
- use of insulation materials that do not respect the functional requisites (C-P9, C-E9, C-E13)	
- excessive environmental humidity / high production of water vapour (C-A9)	
- temperature on the coating's surface equal to the dew point (C-A8)	
- alteration of the conditions of use initially predicted (C-U7)	
POSSIBLE CONSEQUENCES:	
- degradation of the coating	
- degradation of the underlying layers, due to contact with water	
- formation of dark patches due to dust retention	
- development of fungi and mold	
- detachment, formation of bubbles and cracking in asphalt shingles	
- corrosion of metallic elements	
ASPECTS TO INSPECT:	
- temperature and inner and outer hygrothermal conditions	
- thickness of each of the roof's layers	
- thermal conductivity or thermal resistance of each of the roof's layers	
- resistance to the diffusion of water vapour of each of the roof's layers	
- existence of thermal bridges (Y/N)	
- condition of the thermal insulation	
- excessive production of water vapour (Y/N)	
- type of use of the spaces beneath the roof	
- insufficient ventilation (Y/N)	
TESTS TO CONDUCT:	
- visual inspection (D-A1)	
- measurement of the temperature and of the superficial and / or atmospheric relative humidity (D-C1)	
- evaluation of the distribution of temperatures by infrared thermography (D-C2)	
CLASSIFICATION PARAMETERS:	
- conditions for the phenomenon to progress (Y/N)	
- presence of excessive humidity in the space beneath the RECI (Y/N)	
- aesthetic value of the affected areas (high; medium; low)	
SEVERITY LEVEL / REPAIR URGENCY:	
1 – when there are conditions for the progression of the phenomenon and consequent degradation of the coatings or when the aesthetic value of the affected areas is high	
2 – when the phenomenon is circumscribed and does not present conditions for progression	

Table 4 - *In situ* diagnosis techniques

D-A - VISUAL ANALYSIS
D-A1 visual inspection
D-A2 measurement of slope
D-B - ELECTRICAL METHODS
D-B1 eddy currents
D-C - THERMAL-HYGROMETRIC METHODS
D-C1 evaluation of temperature and relative humidity
D-C2 infrared thermography
D-D - ULTRASONIC METHODS
D-D1 ultrasounds

4.2. MEASUREMENT OF SLOPE

This technique serves to verify if the RECI's slope is according to the minimum and maximum values valid for each type of coating, roof type, location, and adopted constructive characteristics. The slope may be measured by resorting to an inclinometer, for an example, for verification in small areas, or a laser device, for larger areas. The technique is quick and simple, not requiring any qualified labour in the execution or interpretation of the measurements.

4.3. EDDY CURRENTS

This test consists of the measurement of the variation of the limitation to the propagation of induced current, allowing for the execution of several control actions, such as the detection of flaws (cracking, corrosion), dimensional changes (loss of thickness) and the measurement of the thickness of the conductive or non conductive protective layers. It is a clean, fast, and relatively cheap method, but requires technology and experience in the conduction of the tests and interpretation of the results.

4.4. EVALUATION OF TEMPERATURE AND RELATIVE HUMIDITY

The control of temperature and humidity can be done through digital thermo-hygrometers which allow for the detection of changes on the level of the thermal insulation as well as the concentration of humidity in specific areas. The ultimate objective is to assess the possibility of the occurrence of condensations. The use of this technique in preventive actions allows for the early adoption of measures aiming at eliminating the causes of future anomalies and their use in curative actions allows for a quick and easy diagnosis of the anomalous phenomena observed.

4.5. INFRARED THERMOGRAPHY

This technique allows for the detection of the inexistence or degradation of, and discontinuities in, the thermal insulation, by capturing the thermal radiations emitted by the materials. The thermal images can assist in the detection of colder areas in the roofs, which stand as critical points for the occurrence of condensations. Infrared thermography further allows for the evaluation of water tightness of the roofs through the localized detection of water infiltrations. This technique doesn't necessarily require for a technician to be on the roof, for which reason it does not entail any damages. However, the results imply the conduction of further, more circumscribed tests, and their interpretation requires a professional with experience and knowledge in the field of materials' thermal behaviour.

4.6. ULTRASOUNDS

This test allows for the automatic detection of defects and discontinuities on the inside of the elements and determine thicknesses (of materials and corrosion phenomena), via the propagation of acoustic waves. In slate elements, the speed of propagation of the ultrasonic waves allows for the indirect evaluation of their state of degradation. This method is non destructive, being possible to use on fragile surfaces and, given its low costs, reveals itself as one of the more used and fastest growing techniques in its areas of application. Due to the complexity of the technique, the ultrasound equipment's operator requires specific training and high experience to interpret the results.

