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Operationalisation of Building Inspections and Repair: Systematisation-Based Approach

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Featured Application: This article applies to building maintenance and the life-cycle assessment of repair operations.

Abstract: The possibility of diagnosing and repairing specific sets of defects (those with more severe consequences and impact on the degradation of building components) with the same means is considered. It is important to optimise the planning and kick-off of building inspections by using, from the start, a predetermined set of equipment and to optimise the maintenance and rehabilitation of the building envelope in terms of funds invested and resources. An existing methodology is used to create inter-defect correlation matrices, taking into account an expert knowledge-based building inspection system. The main results include a set of essential diagnosis methods—crack measuring and monitoring; temperature and moisture measurement; infrared thermography; and water absorption tests—and the identification of the most transversal repair techniques—cleaning; protection coating; replacement/reapplication of claddings/glazing; re-application of finishing coats or more adequate claddings—which were also analysed in terms of resource consumption, as a preliminary approach to their life-cycle assessment. The main conclusions indicate that there is still a long path to cover in the field of life-cycle assessment of repair techniques, which can be extended to the application of diagnosis methods.

Keywords: building maintenance; building pathology; diagnosis methods; repair techniques; life-cycle assessment

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1. Introduction

Building maintenance, and specifically building inspection, is paramount to upkeeping the building stock, considering adequate levels of performance, thus contributing to sustainable development goals within the built environment—lower use of resources, improving habitability conditions of dwellers, promoting sustainable cities connected with their history, following SDGs 11 and 12. This study of building pathology contributes to that purpose and is not independent of diagnosis procedures and repair and refurbishment. In this paper, a new approach is presented regarding the connection between building defects and diagnosis methods and repair techniques.

1.1. Background

The building envelope, as the physical barrier separating the indoors from the outdoors, thus controlling heat, air, and moisture flows [1], has major importance in the overall performance of the building, as have its claddings.

There are several different inspection protocols defined in the context of building pathology and forensic engineering, all of them adapted to the purposes of research, like those developed by Ribeiro and Cóias e Silva [2], Juan et al. [3], Rojas and Songer [4], SEI and ASCE [5,6], Hegazy et al. [7], Linggar et al. [8], Matos et al. [9,10], and Bortolini and

Forcada [11]. Those protocols should also be adapted to the inspected reality, considering the type of inspected building elements and aiming at unifying and standardising inspection procedures, regardless of building materials. This activity should have a holistic approach as long as the analysis of the inspection results and recommendations has specific references to the involved materials.

In the context of the research of Pereira [12], an inspection protocol for the non-structural building envelope was developed, and several auxiliary materials were made available, such as the classification lists of diagnosis methods (Table 1), repair techniques (Table 2) and defects (Table 3). Correlation matrices were also developed as the backbone of the inspection system, namely, defects–causes of defects, inter-defects (based on the defects–causes of defects correlation matrix), defects–diagnosis methods, and defects–repair techniques correlation matrices [13].

Table 1. Classification list of diagnosis methods within a global inspection system for the non-structural building envelope [14].

