METHODOLOGY FOR DIAGNOSTICS, REPAIR AND PREVENTION OF PATHOLOGIES IN CERAMIC FACADE CLADDINGS

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ABSTRACT

This work deals with the development of a methodology for diagnosing, preventing and repairing ceramic claddings on building facades, when these tilings exhibit pathologies. The work discusses the severest problem of ceramic tile facades: bond failure.

The concepts of durability and service life are discussed, as well as the factors affecting both. The study establishes the parameters that allow the planner to define the cladding's design life and the necessary procedures to transform this into the real service life of the ceramic facade subsystem.

Based on the definition of these concepts, a methodology is proposed that allows diagnosing the existing manifestations, establishing repair procedures and defining parameters to prevent their appearance, so that the planned service life is actually achieved in practice.

1 INTRODUCTION

The main reason why buildings have been clad with ceramics for decades is mainly due to their high resistance to highly varying environmental conditions, i.e., the material does not generally exhibit significant wear with time.

The capacity of ceramic tilings to last is discussed by SHOHET; LAUFER (1996). They compare this type of cladding with others, such as cementitious mortars, synthetic mortars and stone. In this case, the clear superiority of ceramic tilings is noted compared with mortar facings, as Table 1 shows.

Type of environment	Cementitious mortar	Synthetic mortar	Ceramic tiling	Stone
Non-corrosive	10-15	12-15	over 15	over 25
Corrosive	5 years	8-12	10-15	around 25

Table 1: Estimated service life of different types of external building facings in different environments (SHOHET; LAUFER, 1996).

This capacity to remain unaffected over time, associated with other factors listed by MEDEIROS (2000), such as: ease of composing geometric patterns, cleanability, good moisture resistance, satisfactory general performance and low maintenance cost, are the main reasons for the use of this type of facing for building facades, particularly along the coast.

However, ceramic facade claddings (CFCs) should be understood as a: "Monolithic set of layers (including the background render) adhered to the building facade background (fill-in or structural), whose outer layer is made up of ceramic tiles, fixed and grouted with mortar or adhesive material", (MEDEIROS, 1999).

The prevention of pathological manifestations, failures, depends on the understanding of the various properties of each of these components and of their interface behaviour, as such failures can occur very early on, as analysed by CAMPANTE; SABBATINI (2000), who report that 50.9% of the studied buildings presented detachment of ceramic tiles in facades within 5 years of service.

2 PATHOLOGICAL MANIFESTATIONS IN CFC_s

In CFCs the pathological manifestations can be understood as situations by which, at a certain moment of their service life, they stop performing as expected, i.e., do not perform the functions for which they were designed, and cease to satisfy user needs.

These functions can be summed up as: protection of the enclosing elements of the buildings, helping the building envelope perform its functions (thermal and acoustic insulation, gas and damp-proofing, etc.), regulation of the enclosing element surface and performance as building finish, with aesthetic functions, economic valorisation and functions relating to building use.

PERRY; WEST (1994) classify the most common pathologies found in CFCs according to the layer where they happen: tile defects (moisture expansion and in tile glaze surface defects), failures in the substrate (relating to building movements due to thermal shock, deformations of the base, creep and shrinkage of the concrete) and failure in the "adhesive" (problems in the fixing mortar or caused by inadequate coverage and/or made by poorly skilled labour).

The main pathological manifestation affecting CFCs is ceramic tile debonding from facades, which is caused by the resulting effects: when a 250g ceramic tile comes off a building at the 10^{th} storey, it has the same destructive power on hitting the ground as a bullet from a firearm (TAN et al., 1994).

For a good analysis of the mechanisms of pathological manifestations in CFCs it is necessary to make a hierarchical analysis, beginning by observing the defect or pathological manifestations, subsequently establishing their immediate cause, via their nature, i.e., secondary cause, then going on to the origin of the problem, to their primary cause.

According to CHEONG (1992), analysis of detachment can lead to four different natures: bond failure between the ceramic tiles and the fixing mortar, bond failure between the fixing mortar and the substrate, failure in substrate layers and occurrence of a hollow sound in the ceramic tiles when struck.