A matrix of correlation of anomalies - diagnostic techniques was prepared, which, after the identification of an anomaly on an RECI, enables the selection of the most adequate method, in respect to extension and seriousness. On the intersection of each line with every column, a number is inserted, representing the degree of correlation between the two (0 - no correlation; 1 - small correlation; 2 - great correlation). In this work, sheets for the diagnosis methods were also created, in which all of the information pertaining to each method is indicated, as can be seen in the example of Table 5.

5. VALIDATION OF THE SYSTEM AND STATISTICAL ANALYSIS

In this chapter, the information obtained with the inspections of the RECI of buildings with at least one related anomaly is presented. The programme of randomly conducted inspections comprised a total of 207 cases, spread between 164 buildings of the Greater Lisbon and Greater Porto areas. The inspections were documented on standard-sheets of in-

spection and validation. The inspection sheets include the characteristics of the buildings and the coatings, allowing for an effective comparison of the different inspections. In the case of the validation sheets, the anomalies identified in each RECI are marked and characterised, as well as all the parameters related to the system of classification which was created. The programme of inspections had as its objective the validation of the proposed system of classification of anomalies of RECI, and also aimed to ascertain and calibrate the correlation matrices. In this way, the relations presented in the theoretical correlation matrices were compared with those resulting from the inspections programme.

Table 5 - Test sheet D-C2 - infrared thermography

TEST SHEET D-C2	
	
NAME:	
Infrared thermography	
DESTRUCTIVE (D) / NON DESTRUCTIVE (ND):	
ND	
OBJECTIVES:	
evaluate the water tightness and locate discontinuities in roof thermal insulation by capturing the heat radiation from the materials	
EQUIPAMENT NEEDED:	
Thermal imager sensitive to infrared radiation; thermocouples for monitoring temperatures and recording equipment in video tape and on floppy disk, for recording the thermographic images obtained	
DESCRIPTION OF THE METHOD:	
1 - taking advantage of the warming caused by solar radiation, observe the thermographic images obtained by infrared camera; 2 - record on floppy disks or videographic equipment the images collected , for further interpretation and diagnosis	
ADVANTAGES:	
Low cost and effective technique, allowing the inspection without contact with the elements to diagnose; technical testing areas instead of points; present a picture of the area analyzed	
LIMITATIONS:	
Infrared observations imply further tests more localized; the interpretation of the results requires a professional with experience and knowledge in the field of materials' thermal behaviour.	
BIBLIOGRAPHIC REFERENCES:	
BRANCO (2003); CÓIAS (2006); IMPIC (2009); MENDONÇA (2005); PEREIRA (2008)	

After this assessment, some changes emerged in some of the indices of correlation of the anomalies - causes matrix, which also led to adjustments in the matrix of correlation of anomalies between themselves, and to the definition of new percentage correlation indices between anomalies, $CI_{\%}$. According to the percentage difference between the new indices and the initial ones, it was verified that the adjustment is very good in 43% of the cases, good in 33%, satisfactory in 20% and weak in only 3%. Considering the percentage difference between the indices of theoretical correlation and those based on the sample, the matrix of correlation of the anomalies between themselves is considered to be rather good (Table 6) and adequate to the cases where it is intended to estimate the probability of simultaneous occurrence of the various anomalies of the RECI.

For each of the anomalies identified in the inspections, the diagnosis methods most adequate to their characterisation were specified. The comparison of the results obtained from the inspections with the anomalies - diagnosis techniques correlation matrix allows us to see that the adjustment is very good in 91% of the cases and that observable discrepancies are slight in 8% of the cases and elevated in 1%. As done in the validation of the anomalies - causes correlation matrix, an analysis of the discrepancies between the theoretical and practical correlations was conducted (obtained with the inspections to the RECI) and it is concluded that the correlation degrees proposed in this system of classification should be maintained. Thus, no change to the anomalies - diagnosis techniques correlation matrix, presented in Table 7, is proposed.

After the validation of the system of classification and correlation matrixes, a statistical treatment of the data gathered in the inspections was conducted, from which a few noteworthy conclusions derived. The distributions of the inspected coatings, by age and by type of material, are represented in Figure 1 and in Table 8.

