TECHNOLOGY AND REHABILITATION OF EXTERIOR COATING OF PITCHED ROOFS

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EXTENDED ABSTRACT

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1. Introduction

The roof of a building has the inner protection to the weathering / climate conditions (rain, snow, wind, dust in the air, among others), to preserve the building structure and to ensure certain standards of habitability and health. The secondary function is to integrate the building in geographical and architectural heritage. The types of exterior coatings to be applied on pitched roofs are in function of a certain technical specifications established for a building. The selection is on function of the exposure conditions and operational requirements. The economic factor is the deliberative condition. The theme of the exterior coating of pitched roofs (ECPR) is the focus of many studies and publication of documents in Portugal by its importance in the build heritage. However, there isn't a manual that bring out the needs of the teams that perform monitoring and rehabilitation of these constructive components. To fill this gap, this dissertation aim primarily to present a set of methods in relation to certain anomalies, which seeks recovery of the properties of ECPR and the establishment of correlation matrix anomalies-rehabilitation techniques, validated by a statistically significant sample of a previous round of inspections carried out into ECPR. The methodology of each rehabilitation technique is associated with a form that synthesizes rehabilitation processes, materials, and equipment, skilled labour and economic resources involved. Given the variety of coatings, there were selected for this study those with higher expression in Portugal: The natural stone (slates), artificial stone (micro-concrete tile, clay tile and fiber-cement), metal (steel, zinc, copper), plastics (PC, PVC, GRP, PPMA) and composite (asphalt shingle and sandwich panels).

2. Technology

In this chapter, we present the "*State of the Art*" of ECPR. The purpose of a particular building is reflected in the type of ECPR adopted. The types of roof and ECPR can be defined according to the number of slopes, form of the covering, structural function of coating elements, size, shape, nature of ECPR and type of load-bearing structure. The different types of ECPR are summarized in **Table 1**.

Table 1 - Different types of ECPR.

ECPR	Nature
Slates, granite e schist	Natural stone
Clay tile, micro-concrete tile, fibre-cement and glass	Artificial stone
Aluminium, steel, lead, copper, iron e zinc	Metallic
Polycarbonate (PC), polyvinyl chloride (PVC), Glass reinforced plastic (GRP) and poly(methyl methacrylate) (PMMA).	Plastic
Sandwich panels, asphalt shingle, bio-fibres, metallic tile with mineral granules and steel sheets cover with bitumen and aluminium sheet	Composite
Culm, thatch, tree branches, vegetation e wood slates.	Vegetal

2.1. ECPR natural slates

The natural stone ECPR discussed in this dissertation are slate, schist and granite. The schist and granite are used in roofing materials few centuries ago aren't now as adapted solutions face to the current operating parameters.

2.1.1. Slates

The application of slates dates back to the seventeenth century and is now restricted mainly to housing and historic buildings. This is a natural coating which physical, chemical and mechanical properties depends mostly on its microstructure. The geometry of slates it's changeable with different shapes and thicknesses. The advantages of applying this ECPR are high durability, excellent dimensional stability in view of changes of temperature, waterproof and fireproof. This coating is applied usually on planking roof deck which is mechanically fixed to the support through hails and between elements with clips. The singularities are performed with metallic elements, usually copper, lead on own ECPR.

2.2. Artificial stone

The artificial stone materials are manufactured with the desired properties, depending of the type of roof and environmental exposure to which they are designated. The artificial stone types are the fibre-cement, clay, micro-concrete and glass. The glass is a material that usually complements other ECPR in order to allow the entry of natural light in the attic.

2.2.1. Clay Tile

The clay tiles are probably the first artificial material applied to the construction with standard sizes. They are part of the Portugal architectural heritage. It is the the more applied ECPR in pitched roofs in Portugal. Have a good performance against the main atmospheric agents (rain, hail, frost, freeze-thaw cycles, wind, temperature variations, solar radiation), high durability, high dimensional accuracy, manufacturing process relatively simple, high availability of material, which allows a low cost of production, adaptability to different types of coverage, high quality esthetics, non-toxic, biodegradable and recyclable. The disadvantages are related to its fragility, which leads to the fracture of many elements (manufacture, transport, storage, inspections and maintenance, among others), sluggish process (most expensive solution) and very susceptible to human error. The most commonly used clay tile were grouped into joint tiles (Marseille and Lusa) channel-cover tile (tube tile and Roman) flat and joint flat. This are presented and described the main features and fittings accessories for each type of tile, tilt, overlap and minimum setting as well recommended in regard to the exposure tiles, and methodology of application below. Take on these data and as recommendations and guide lines when you want to design and install a cover with these coatings. This ECPR is majority applied on traditional buildings, housing, trade services, and industrial buildings with older or esthetic concerns, churches, among others.