Code	Category	Code	Diagnosis Method
D-A	Assisted sensory analysis	D-A1	Endoscopy (NDT)
		D-A2	Analysis by touch (NDT)
		D-A3	Assessment of the slope, flatness, orthogonality, and alignments (NDT)
		D-A4	Tell-tale gauge and gypsum testimonies (NDT)
		D-A5	Crack width ruler and crack-measuring microscope (NDT)
		D-A6	Mechanical strain gauge (NDT)
		D-A7	Assessment of the cracking and blistering level (standards EN ISO 4628-4:2016 [15] and EN ISO 4628-2:2016 [16]) (NDT)
		D-A8	Polyethylene film (NDT)
		D-A9	Thickness measurement by depth gauging and difference in thickness (standard EN ISO 2808:2019 [17]) (DT)
D-B	Electrical methods	D-B1	Eddy currents (standard ASTM E2884-17 [18]) (NDT)
		D-B2	Leakage electrical detection (standards ASTM D8231-19 [19] and ASTM D7877-14 [20]) (NDT)
		D-B3	Electrical capacitance test (NDT)
		D-B4	Magnetometry (NDT)
		D-B5	Conductivity meter (NDT)
		D-B6	Galvanic half-cell (standard ASTM C876-15 [21]) (DT)
D-C	Thermo-hygrometric methods	D-C1	Measurement of the ambient and/or surface temperature and humidity (NDT)
		D-C2	Measurement of the in-depth humidity (DT)
		D-C3	Infrared thermography (standard ISO 18251-1:2017 [22]) (NDT)
D-D	Sound and acoustic methods	D-D1	Ultrasound (NDT)
		D-D2	Percussion (NDT)
		D-D3	Assessment of acoustic insulation (NDT)
D-E	Nuclear methods	D-E1	Nuclear method (NDT)
D-F	Hydric methods	D-F1	Watertightness test (NDT)
		D-F2	Water jet (NDT)
		D-F3	Submersion of the base of window frames (NDT)
		D-F4	Initial surface absorption test (ISAT) and Karsten-tube (NDT)
D-G	Mechanical methods	D-G1	Sphere impact, grid cutting, scratching and abrasion tests (Martinet Baronnie) (DT)
		D-G2	Pencil method (standard EN ISO 15184:2020 [23]) (DT)
		D-G3	Surface hardness and pendulum rebound hammer (NDT)
		D-G4	Metal blade (NDT)
		D-G5	Micro-perforation (DT)
		D-G6	Controlled penetration and perforation test (DT)

Table 1. *Cont.*

Code	Category	Code	Diagnosis Method
D-G	Mechanical methods	D-G7	Pull-off test (standards ASTM D4541-17 [24] and ASTM D7234-19 [25]) (DT)
		D-G8	Coring (DT)
		D-G9	Adhesion assessment by grid and knife tests (standards EN ISO 2409:2013 [26] and ASTM D6677-18 [27]) (DT)
		D-G10	Adhesive tape method (standard EN ISO 4628-6:2011 [28]) (NDT)
D-H	Pressure methods	D-H1	Ventilator test (standard ASTM E741-11(2017) [29]) (NDT)
D-I	Colour methods	D-I1	Colour-meter (NDT)
		D-I2	Munsell system or NCS scale colour specification (standards ASTM D1535-14(2018) [30] and ASTM E2970-15 [31]) (NDT)
D-J	Chemical methods	D-J1	Speedy moisture test (DT)
		D-J2	Test strips and field kit (NDT)t
		D-J3	Phenolphthalein indicator (NDT)

Note: NDT = non-destructive test; DT = destructive test.

Table 2. Classification list of repair techniques within a global inspection system for the non-structural building envelope [32].