The inspections consisted only in the visual analysis of the RECI, with no kind of *in situ* or laboratory test having been conducted. 1195 anomalies were identified in the 207 RECI which were inspected, resulting in an average of 5,8 anomalies per RECI. The probable causes numbered 2822, which results in an average of 2,4 causes per anomaly and, about the diagnosis methods, 1640 were listed - 1,4 per anomaly.

In Figure 2, the percentage of occurrence of each anomaly in the total sample of anomalies is presented. The **A-E4 - development of parasitic vegetation / biological colonization, A-06 - defects in the ventilation system** and **A-O2 - defects in the finishing** are the most prevalent, whilst the **A-C - condensations**, **A-E6 - disintegration / oxidation (aging)** and **A-O3 - inexistence or deterioration of the water tightness cords** present the lowest prevalence.

Table 6 - Anomalies between themselves percentage correlation matrix

	A-C	A-D1	A-D2	A-D3	A-E1	A-E2	A-E3	A-E4	A-E5	A-E6	A-E7	A-O1	A-O2	A-O3	A-O4	A-O5	A-O6	A-O7	A-O8
A-C		23%	3%	17%	0%	27%	23%	7%	10%	20%	23%	7%	17%	27%	7%	33%	17%	3%	13%
A-D1	13%		27%	27%	15%	31%	25%	21%	8%	15%	48%	4%	2%	31%	25%	29%	13%	6%	12%
A-D2	4%	50%		50%	21%	14%	4%	18%	7%	0%	21%	14%	4%	11%	71%	21%	18%	11%	21%
A-D3	18%	50%	50%		29%	32%	7%	21%	14%	4%	21%	21%	18%	11%	39%	25%	11%	18%	14%
A-E1	0%	44%	33%	44%		22%	11%	56%	11%	0%	22%	0%	11%	22%	22%	11%	17%	22%	0%
A-E2	24%	47%	12%	26%	12%		35%	18%	32%	29%	41%	6%	21%	47%	12%	35%	6%	3%	15%
A-E3	22%	41%	3%	6%	6%	38%		19%	16%	16%	31%	0%	13%	34%	3%	19%	25%	0%	9%
A-E4	6%	34%	16%	19%	31%	19%	19%		22%	19%	9%	0%	6%	31%	9%	22%	38%	6%	13%
A-E5	10%	13%	7%	13%	7%	37%	17%	23%		37%	13%	0%	7%	37%	3%	13%	3%	0%	3%
A-E6	33%	44%	0%	6%	0%	56%	28%	33%	61%		50%	0%	0%	89%	0%	33%	0%	0%	0%
A-E7	19%	69%	17%	17%	11%	39%	28%	8%	11%	25%		11%	3%	47%	17%	22%	3%	3%	6%
A-O1	25%	25%	50%	75%	0%	25%	0%	0%	0%	0%	50%		25%	25%	50%	50%	25%	25%	50%
A-O2	25%	5%	5%	25%	10%	35%	20%	10%	10%	0%	5%	10%		25%	10%	25%	40%	10%	30%
A-O3	21%	42%	8%	8%	11%	42%	29%	26%	29%	42%	45%	5%	13%		11%	26%	3%	3%	11%
A-O4	7%	46%	71%	39%	14%	14%	4%	11%	4%	0%	21%	14%	7%	14%		18%	18%	14%	29%
A-O5	26%	39%	16%	18%	5%	32%	16%	18%	11%	16%	21%	11%	13%	26%	13%		13%	3%	16%
A-O6	17%	23%	17%	10%	10%	7%	27%	40%	3%	0%	3%	7%	27%	3%	17%	17%		7%	33%
A-O7	13%	38%	38%	63%	50%	13%	0%	25%	0%	0%	13%	25%	25%	13%	50%	13%	25%		25%
A-O8	20%	30%	30%	20%	0%	25%	15%	20%	5%	0%	10%	20%	30%	20%	40%	30%	50%	10%	

Table 7 - Anomalies - diagnosis techniques correlation matrix

	D-A1	D-A2	D-B1	D-C1	D-C2	D-D1
A-C	2	0	0	2	2	0
A-D1	2	1	0	1[1]	0	0
A-D2	2	0	0	0	0	0
A-D3	2	2	0	0	0	0
A-E1	2	2	0	0	0	0
A-E2	2	0	2	0	1	2
A-E3	2	0	2[2]	0	1	2[3]
A-E4	2	1	0	0	2	0
A-E5	2	0	2[2]	0	0	2[2]
A-E6	2	0	0	0	0	0
A-E7	2	0	0	0	2	0
A-O1	2	0	0	0	0	0
A-O2	2	0	0	0	2	0
A-O3	2	0	0	0	2	0
A-O4	2	0	0	0	0	0
A-O5	2	0	0	0	2	0
A-O6	2	0	0	0	0	0
A-O7	2	2	0	0	0	0
A-O8	2	0	0	0	1	0