2.2.2. Micro-Concrete tile

The tiles on micro-concrete emerged in the countries of northern Europe in response to the scarcity of clay. In Portugal, this ECPR arrived in the 70´s, nowadays has some significance in the national coverage, enclosing mainly residential houses. The profiles used in Portugal are the double S and double roman. The advantages of this material are good dimensional ability, homogeneous characteristics, good tightness, high mechanic strength, low sensitivity to temperature variation, good performance in areas near the coastline or severely affected by freeze-thaw cycles and have a wide range of colors and finishes. This ECPR has its disadvantage as higher self-weight, intensive energy consumption and esthetic quality inferior. Recommendations on technical issues relating to slope, and overlap and attachment are made to help the projection and execution of this ECPR.

2.2.3. Fibre-cement

The fiber-cement was, maybe, the first composite material used in buildings, beginning its implementation in Portugal in the mid 40's. It is a non combustible material, stainless, unlikely to deformation by shock, waterproof, rot proof and with a highly resistant to aggressive agents, rather susceptible to thermal differential with a reasonable capacity to absorb impact noise, good mechanical performance (compression, traction and flexion) allowing to win large space emptiness, of application with productivity and low cost. This disadvantage is related to one solution that wouldn't esthetically please. Acquire fragility by prolonged exposure to UV and replacement of an element take longer time than on small items (tiles and shingles). The sheets of fiber-cement have been applied on the roof of schools, factories, farming, building´s near the coasts buildings, sports facilities or warehouses. Can be plain or corrugated with different wave lengths (177, 190 or 230 mm). The sheets with 190 and 230mm of length are to function as sub-tile. The pending and overlapping minimum and recommended, as well as the type and arrangement of attachments to give this ECPR are defined in detail, to support several organizations that perform and plan roofing with this ECPR.

2.3. Metal roof

The use of metal roof in pitched roofs dates back to the late nineteenth century. At that time, plates were applied in iron, copper, lead and zinc. Currently, the scope includes industrial buildings, sports halls, the aircraft hangars, agricultural buildings, farming buildings and commercial buildings.

The advantage of this ECPR are lightweight, which allows the execution of a large range roof, reduced number of joints, when compared with ECPR of small dimensions, allows the smooth flow of rainwater with low pendent (low roughness), allow the realization of the curved roof and can be a recyclable material. The disadvantages are related to the poor soundproofing, low thermal insulation, high absorption of solar radiation, high volume variation and a lot of susceptibility to condensation. The metal coatings received a protective film to give protection to the atmospheric conditions. The finishes can be polymer inks, oxides, metallizations, plastics films or reflective layer. The more important metallic ECPR are steel, aluminum copper and zinc. ECPR are in the form of tile, slates, flat plates or corrugated sheets. The coatings of iron and lead have fallen into disuse due to its limitations when applied on roofs. This dissertation presents the form of application of ECPR, as well the setting overlap and pending to support entities that operate with this coverage material.

2.4. Plastic sheet

The main plastic sheet used in roofing are polyvinyl chloride (PVC), polymethyl methacrylate (PMMA), polycarbonate (PC) and fiber glass reinforced polyester (GRP). The plastic plates have two types of profile: plain or corrugated sheets. The advantages of ECPR are transparency, which allows natural light inside buildings, low weight, which allows ease the support structure compared to glass, imputrescibility and low cost. The disadvantages are its reduced lifetime by the action of solar radiations, high susceptibility to differential temperatures, mechanical strength and reduced resistance. The form of application of ECPR follows the recommendations made to the ECPR metal and fibre-cement. The flexibility of these ECPR allows the designer to resolve the singularities of coverage without applying many accessory parts. The transverse and longitudinal overlap should be made according to slope and exposure conditions.

2.5. Composite ECPR

The composite ECPR combines different elements to fill the gaps of each one in a new improved material. The visible asphalt shingles, sandwich panels bio-fibers, steel plates coated with bitumen and sheets of aluminum and metal tile with mineral granules. The bio-fibers are still in the implementation phase, so will not be the subject of study in this dissertation. The steel plates coated asphalt with bitumen and sheets of aluminum and corrugated metal with mineral granules are insignificant in Portugal and they are only presented their main characteristics.

2.5.1. Asphalt shingle

The asphalt shingles are fabricated with granular ceramic, oxidized bitumen, fiber glass and silica sand. Their including of fiber glass, oxidized bitumen as well ceramic granules, gives it a greater sound insulation to rain impact. The asphalt shingle is waterproof, simple to apply, flexible and without the need of accessories for the trim. However, its implementation is slow and has low productivity, it captures a lot of heat radiation due to its dark color, which can lead to its cracking. In places with hot climates, its application is not appropriate. The application of asphalt shingles needs a planking roof deck, usually wood boards, which can be applied with a flexible membrane to increase the tightness. The ECPR must have the minimum overlap and pending to defend against the weather conditions. The number and type of fastener must meet the specificities of each ECPR.