Code	Category	Code	Repair Technique
R-A	Surface of the cladding	R-A1	Cleaning (cr, pr, pmw)
		R-A2	Application of a protective coat (paint, varnish, water-repellent, antifungal, biocide) (cr, pr, pmw)
		R-A3	Corrosion removal and re-establishment of the anti-corrosion protection in metallic elements (cr)
		R-A4	Surface rehabilitation of the plastic external claddings of pitched roofs (cr)
		R-A5	Repair/execution of supplementary watertightness measures in pitched roofs (cr, pr)
		R-A6	Creation of pathways (pr)
		R-A7	Application of ventilation systems/accessories (cr, pr)
		R-A8	Encapsulation of asbestos–cement external claddings of pitched roofs (pr)
		R-A9	Application of spray polyurethane foam (SPF) on the external surface of pitched roofs (cr, pr)
		R-A10	Glazing repair in door and window frames (cr)
		R-A11	Replacement or reapplication of the cladding/glazing (partially or completely) (cr, pr)
		R-A12	Application of a new (adequate) cladding/finishing coat over the existent/replacement (cr, pr, pmw)
		R-A13	Application of another type of cladding (not epoxy) (cr)
		R-A14	Treatment of cracks or other holes in the cladding (cr)
		R-A15	Treatment of biodegradation in wood floorings (cr)
		R-A16	Complete/partial removal of the existing coat in painted façades (cr)
		R-A17	Correction of surface irregularities or evening an architectural concrete surface with mortar (cr)
R-B	Cladding system	R-B1	Application of underlayment in pitched roofs (pr)
		R-B2	*Flocage* in metallic claddings of pitched roofs (pr)
		R-B3	Application of spray polyurethane foam (SPF) on the interior surface of pitched roofs (cr, pr)
		R-B4	Application/repair/replacement of the vapour barrier (cr, pr, pmw)
		R-B5	Application/repair/replacement of the thermal insulation (cr, pr)
		R-B6	Application/repair/replacement of the waterproofing system or separation layer in flat roofs (cr, pr)
		R-B7	Injection of filling resins (bedding material) (cr)
		R-B8	Reinforcement of the bedding layer in localised areas (cr, pr)
		R-B9	Reinforcement with metallic elements or composite materials in wood floorings (cr)
		R-B10	Consolidation with concrete in wood floorings (cr)
		R-B11	Execution of prostheses or application of reinforcement profiles in door and window frames (cr, pr)
		R-B12	Deformation repair (distortion/shrinkage/warpage/expansion) in door and window frames (cr)
		R-B13	Change/replacement/repair of the fastening system or correction of holes in plates or substrate (cr, pr)
		R-B14	Application of a higher performance render (cr, pr)
		R-B15	Perforation/gap filling in ETICS (cr)
		R-B16	Repair of corroded reinforcement/concrete cover spalling in architectural concrete surfaces (cr)
		R-B17	Application of an additional concrete layer in architectural concrete surfaces (cr, pr)
R-C	Change in the bearing structure/substrate	R-C1	Execution of a roof slab in pitched roofs (cr)
		R-C2	Repair/reinforcement/replacement of the bearing structure in pitched roofs (cr, pr)
		R-C3	Application/replacement of the shaping or levelling layer (cr)
		R-C4	Repair of dead cracks in the substrate and reapplication of the cladding (cr, pr)
		R-C5	Pavement levelling in epoxy resin floor coatings (cr, pr)

Table 2. *Cont.*

Code	Category	Code	Repair Technique
R-D	Singularities	R-D1	Application/repair/replacement of expansion joints (cr, pr, pmw)
		R-D2	Replacement/repair of current joints' filling material and/or joints cleaning (cr, pr, pmw)
		R-D3	Application of fungicide, biocide, or herbicide in joints (cr, pr)
		R-D4	Joint thickness increase or joint insertion (cr, pr)
		R-D5	Repair/application of tail-ends and associated protection elements (cr, pr, pmw)
		R-D6	Application/repair/replacement/cleaning of drainage systems/plumbing (cr, pr)
		R-D7	Removal of corroded or damaged metallic elements, with hole and notch filling (if applicable) (cr, pr, pmw)
		R-D8	Repair of water penetration spots (cr, pr)
		R-D9	Protecting or smoothing of protruding corners or edges (cr, pr)
		R-D10	Cleaning of façade's horizontal areas in adhesive ceramic tiling (pr, pmw)
		R-D11	Repair, insertion, or replacement of sealants or insulation mastics in door and window frames (cr, pr)
		R-D12	Replacement of degraded or missing elements in door and window frames (cr, pr)
		R-D13	Adjustment, replacement, or additional installation of hardware (hinges/locks/span-frame connections) in door and window frames (cr, pr)
		R-D14	Lowering of the tail-end area in epoxy resin floor coatings (cr, pr, pmw)
		R-D15	Execution of coves in epoxy resin floor coatings (cr, pr, pmw)
		R-D16	Correction of geometrical construction details (pr)

Note: cr = curative repair; pr = preventive repair; pmw = planned maintenance works.

Table 3. Classification list of defects within a global inspection system for the non-structural building envelope [33].