[1] Only plastic RECI

[2] Only metallic and mixed RECI (exception to asphalt shingle)

[3] Only metallic and slate RECI

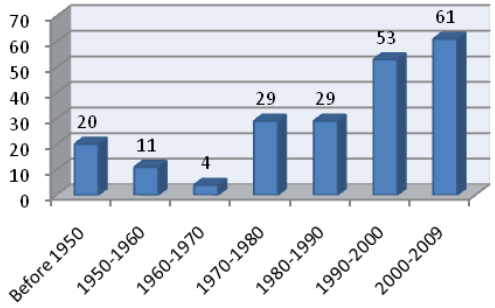

Figure 1 - Absolute frequency of ages of RECI inspected

RECI typology	Number of inspections
Slate	20
Ceramic	62
Micro-concrete	21
Fiber-cement	23
Metallic	20
Plastic	20
Sandwich panel	20
Asphalt shingle	21

Table 8 - Number of inspections to RECI

The average of anomalies registered in the various types of the inspected RECI is presented in Figure 3 and was calculated by dividing the total number of anomalies in the RECI by the total number of coatings of that type in the sample. The slate and micro-concrete coatings are the ones which, on average, present a greater number of anomalies and plastic and metallic coatings are the ones in which the least anomalies occur. In general terms, there is a tendency for larger elements, such as slate, ceramics, and micro-concrete, to register a greater number of anomalies, in comparison with smaller elements such as metallic ones, plastic ones and the sandwich panels.

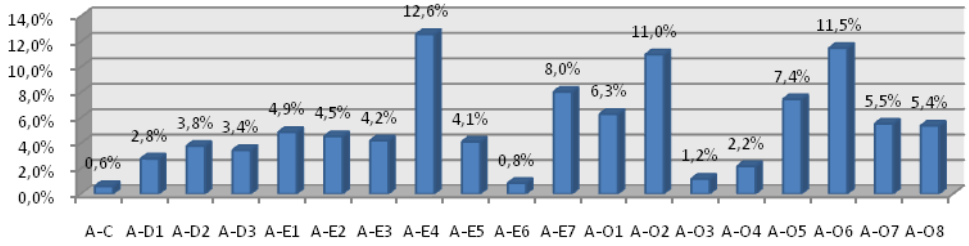

Figure 2 - Relative contribution of each anomaly in the total of anomalies

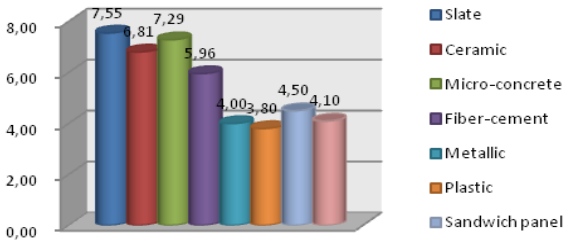

Figure 3 - Average of anomalies in different RECI inspected

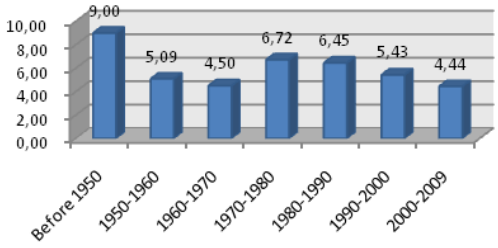

Figure 4 - Average of anomalies by RECI age

The distribution of the number of anomalies by age of the RECI is presented in Figure 4, for various intervals of time. The referred values correspond to the average of the anomalies per coating in each time interval, since the number of inspected RECI differs for each time interval. It is observed that there is a tendency for the reduction of anomalies in time, as would be expectable. The [1950-1960[and [1960-1970[time intervals do not match this tendency, due to the small number of inspections to RECI of that age and also because those RECI are not representative of the number of anomalies for those intervals of time.