2.5.2. Sandwich panels

The sandwich panels consist in two metal plates or one metal and other of fiber cement, with an insulating material inside. The sheets have the flat or corrugated profile. The application of this ECPR has the benefits from the use of metal improving his thermal performance and sound isolation. The high specialization of sandwich panel joint increases the level of tightness of a pitched roof. It has a good thermal performance and high efficiency in the implementation work. The disadvantage of this material is the difficulty of carrying out the recycling. Its application is with the profile in the direction of profile. The plates are placed in the direction of prevailing winds that interact with the coverage. The overlap between elements fit for this purpose in the previous works. The fixing elements which connect the ECPR to support are metal screws.

2.5.3. Support Structure

The load-bearing structure is designed to withstand to the actions that act upon it, without the collapse occurs or excessive deformation that conditions the functionality. The supporting structure can be continuous slab of concrete, timber roof decking, steel, reinforced concrete beams or mixed structures.

2.6. Functional Requirements

The main functional requirements of a pitched roof to achieve quality standards implemented in construction, are summarized in **Table 2**.

Table 2 - Categorization of the main functional requirements of the ECPR.

Structural safety	Variable actions (precipitation, wind, accessibility); Accidental actions (burning behavior and fire safety)
Habitability	Leak (water, air dust mixtures, tilt overlap and fixation) Thermal behavior (thermal comfort, energy performance, susceptibility, acoustic comfort.
Durability	Mechanical behavior, geometrical requirements and dimensional stability, corrosion resistance, resistance to chemicals, behavior to freeze-thaw cycles, uniform appearance.
Economics	(aplicatibilidade) maintenance, replacement and treatment of waste.
Others	Sustainability

3. Pathology

According Garcez (2009) the most frequent anomalies in ECPR are presented in **Table 3**.

Table 3 - Proposed classification of anomalies in ECPR (Garcez, 2009).

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 aging
A-E7 cracking / fracture
A-O Design / execution defects
A-O1 defects in connection systems
A-O2 defects in the finishings
A-O3 inexistence or deterioration of water tightness complements
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

4. Rehabilitation

In this chapter its presents a set of techniques designed to repair various deficiencies in ECPR and the elimination of its causes. However, it is difficult to define these two actions as an alternative or complement to other strategies, such as for example, protection against aggressive agents, strengthening of the functional abnormalities of concealment (GONÇALVES 2001, PALHA 2008). The rehabilitation techniques are presented in **Table 4** being arranged according to the degree of intervention, increasing the extent of intervention as it rises in the category (R.A - R.E). Each rehabilitation techniques has a form attached that summarizes the procedures to perform and gives an estimate of costs, materials, equipment and labour intensive to employ.

Table 4 - Classification of rehabilitation techniques.

R.A: Upper surface of ECPR
R.A1: Cleaning ECPR
R.A2: Application of water repellent
R.A3: Removal of corrosion and restoration of the ECPR corrosion of protection
R.A4: Rehabilitation of the surface of the plastic ECPR
R.A5: Repair of the thickness elements
R.A6: Application / repair / implementation of fixations
R.A7: Creating circulation paths
R.A8: Application of ventilation accessories
R.A9: Repair of the finishing and singular points
R.A10: Capping
R.B: Underside of ECPR
R.B1: Application of undertile
R.B2: *Flocage*[1]
R.B3: Application / repair / replacement of vapour barrier
R.B4: Application / repair/ replacement of thermal insulation
R.C: Upper and Underside surface of ECPR
R.C1: Application of spray polyurethane foam (SPF[2])
R.C1-A: Upper Surface of ECPR
R.C1-B: Underside Surface of ECPR
R.D: Replacing ECPR
R.D1: Replacement ECPR
R.E: Replacing of load-bearing of ECPR
R.E1: Execution of a slab
R.E2: Repair / reinforcement / replacement of the support structure

[1] Definition taken from French literature whose translation was not made in the absence of a related term in Portuguese.

[2] SPF - *Spray Polyurethane Foam,* name this material in the international literature.

The implementation of any rehabilitation measure, involves an analysis of the general level of degradation and the determination the pathological causes. To do this, it resorts to a detailed inspection, systematic and objective, to collect information for an sustained decision (VEIGA et al. 1995, APPLETON 2003, PALHA 2008). The application of these techniques, restore the ECPR properties and bring a general improvement, making it able to cover the functional requirements. The techniques of rehabilitation of ECPR were listed in rehabilitation techniques used (RC) techniques, preventive maintenance (RP) and/or maintenance (M) (**Table 5**) (SILVESTRE 2005).

Table 5 - Types of rehabilitation techniques.

curative repair (CR)	R.A1; R.A3; R.A4; R.A5; R.A6; R.A9; R.A10; R.B3; R.B4; R.C1-A; R.C1-B; R.D1; R.E1 e R.E2.
preventive repair (PR)	R.A2; R.A3; R.A5; R.A6; R.A7; R.A8; R.A10; R.B1; R.B2; R.B3; R.B4; R.C1-A; R.C1-B e R.E2.
maintenance (M)	R.A1 e R.A2.