Code	Category	Code	Defect
A-A	Defects of physical nature	A-A1	Leakage damp
		A-A2	Surface moisture
		A-A3	Dirt and accumulation of debris
		A-A4	Colour changes
		A-A5	Spalling/peeling/exfoliation and pop-outs
		A-A6	Cohesion loss/disaggregation and chalking
A-B	Defects of chemical nature	A-B1	Biodeterioration/biological growth
		A-B2	Vegetation growth
		A-B3	Efflorescence/cryptoflorescence and carbonation
		A-B4	Blistering/bulging
		A-B5	Corrosion on the current surface
		A-B6	Corrosion in metallic fastening or tail-end elements
A-C	Defects of mechanical nature	A-C1	Mapped cracking
		A-C2	Oriented cracking on the current surface
		A-C3	Fracture or splintering on the current surface
		A-C4	Cracking and/or splintering adjacent to joints/edges
		A-C5	Wear or scaling of the finishing coat
		A-C6	Scratches/grooves and deep wear
		A-C7	Warpage, swelling, deformation, and other flatness deficiencies
		A-C8	Material gap/puncture
		A-C9	Detachment
		A-C10	Loss of adhesion
		A-C11	Bending and rupture of metallic fastening elements
A-D	Other defects	A-D1	Flaws in tail-end elements
		A-D2	Misalignment of cladding elements
		A-D3	Finishing defects/discontinuities in architectural concrete surfaces
		A-D4	Finishing colour flaws in painted façades
		A-D5	Finishing texture flaws in painted façades
		A-D6	Degradation of the filling material of current joints

Table 3. *Cont.*

Code	Category	Code	Defect
A-D	Other defects	A-D7	Absence/loss of filling material in connecting elements or current joints
		A-D8	Inadequate operation of expansion joints in flat roofs
		A-D9	Insufficient or excessive overlap of the cladding elements in roofs
		A-D10	Clearances/gaps in door and window frames
		A-D11	Absent or damaged hinges or locks in door and window frames
		A-D12	Ponding/insufficient or excessive slope in roofs
		A-D13	Inadequate operation of elements of the rainwater drainage system
		A-D14	Deficient capping adjacent to flat roofs
		A-D15	Incorrect or deficient interventions in claddings of pitched roofs

1.2. Scope and Objectives

The presented study is included within the scope of inspection of the envelope of current buildings as a support task to proactive and reactive maintenance strategies. Considering the categories roofs, façades and floorings, the research objectives are as follows (Figure 1):

- understanding if and which defects can be diagnosed using the same means, considering visual observation as the base procedure and the use of tools and equipment as specific diagnosis methods;
- understanding if and which defects can be repaired using the same techniques and the number of resources associated with those practices.