For SABBATINI; BARROS (1990) the main factors associated with the origin of detachments are: deformation occurring in the base (fill-in/structure) due to settling of the building after occupation, creep of the concrete structure, which is not immediately reached and hygrothermal variations; absence of control joints; inadequacies in mortar renders, settling and grouting and faulty preparation of the background.

One of the main causes of detachments in CFCs is the reduction in the mechanical strength of the various layers on exposure to the arising mechanical stresses. These stresses are produced by movements generated in the CFCs, by the structure of the building itself or by the environmental conditions to which they are exposed.

For MEDEIROS (1999), the pathological manifestations found in CFCs are the result of two essential factors:

1. Designs that fail to take into consideration performance parameters and do not consider production stage needs.

2. Inadequate control of the production technology involved in tilings, as well as of existing tilings, by the whole production chain, from engineers and architects to tile fixers.

3 THE CONCEPT OF DURABILITY AND ITS APPLICATION TO CFC_s

In the CFC subsystem, the quantification of durability takes on fundamental importance for two reasons: the first one is to allow the use of these data to define the economic feasibility of using of certain types of components and materials. The second reason is to allow comparing them in terms of the durabilities afforded by other alternatives, so that those can be selected that best adapt to the existing conditions.

To establish the durability of this subsystem first requires knowledge of the deterioration mechanisms associated with each CFC component, and based on these data, these can be related to the subsystem, analysing its degradation mechanisms. In other words:

Deterioration would be a term associated with the **components** of the subsystem, and

Degradation would be a term directly linked to the **subsystem** as a whole.

For the CIB (1983), durability should be studied according to four separately considered aspects:

I. Materials used, which are classified on a scale that goes from perishable to non-perishable, in accordance with the degree of deterioration found during use;

II. Design, which would also be analysed with the aid of a scale that goes from bad to excellent, according to the factors considered for the material involved;

III. Conditions of use, which should be classified in a range from severe to gentle;

IV. Maintenance, which should be evaluated on a scale from frequent to non-existent, according to the design prediction.

These aspects hardly take into account the materials or components of the subsystem, nor this last item as a whole. The explanation is to be found in the fact that to determine the durability of a subsystem like the CFCs, it is necessary to know the interface mechanisms between the various components, this being still poorly understood.

4 CONCEPT OF SERVICE LIFE AND ITS APPLICATION TO CFC_S

Service life in the case of CFCs can be defined as:

Period of time in which this is able to maintain the properties that allowing performing the functions for which it was designed, taking into account the remaining service time and the estimated maintenance or replacement costs.

On dealing with the Service Life of CFCs, it is necessary to establish two different dimensions for this concept: design life (DL) and actual service life (ASL).

Design life (BSI, 1992) can be defined as a value preset by the planner, which it is sought to meet in actual service. This determines management decisions, fundamentally, selection of materials, techniques for executing the subsystem, maintenance actions and the costs to be borne by the users.

There are a number of conditioning factors for the DL; of these, to be noted are the lifecycle of the building, which will define the period of time that the subsystem is required to keep its initial characteristics. In this way, in general lines, it is clear that the DL of CFCs should be the same as the one specified for the structural subsystems and for the building enclosures. However the DL of the subsystem must not be confused with that of its components. Table 2 lists certain criteria for defining different values for the subsystem components.

Subsystem component	Importance rating in the subsystem	DL class
Fixing layer	A1	1
Ceramic tile	A2	1
Grout	B	2
Movement joints	C	3

Table 2: DL estimates for CFC components.

In the previous table various components are classified according to the effects of their failure. In this way, a component classified as A1 would on failing have a knock-on effect on the others. It is thus sought to establish a relation between the different components; failure in the fixing mortar would cause collapse of the whole subsystem, producing detachment of the ceramic tiles. For this reason, it should have its DL classified as 1, that is to say, the same value set for the subsystem as a whole.