4.1. Cleaning ECPR

The cleaning of ECPR uses physical and chemical methods with varying intensity to remove dirt accumulated and biological colonization over the ECPR. The sandwich panels, metal and plastics ECPR have different methodologies, depending of the material and substance to clean. The surface cleaning of slates, clay tiles, micro-concrete, asphalt and fiber-cement sheets, may be use with brushing, jet cleaning (wet, dry or wet and dry) and/or application of chemicals. The selection of these methodology materials must be adapted to the level of encrustation of dirt and biological colonization. It can also be applied as a preventive measure in the ridge and corner with a fixation of copper ribbon that prevent biological growth running as herbicide.

4.2. Application of water repellent

Application of waterproofing products is a preventive measure against the biological growing and penetration of salts in marine environments. It can be applied only for clay tiles. This product increases the impermeability of the material, keeping the original aspect because it is colorless. The water repellent avoid problems of condensation. The disadvantages associated with this product are limited life cycle, reduced breathing of ECPR and flammability. The application should be made after cleaning the surface, removing debris and parasites, and should be reapplied when there is a loss of efficiency.

4.3. Removal of corrosion and restoration of the ECPR corrosion of protection

This technique removes the corrosion present in ECPR metal and reapplication of protective film / layer. ECPR in galvanized steel, (with or without protective film/layer) can be repair by scrubbing and if necessary the addiction of a chemical compound. Then it’s applied the protective film/layer to ECPR. The lacquered galvanized steel were restored with a painting, painting and replacement of the zinc coating or painting, painting and replacement of the zinc coating and removing the rust from steel. The depth of intervention depends on the state of ECPR, evaluated with a device that determines by magnetic induction the thickness of the rust coating. The other metal ECPR are repair by removing all rust material and degraded protective film. The next process is the application of primer, followed by primary adhesion and finishing paint.

4.4. Rehabilitation of the surface of the plastic ECPR

The rehabilitation of GRF (opaque and translucent), PVC (translucent, rigid and opaque), galvanized steel should be made when giving the appearance of laminated glass fiber for loss of protection gel. The other plastic ECPR need a test zone to verify the affectivity of measure. The rehabilitation consists on applying a protective isophthalic gel with a thickness of about 400 µm. The preparation of the substrate is done with emery paper or on water to remove the dust. Next, we will choose to apply the paint that can be of glicerophthalic, acrylic or polyurethane.

4.5. Repair of the thickness elements

<u>Sealant</u>

The rehabilitation of sealant joints is justified when it has a detachment with ECPR. Rehabilitation begins with the removal of the sealant deteriorated by brushing, followed by the application of a solvent to prepare the joint for the new sealant. Next, a primer is applied to the joint to improve sealant adhesion to the substrate and sealant, preferably based on acrylic polymer. The application is done with a spray nozzle, uniformly filling the gap.

Overlap

In slates and asphalt shingles, we can apply a double lap between the elements, which increases the tightness. This technique is to decrease the thickness of the fillets increased the overlap between elements. In fit clay tiles and metal tiles, the correction of the overlap is the right fit between the elements. In sandwich panels, sheet metal, plastic and fiber-cement, should be applied overlapping recommended against the local exposure. The increase of overlap may present itself as remedy to the inadequate coverage of slop which is in ECPR slates, tiles, micro concrete tiles cover channel and flat, asphalt, sheet metal, plastic or fiber cement.

4.6. Application / repair / implementation of fixations

The fittings corroded metal/nonexistent should be replaced/placed. In ECPR metal, plastic or fiber cement, should be checked the status of washers. If not, it should be placed in their attachments missing and if exists corrosion, should be replaced. The fastenings in these ECPR must have a plastic cap. In the event of loosening the fixings of ECPR metal, screws must be applied with larger diameter. When this occurs in tubular rivets, must place a self-tapping screws to maintain the cohesion between the ECPR and the support. The screws shall be copper, stainless steel or galvanized steel (not recommended for marine environments of industrial). In the event of deterioration of synthetic materials such as polyurethane foam or mortar, they must be properly removed and reapplied. In fit clay tile, if there is a detachment and misalignment of elements and it appears that the site presents meteorological aggressively, should be applied the fixation to the elements.

4.7. Creating circulation paths

In the absence of circulation paths, clay and micro-concrete tiles, they can be executed with mortar and tile itself, in a more enhanced or use of carpet-tiles. These elements must be created with preferential paths on string points of support. In slates, slabs of fiber cement, metal, plastic and sandwich panels isn´t recommended due to movement, and the inspections as well the maintenance carried out with aid of platforms. In asphalt shingles, it is not necessary to made circulation paths, may move freely both for inspection and maintenance.