The urgency of intervention for each anomaly was estimated based on the information gathered in the inspection and validation sheets, and on the severity levels / repair urgency described in the anomaly sheets. The most commonly registered severity level / repair urgency was 2 (control of the anomaly) in 59% of the cases of the sample, it being that the severity level / repair urgency 0 (immediate intervention) was registered in 12% of the observed anomalies, with special incidence on the **A-D3 - detachment of the coating elements**, **A-E7 - cracking / fracture** and **A-O1 - defects in the connections**.

In Figure 6, the contribution of each group of causes to the total of occurrences of anomalies in the sample can be seen. The causes of the **C-E - execution errors** group are the ones which most contribute to the occurrence of anomalies in

the RECI, followed by those of the **C-P - design errors** group. The location of the RECI in a building subjects them directly to the atmospheric agents, for which reason the **C-A - environmental actions** group also has a strong contribution towards the occurrence of anomalies in these coatings. Although lesser representative, the contribution of the causes of the **A-U - errors of use / maintenance** group merit mentioning, especially due to the **C-U1 - inexistent or inadequate maintenance** cause, as well as the causes of **C-M - actions of mechanical origin** which, as expected, have the lowest number of records.

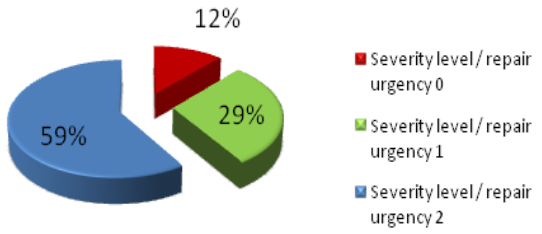

Figure 5 - Severity level / repair urgency of all anomalies

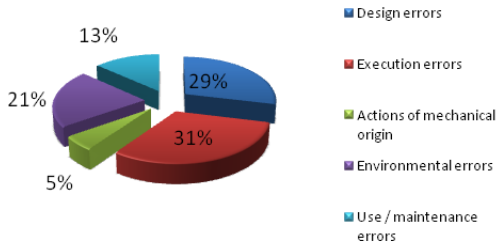

Figure 6 - Relative contribution of each group of causes

In Figure 7, the frequency of each method of diagnosis for the total of anomalies can be seen. The **D-A1 - visual inspection** method is applicable to the diagnosis of all anomalies on RECI and is a primary auxiliary of diagnosis, followed by other more specific ones, should they be available and necessary. The methods of the **D-B - electrical methods** and **D-D - ultrasonic methods** groups, as well as of the **D-C1 - evaluation of temperature and relative humidity** group have very limited application scopes in terms of types of RECI and type of anomalies and thus present relative frequencies that are far lower than the others.

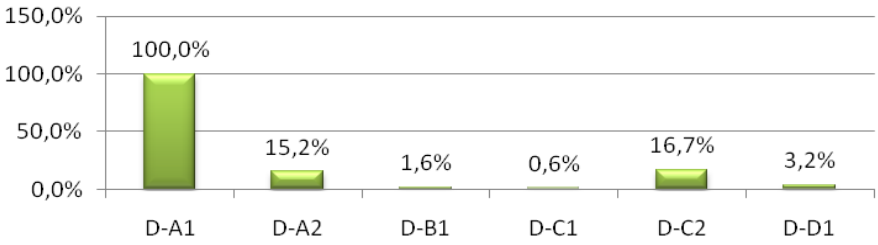

Figure 7 - Frequency of each method of diagnosis in the inspections

6. CONCLUSIONS

The pathologies of the RECI are originated by causes associated to errors in all stages of their existence. As such, for the precocious degradation of coatings not to occur, it is necessary to implement a strategy of proactive maintenance, of the predictive type, which defines the actions to perform on the design, execution, and maintenance stages. The practical implementation of this work, with the dissertation "**Technology and Rehabilitation of Exterior Coatings of Pitched Roofs"** (Lopes, 2009), constitutes an innovative tool for the knowledge, inspection, diagnosis and repair of RECI. All of the objectives laid out for this dissertation are generally considered achieved. The system of classification of anomalies and probable causes embarks all the cases of pathologies already observed and registered in RECI; however, it is possible for there to be sporadic future changes, as a result of the experience of continued use of this system. As with any investigation work, this one also presents the possibility of being further developed and improved: the conduction of more inspections (if possible with *in situ* tests), to perfect the systems of classifications of anomalies, causes and diagnosis techniques and to increase the number of conclusions of the statistical analysis. The development of a new IT module which offers assistance during tests and permits the storage of data for investigation is also proposed.