To help the facade planners make decisions with regard to establishing the different service lives for the components of the CFCs, a proposal is made that is summarised in Table 3. Thus, a table of durability for CFCs can be established, enabling the period of time to be chosen during which the subsystem should hold its initial characteristics, as a function of the variables: Design for production, Materials of the subsystem components and Procedures for executing the subsystem.

Quality levels of the variables	Durability grades				
	A	B	C	D	E
DFP	10	7	6	4	2
MAT	8	6	4	3	1
EXE	12	8	7	6	2

Table 3: Estimate of CFC durability based on its DL.

where: DFP: Design for production

MAT: Materials of the subsystem components

EXE: Procedures for executing the subsystem

Grade A: 25 to 30 points ⇒ more than 25 years

Grade B: 20 to 25 points ⇒ 20 years

Grade C: 15 to 20 points ⇒ 15 years

Grade D: 10 to 15 points ⇒ 10 years

Grade E: 5 to 10 points ⇒ less than 5 years

The ratings described in the table are in turn found through an analysis of each of the three basic factors listed in the table. Depending on the level of quality of each factor, it is possible to define how long the CFC is expected to "last".

After defining the factors of influence of each variable, it is necessary to "weight" each one, defined in Tables 4, 5 and 6 proposed below.

FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT
Analysis and definitions	**5**	**Specification and detailing**	**5**
Physical executability	0.2	Definition base and substrate preparation	1.0
Economic executability	0.2	Definition joints and substrate reinforcings	1.0
Financial executability	0.2	Definition construction details	1.0
Conditions of exposure	1.1	Definition construction methods	1.0
Facade architecture	1.1	Definition control criteria	1.0
Deformability of structure	1.1		
Characteristics of external enclosures	1.1		

Table 4: Maximum weights attributed to the factors associated with the DFP variables in the definition of subsystem CFC durability.

FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT
Tile typology study	**2**	**Materials selection fixing layer**	**2**	**Materials selection grout layer**	**2**	**Materials selection control joints**	**2**
Historical problem events	0.1	Mortar properties fixing/grout	0.5	Deformability	0.4	Expected extent of CFC movement	0.3
Costs direct/indirect	0.1	Surface application characteristics	0.2	Side adhesion ceramic tiles	0.3	Local stress concentrations in CFC and base	0.3
Surface treatment rear side	0.3	Prediction of CFC structural performance	0.5	Workability	0.4	Tile modulation	0.3
Tile weight	0.3	Environmental conditions	0.3	Drying shrinkage	0.4	Position/thickness grout joints	0.2
Porosity rear side	0.3	Tile position	0.2	Aesthetic requirements	0.1	Materials characterisation CFC and base	0.3
Tile thickness and surface area	0.3	Position relative to facade	0.3	Resistance to deterioration	0.4	Sealant properties	0.3
Tile colour	0.3					Geometry/ dimensions / quantity / positioning control joints	0.3
Tile properties	0.3						

Table 5: Maximum weights attributed to the factors associated with the MAT variables in the definition of subsystem CFC durability.

FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT	FACTORS OF INFLUENCE	MAXIMUM WEIGHT
Service programming	**1**	**Definition of manpower**	**4**	**Definition of tile fixing technique**	**5**	**Control project being executed**	**2**
Definition logistics	0.1	Sizes of teams	0.3	Procedure preparation / handling materials	0.5	Definition process control station	0.7
tools / equipment	0.3	Elaboration of procedures	1.5	Techniques marking / levelling control joints	0.5	Definition service reception criteria	0.7
Installation / handling hoists	0.3	Elaboration of training manuals	1.5	Techniques adjusting panel dimensions for project modulation	0.5	Feedback project process	0.6
Supply /handling materials	0.1	Qualification of manpower	0.7	Techniques spreading fixing mortar	0.5		
Organisation of production	0.2			Techniques setting tiles in position	0.5		
				Techniques use of manual tools	0.5		
				Techniques grout mortar application	0.5		
				Techniques execution of grout joints	0.5		
				Techniques execution f control joints	0.5		
				Techniques cleaning after execution	0.5		

Table 6: Maximum weights attributed to the factors associated with the EXE variables in the definition of subsystem CFC durability.