4.8. Application of ventilation accessories

Poor or nonexistent ventilation is responsible for a wide range of abnormalities in ECPR and the support structure. The inefficient number of incoming and outgoing air, areas of the underside of ECPR blocked and “dead zones” where it is allowed the air circulation. To improve ventilation, should be apply elements that complements the ventilation, such as holes in the caves, windows, grilles, tiles or double vent, for different ECPR. It should be guaranteed the flow of air into the soffit of ECPR and the caves to the ridge, repairing these singularities when this flow is blocked or restricted.

4.9. Repair of the finishing and singular points

The finishing and singularities are weaknesses in the coverage that, when neglected, stem the loss of functionality. When you see the poor execution of finishing and singularities of roof, due to the removal of the elements performed poorly, and then proceed to the proper implementation. If possible, should be taken advantage of the existing material, reducing the costs associated with rehabilitation of coverage. It should use existing fittings and accessories that best suit and perform the designed function, and the adjustments usually focuses fault coverage.

4.10. Capping

This is a technique for the rehabilitation of fiber-cement ECPR only. This technique aims to repair cracks, peeling / scaling / exfoliation of ECPR and inhibition of biological development. The advantage of this method is the possibility of reuse of ECPR, avoiding the production of waste and full replacement coverage. The capping consists on applying products able to agglomerate the particles and to fix them to cement matrix, avoiding the degradation process continues. Capping products may be pervasive, acting on saturation of surface layer by gluing the fibers and the matrix between them, or covering, which form a continuous protective coating, thick and compact on the surface of the sheets.

4.11. Application of undertile

The application of undertile increases the tightness to improve ventilation, thermal and acoustic insulation. The sub-tile is a good solution when roof has a insufficient slope that allows the rain, coupled with the wind, to penetrate into the roof. When the slope is less than 10% should be increased overlap of the undertile. In the fiber-cement sheets, where there is insufficient slope, this ECPR can be converted into undertile.

4.12. *Flocage*

Flocage of ECPR is a good measure to prevent the establishment of moisture due to condensation on the underside of ECPR. It also improved the behavior of fire, thermal as well acoustic insulation of the roof. It consists of direct application of small fibers, natural or artificial, on the substrate with the aid of an adhesive material applied previously. These fibers are fixed to the surface through the pneumatic projection.

4.13. Application / repair / replacement of vapour barrier

The existence of a vapour barrier is to protect ECPR due to condensation. Its absence, end of a profitable life, poor or inadequate implementation of the volume of water vapor produced must be corrected. If the vapour barrier doesn´t exist, it proceeds to its placement. If we need to repair the affected areas, should be properly applied an amendment attached to the vapour barrier. The setting of the amendment must be mechanical, sealing properly these same anchors and the amendment together with bi-adhesive tape. Replacing imply its reapplication.

4.14. Application / repair/ replacement of thermal insulation

The thermal insulation plays an important role in the habitability of the interior spaces and energy efficiency of the coverage. An anomaly in this element must provide for its prompt correction. The lack of insulation should trigger its application in the manner set forth herein. An insulation thermal anomaly should be repaired. The repair of this insulation can be through the application of polyurethane foam, when the cracks have some thickness, or by *mastique* if they are small. If the insulation is deeply affected will have to provide their total replacement.

4.15. Application of spray polyurethane foam (SPF)

4.15.1.Upper Surface of ECPR

The projection of spray polyurethane foam on the upper surface of metal ECPR increases the protection to ultraviolet rays, reduces the volumetric variations due to differential thermal and improves performance against the occurrence of condensation affords on the surface of ECPR. The technique starts with the removal of corrosion, if any, and cleaning of ECPR. Next, remove the protective finish by sanding and to seal the joints. Now applies the primary and foam polyurethane. Then is applied an elastomeric membrane (acrylic, butyllic rubber, CSPE, neoprene, silicone or polyurethane elastomer or modified asphalt). Finally, it is applied as a protective paint finish, color clear if the site presents a warm climate.

4.15.2. Underside surface of ECPR

The application of polyurethane foam on the underside of ECPR metal fill small cracks, decrease susceptibility to the occurrence of condensation and complement the insulation. The application of polyurethane foam is made, after cleaning the support by spray gun, giving up some passages to set a recommended thickness of ,approximately, 40 mm. Then proceed to painting, if necessary.

4.16. Replacement ECPR

The replacement of ECPR is a limit as far as anything can be done to restore the properties necessary for it to fulfill functional requirements. Total replacement of ECPR is recommended when the lack of quality of material applied to the environment or inadequate exposure. In ECPR slate, asphalt, ceramic, micro concrete, and fiber cement, the replacements of elements is when the ECPR presents cracking, fracture, peeling or aging (end of profitable life). In ECPR or metal sandwich panels, the elements present excessive deformation or corrosion, widespread or deep. The ECPR plastics are subject to replacement when very aged by UV radiation.

4.17. Execution of a slab

The coverage is based on a slab of mortar thin (30 to 50 mm), where the armor is made of galvanized steel stretched (mesh < 5mm). This will bring a greater cohesion to the tightness and roof, achieve a better thermal and acoustic insulation as well reduced susceptibility to the occurrence of excessive deformation. Applies only when the support is made of wood and tile ECPR is in straw.

4.18. Repair / reinforcement / replacement of the support structure

The intervention in the support structure should be subject to prior review which establishes the state of deterioration that is the factor that led to their loss of functionality. It is necessary to identify the type of support structure that is present in the building to suit the strategy of rehabilitation.

5. System validation and statistical processing of data

This dissertation proposed a system for ECPR establishing a matrix of correlation between anomalies-rehabilitation techniques. For it to be consistent and capable of achieving a credible and sustainable results, was established an inspection plan in most common ECPR in Portugal. The plan of inspections contemplated a total of 207 roofs that had abnormalities in ECPR. The result of these inspections was documented in inspection and validation forms. In the campaign of inspections, are detected anomalies which are associated with one or more means of rehabilitation. Previous data from inspections allow calibrate and validate the theoretical system proposed by taking some adjustments when there are inconsistencies between the theoretical values and the previous inspections. The settings for the cases collected in the sample are very good in 82% of the cases, fair in 15% and bad in only 3%. The correlation matrix calibrated and end date is shown in **Table 6**.

Quadro 6 - Correlation matrix anomalies- rehabilitation techniques calibrated based on the sample.

Matriz correlação anomalias - técnicas de reabilitação																			
A / R	A.1	A.2	A.3	A.4	A.5	A.6	A.7	A.8	A.9	A.10	B.1	B.2	B.3	B.4	C.1A	C.1B	D.1	E.1	E.2
A-C	0	0	0	0	0	0	0	1	0	0	0	1	2	0	1	1	0	0	0
A-D1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	2
A-D2	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	1	1
A-D3	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	1	1	1
A-E1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A-E2	0	0	2	0	0	2	0	1	1	0	0	1	0	0	1	1	1	0	0
A-E3	0	1	1	1	0	0	0	2	0	1	0	0	0	0	1	0	1	0	0
A-E4	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
A-E5	1	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0
A-E6	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
A-E7	0	1	1	1	0	0	1	1	0	1	0	0	0	0	1	0	2	0	0
A-O1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1
A-O2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
A-O3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	1
A-O4	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	1	0	1
A-O5	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	1	0	0	0
A-O6	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0
A-O7	0	0	0	0	2	2	0	0	0	0	2	0	0	0	1	0	0	0	2
A-O8	0	0	1	1	1	1	0	0	1	1	0	0	0	0	1	0	2	0	1

During the fieldwork, were recorded in 1195 anomalies associated with 1540 rehabilitation techniques, making an average of approximately 1,3 rehabilitation techniques for each anomaly. Obtaining a value close to 1 is characterized by selection, in most cases, those techniques that rehabilitated the ECPR objectively and act on the pathology causes. The absolute frequency of rehabilitation techniques address the anomalies observed in inspection carried out is shown in **Figure 1**.

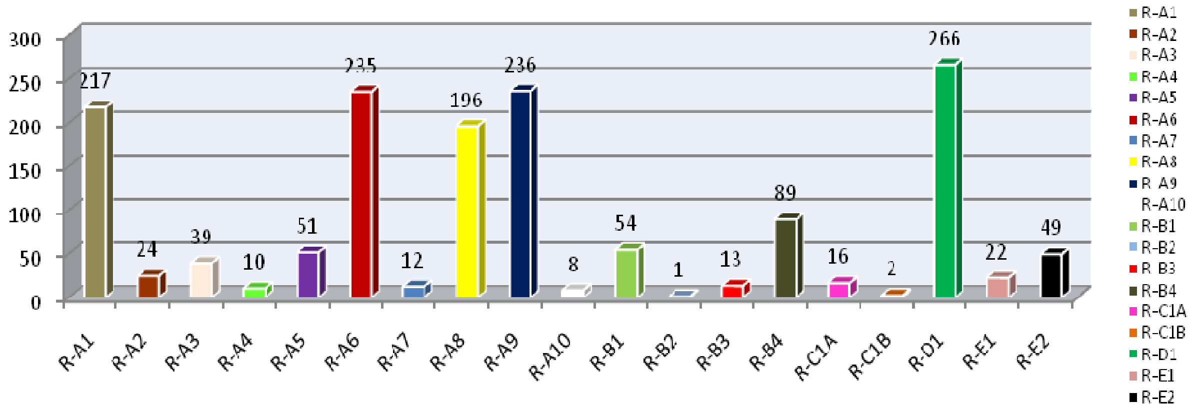

Figure 1 - Absolute frequency of rehabilitation techniques address the anomalies observed in the inspection plane.

It is the domain of rehabilitation techniques **R.D1** (**replacement of ECPR**), **R.A9** (**repair of roof finishing and singular points**), **R.A6** (**application / repair / replacement of fixations**), **R.A1** (**cleaning ECPR**), **R.A8** (**application of ventilation accessories**).