Service life is defined by BSI (1992) as being the period of time in which the component, or construction maintains its characteristics exceeding the users' requirements with regard to operation, maintenance and repair, i.e., this would be the period in which the subsystem **really** holds its properties at the acceptable minimum level, thus meeting user expectations.

The ASL of a subsystem is limited by what the ISO standards (1997, a) call deterioration to which its non-replaceable components are subject. Deterioration in itself may not cause any change in the replaceable components, however, in some cases, their replacement reaches such high values that they can condition the ASL of the subsystem as a whole. This often happens with CFCs.

5 PROPOSED METHODOLOGY

The proposed methodology is based on certain guidelines, which can be summarised as follows:

1. Expected durability of the indicated solution; considering the service lifetime of the building, it is determined if the repair will be permanent or temporary.

2. Expected service life of the subsystem; i.e., the equation *DL x ASL (maximum) of the subsystem*, is considered more consistent with the cost-benefit ratio, which can alter the whole repair procedure of the manifestations indicated.

3. Maximum reliability of the proposed treatment, directly linked to the efficiency of the solution; i.e., it is a measure of "how much trust" can be placed in the proposed solution, primarily conditioned by safety factors.

4. Optimised cost/benefit ratio. This guideline directs the solution in the sense of using the available resources in the best possible way, without wasting any materials.

These guidelines direct the application of the methodology in their three phases: Diagnostics, Definition of treatment and Prediction, which are summarised in Figure 1.

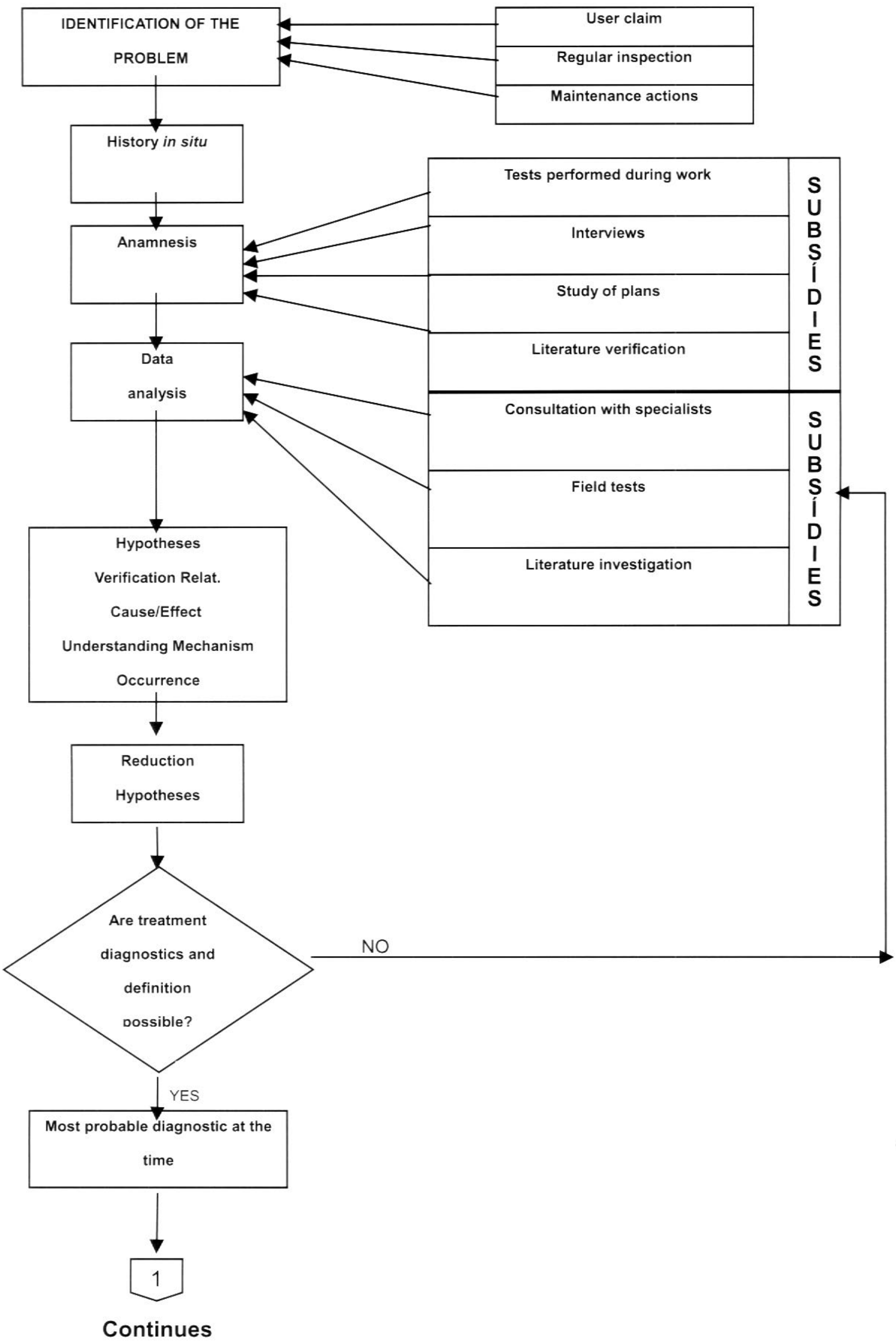
IDENTIFICATION OF THE PROBLEM
User claim
Regular inspection
Maintenance actions
History *in situ*
Anamnesis
Tests performed during work
Interviews
Study of plans
Literature verification
SUBSÍDIES
Data analysis
Consultation with specialists
Field tests
Literature investigation
SUBSÍDIES
Hypotheses Verification Relat. Cause/Effect Understanding Mechanism Occurrence
Reduction Hypotheses
Are treatment diagnostics and definition possible?
NO
YES
Most probable diagnostic at the time
1
Continues