The roofs were inspected more often, with 94% of inspections carried out, with less than 20 years. The geographical distribution of inspections is predominantly in the region of Lisbon and Vale do Tejo, with 177 inspections (57%), and in the Oporto region, with 90 inspections (43%). The inspections focused more on rural and urban buildings (41,1%), with lower expression in the sea (2,4%). The concentration of pollutants at sites inspected was not a factor in the deterioration of ECPR, the occurrence of high concentrations was only in 0,5% of the cases. The type I summer climate showed the highest frequency (66% of inspections), and zones II (18%) and III (16%) with lower expression, as the winter zone, zone I (57%) and II (43%) show a similar frequency, not being carried out inspections on roofs in the area III. In the sample collected, there was a predominance of buildings with 1 floor (71,5%), getting the remaining lower frequency (2 floors - 20,3%, 3 floors - 7,7 % and 4 floors - 0,5%). In the roof inspected, reviewed the class of exposure to meteorological agents, including wind, rain, solar radiation among others. Was detected more frequently in coverage with normal class (55,6%) with lower frequencies the roofs exposed (41,1%) and protected (3,4%). The shape of the roof is inspected, predominantly with valley (53,1%), monopitch (23,7%) and hipped or pavilion (14%).

The support structure traditional wood predominates in the roofs inspected with 38,2%. The metal structures have a high frequency in the roof inspected (29,5%). Supported structures staple in concrete beams (9,7%) are less frequent. The support structure with continuous concrete slab meets about 22% of occurrence. The composite structures and brickwork had a very limited presence in support of ECPR. It was the wood framework decline from the late 80th and early 90th against the rise of metal and concrete structures. The concrete structures experienced its heyday in the range from 1990 to 2000, constituting itself as a good solution in the implementation of support coverage. However, the metal structures have shown a continuous and uniform presenting itself as the largest deployment of support for its rapid implementation, low self-weight, compared with the concrete possibility of applying products adapted to the conditions of exposure and good longevity.

Ventilation in the roof dominates the micro ventilation with a total of 59%. The other forms of ventilation are much lower than that indicated by the good practice in construction. The thermal insulation in the roof proved to be an element often absent (66%) as opposed to expected, as it is now an essential component for the tasks they have. This raises problem in the inner housing and energy costs for heating and cooling. The vapour barrier was not found in any of the 207 inspections. The use of planking coverage is about 38%. The inspection plan contemplates the selection of a representative sample of each of the ECPR currents coverage in Portugal (**Figure 2**).

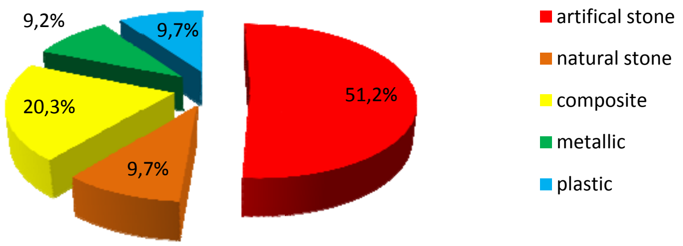

Figure 2 - Frequency of different groups of ECPR inspected.

Was inspected a total area of 44. 543 m^2 making an average of 215 m^2 per roof. The number of inspections of artificial stone materials are superior to the others (51,2%) by the bigger amount of ECPR in Portugal. It was done, in a way, to transpose this distribution for the collected sample so that the data and retrieved conclusions are the closest possible to reality. For the other materials, we tried to obtain a representative sample of each to a proper analysis. The natural stone ECPR inspected were the natural slates, the ECPR artificial stone were clay tiles (58,5%), micro-concrete (19,5%) and fibre-cement (21,7%), the plastics were the PC (30%), PVC (20%), GRP (30%) and PMMA (20%), the ECPR metal were steel (63%), copper (26%) and zinc (11%), and composite ECPR were sandwich panels (50%) and asphalt shingles (50%). In terms of total area inspected in the differents ECPR, there is a larger domain of the ceramic ECPR (27,5), followed by sandwich panels (22%) and fibre-cement (16,6%), which are also a major part. The older coatings are slate, with a previous occurrence of 1900, which is the largest concentration in the sample of ECPR was between 1970 and 1980 included 11 elements. Tube tile is more frequent in the range from 1940 to 1950 (16 elements). The Marseille tile has the largest number of elements in the range from 1980 to 1990 with 12 inspections. The fibre-cement has the most significance in the period of 1970 to 1980 with a total of 14 covers. The year of completion of coverage of the remaining material is scattered in the range from 1990 to 2009. The slates have majority support in wood the same applies to the tube clay tile which on all the inspections were supported on wood. The oldest Marseille tile had support in beams. The fibre-cement is applied in all load-bearing, with predominance of wood structure. The structures of micro-concrete tile are applied to wood and concrete with a slight preponderance for the concrete slab. The metallic ECPR have more frequent metal load-bearing. The plastic ECPR have all supporting structures staple, with a predominance of metal structures. The asphalt shingles are mostly applied on concrete slab. The sandwich panels as they are a recent material, the support is mostly on metal structures. **Figure 3** shows the average number of rehabilitation techniques applied to different ECPR per inspection.