Figure 1(a).

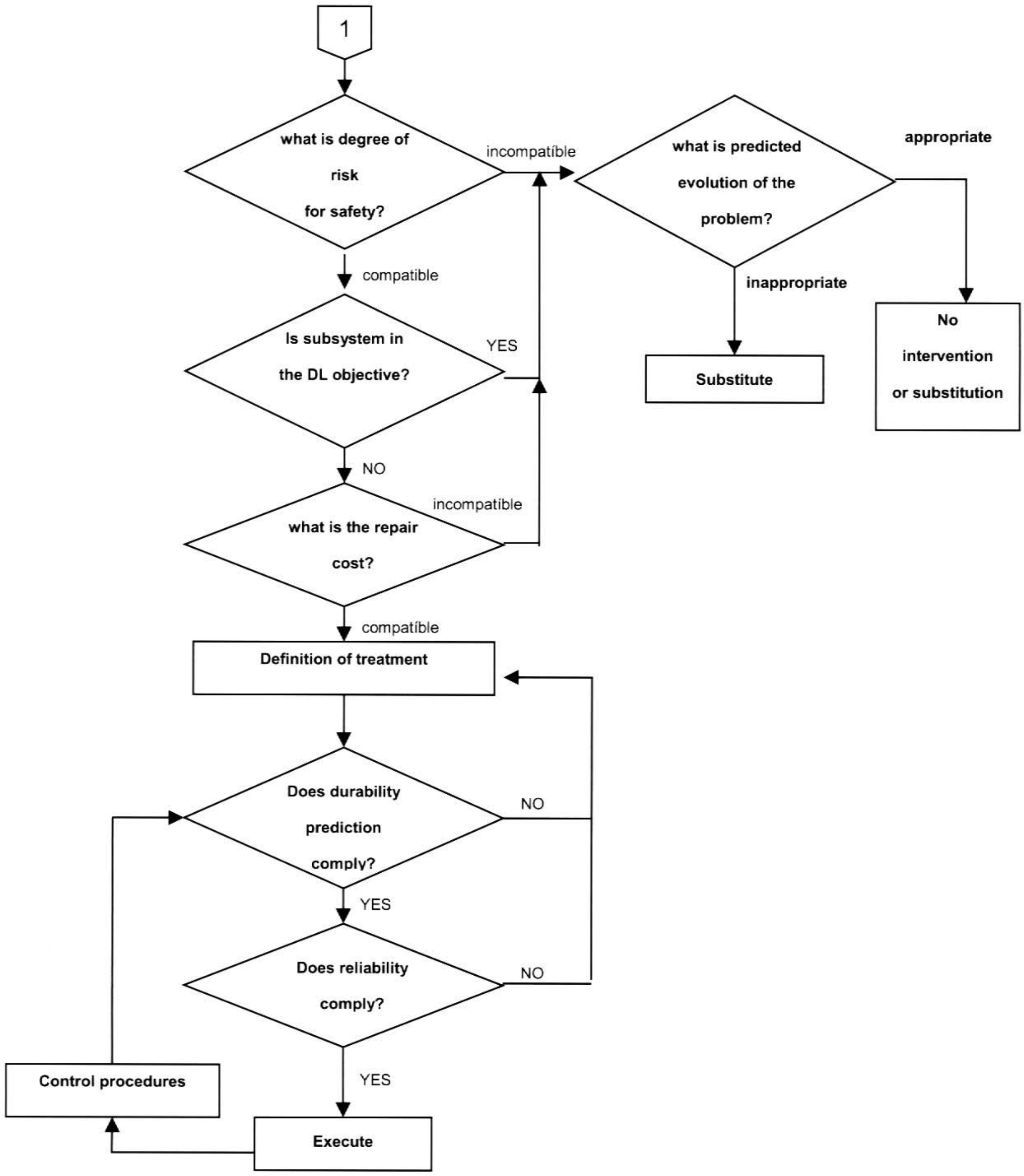

Figure 1(b).

One of the most critical phases during the application of the methodology was the definition of which line to take in treating the pathological manifestations. To guide the professionals responsible for balancing and resolving these pathological manifestations, a matrix is proposed for decision-taking, based on the three key variables in making this type of decision, as shown in Table 7 and Figure 2.

User risk	% Attained area	% Remaining service life
2	0	20
4	25	40
6	50	60
8	75	80
10	100	100

Table 7: Quantitative values for taking decisions on treatment.

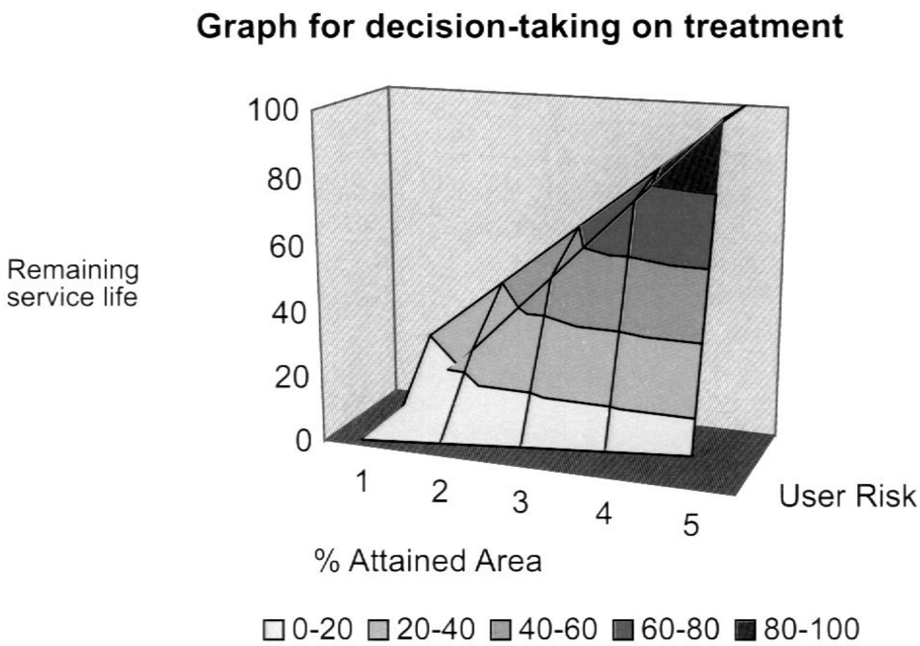

Figure 2: Graph of decision-taking on treatment .