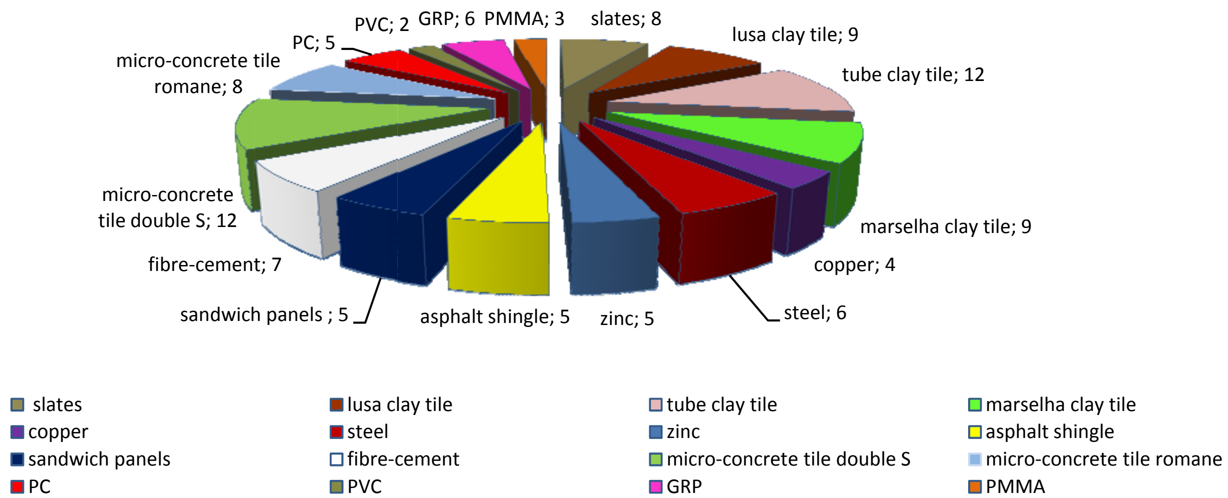

Figure 5.1 - Average number of rehabilitation techniques applied to different ECPR per inspection.

The materials presented are all very similar as the quotas on the number of interventions. However, we can highlight the tube clay tile (12) and slates (8) which by their age, require greater intervention. Figure 3 show that micro-concrete tile had high intervention needs due to the verification of its deficient execution.

The **replacement of ECPR** (**A.D1**) is present consistently in almost all intervals. The same applies to the **cleaning of ECPR** (**R.A1**), **application / repair / substitution of fixations** (**R.A6**), **repair of the finishing and singular points** (**R.A9**) and **application of ventilation accessories** (**R.A8**). The rehabilitation techniques applied to load-bearing of ECPR (R.E) have higher expression in roofs previous to 1960. The methodology **R.B4** (**application of thermal insulation**) was regular along the period study, was relevant when we observe a frequency of approximately 5% of use from 1990 to 2009. The rehabilitation techniques applied for ECPR in rural and urban environment areas are very similar, contrary to what happens in ECPR applied on the coastline. Aggressive maritime causes high accumulation of debris and rapid corrosion of metallic ECPR, which spreads at a frequency of 33% for **cleaning of ECPR** (**R.D1**) and **removal of corrosion and restoration of the ECPR corrosion of protection** (**R.A3**).

There is a higher degree of degradation to roofs in zones with medium/high exposure to pollutants, given the greater use of techniques **R.A1** (**cleaning ECPR**) and **R.D1** (**replacing the ECPR**). There is a high frequency of technique **R.A3** (**removal of corrosion and restoration of the ECPR corrosion of protection**) and **R.A4** (**rehabilitation of the surface of plastic ECPR**) inherent on the further degradation of ECPR metal and plastics due to the increased aggressiveness of the environment. The relation between the class of exposure of the roof and the rehabilitation techniques used, allowed us to observe that the **replacement of ECPR** (**R.D1**) increases with the roof exposure class. The application of technique **R.A1** (**cleaning ECPR**) shows an opposite distribution with a more protected roof to exhibit a higher presence of debris.

6. Conclusion

It is hoped that this dissertation contributes to the dissemination the need of a plan inspections and periodic maintenance activities that increases the quality of coverage. A proactive strategy and execution with quality, following the requirements defined in this document should be spread and implemented in different hierarchical levels of construction, since the designer to the labourer. So, everyone is concerned of its importance and adopt behaviors that will force up the quality levels and reduce costs associated with it. It is intended the importance that start processes of creation databases about the roof, where they placed all the information relevant and subsequent constructive actions, improve the quality of intervention.

The presented rehabilitation techniques system was validated with 207 inspections, is as an asset when it is necessary to repair ECPR.