Figure 2 shows a hypothetical quantitative example. To reach a matrix for a specific case it is necessary to attribute quantitative concepts to each variable, i.e., it is necessary to clearly establish what would really be a "high" attained area, for example. Establishing precise values for each of these variables is recognised to be a complex task, in which analysis should take into consideration the specific features of each case. This requires the specialists to have a good knowledge of the issues, some experience and particularly a high degree of systemic reasoning.

6 FINAL CONSIDERATIONS

In the case of CFCs investments are justified in the measure in which the vast majority of pathological manifestations in the CFC subsystem can be attributed to lack of understanding of the interfaces between its different components, which are directly linked to deficiencies in the technical knowledge of the whole production chain, i.e.:

- Unskilled tile fixers, without training;
- Manufacturers of materials unconcerned about guarantees, technical assistance and information on the use of their products;
- Designers unaware of their responsibilities in the CFC production chain, and;
- Installers (building proprietors) not attending to the real value attributed to the relation between repair costs of the pathological Manifestation x Value of the assets to be recovered.

The main contribution of the methodology developed in this work for the ceramic tile manufacturing companies would be to establish parameters that provide a better understanding of how their products are used in one of the most important subsystems in buildings. And in this way, to understand the need for better technical qualification (in the area of building construction) of those in charge or the Technical Assistance Departments of these companies.

For the developers the contributions of this work are contained in the innovations proposed in the Methodology, which can be summed up in three basic points:

1. Establishing a systematic methodology for the study of the pathological manifestations in the CFC subsystem;
2. Determining parameters to establish values of the planned service life of the CFC subsystem, and;
3. Defining a line of treatment for CFC subsystems affected by detachments, based on accurate technical and economic parameters.

The proposed methodology enables determining the origins of detachments in CFCs, and thus establishing how building production procedures can affect the use of this subsystem. For example, the lack of plumb that reinforced concrete structures may exhibit can make this type of facing quite unsuitable, i.e., it can be concluded that to use this subsystem, it is necessary for the decision on its use be taken in the planning phase, and that during the whole construction of the building, procedures should be employed that take its use into consideration.

Through the proposed methodology it is possible to determine the importance of the "construction memory" of the builder, that is to say, accessing important documents to learn the history of the construction, such as: fiscal notes, working agendas, planned and executed physical time schedules, service execution contracts, materials reception tests, "as built" project, amongst others; in the diagnostics of the problem.

As a result of this, it is possible to arrive at repair procedures that can solve the problem based on technical and financial approaches. This can avoid the option for spot, palliative interventions that most of the times do not provide the expected results owing to the lack of systemic analysis, such as the opening of movement joints in a finished facade, which can do more harm than good. The whole subsystem can be made fragile owing to relieving stresses on opening these joints.

One of the most important conclusions drawn during the development of this work was that the repair of CFCs can entail extremely high costs. These costs include: leasing and installing sophisticated hoists (for facilitating services), use of better quality materials, low productivity owing to the use of small teams for better control in the execution of services, difficulty of finding ceramic tiles like those used in the work, existence of legal actions, amongst others.

However, those responsible for repair, who often consider this to be economically unfeasible, can through the proposed methodology accurately determine this in relation to Cost x Benefit. In the studied cases, it allowed concluding that even with a high outlay, it was worth repairing the subsystems, at least from the point of view of the proprietors. The problem lay in the fact that for the developer this was an "unacceptable" cost, but it is believed that the damage to the developer's image and the value of a possible legal compensation exceeded the value of the repair in itself.

Another of the contributions of this study, for the tile manufacturing companies as well as for the developers would be the discussion of the way this subsystem is used in buildings. There are no efforts being undertaken by the tile manufacturing industries (in a general way) towards attending to demands by the builders, i.e., to sell ceramic tiles as an "'applied product". Developers (at least those heard by the author) no longer want to have to buy all the components of the subsystem separately, to hire manpower to use them and later to accept liability with regard to the users.

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