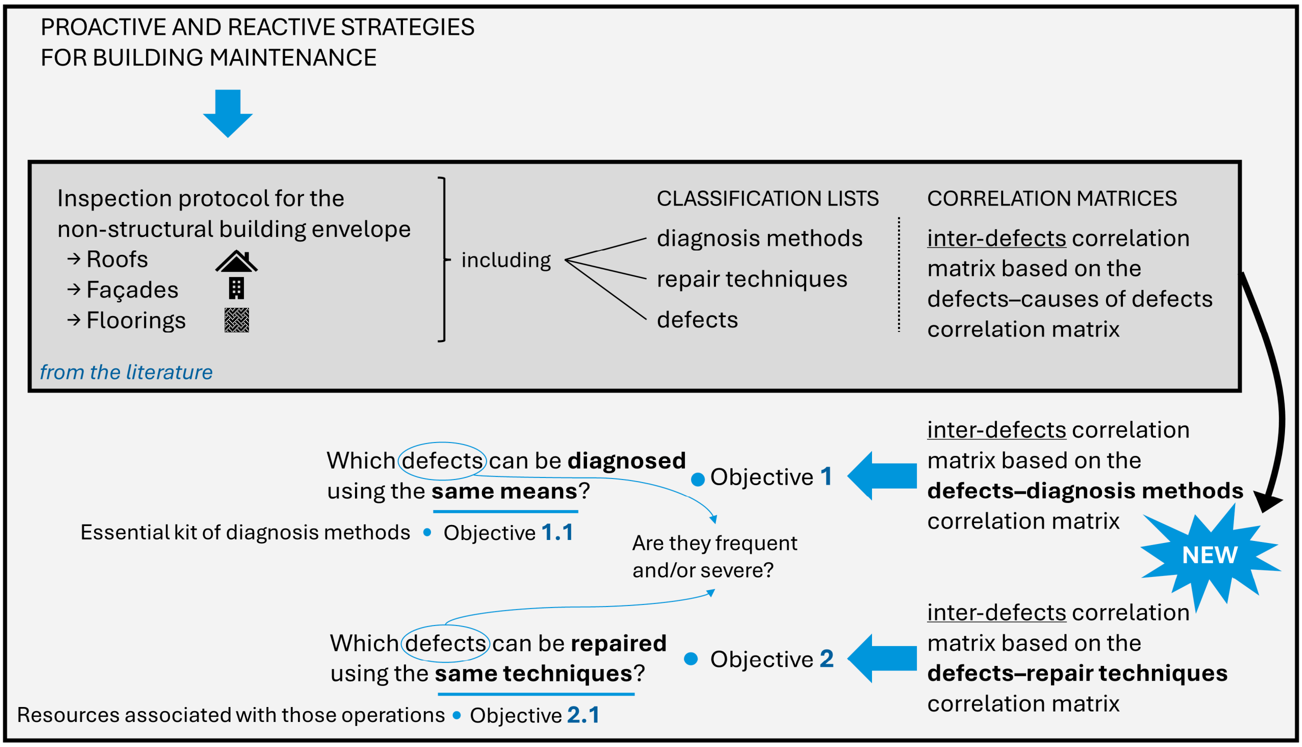

Figure 1. Diagram of the scope and objectives of the present research.

To achieve the mentioned objectives, the authors will develop two new inter-defects correlation matrices, this time based on the (i) defects–diagnosis methods and (ii) defects–repair techniques correlation matrices, which, until now, were excluded from previous research in the scope of the development of the inspection protocol for the non-structural building envelope [12,13,34]. Based on those two new matrices, an analysis of the most relevant and useful diagnosis methods and repair techniques for the building envelope is provided, taking the most common and severe defects into account.

The mentioned objectives are framed within an approach of considering building pathology from the surveyor's perspective, preparing an inspection report with preventive recommendations, acting on the causes of the defects and aiming at cost-effective results.

2. Materials and Methods

2.1. Building New Inter-Defects Three-Dimensional Correlation Matrices

Garcia and de Brito [35] defined the methodology to create an inter-defects correlation matrix based on the defects–probable causes correlation matrix. In the context of expert knowledge-based inspection systems, the inter-defects correlation matrix shows the probability of the occurrence of a second defect when one defect is first detected. I.e., the inter-defects correlation matrix functions as an empirical tool to predict the conditioned probability of subsequent anomalies following the detection of an initial anomaly. Within the global inspection system for the non-structural building envelope [12], the harmonisation of the inter-defects correlation matrix followed the methodology determined by Garcia and de Brito [35], considering the harmonised defects–probable causes correlation matrix [13]. In that context, correlation matrices followed a three-dimensional model, with rows of defects, columns of probable causes, diagnosis methods or repair techniques (according to the type of matrix), and layers of building elements/materials. Three-dimensional inter-defect correlation matrices have rows of given defects, columns of second defects and layers of building elements/materials.

To build new inter-defects correlation matrices based on the correlation of defects with diagnosis methods (Table 4) or repair techniques (Table 5), a similar methodology was considered. The material used for this purpose was published by Pereira [12], created based on expert knowledge, validated by inspection data from significant samples [13], and then further validated (qualitatively) in more restricted inspection samples [34].

Table 4. Excerpt of the door and window frames' layer of the defects–diagnosis methods correlation matrix from the global inspection system developed by Pereira [12].

	Diagnosis Methods					
Defects	**D-C1**	**D-C2**	**D-C3**	**D-D1**	**D-D2**	**D-D3**
A-A1	1	0	1	0	0	1
A-A2	2	0	1	0	0	0
A-A3	1	0	0	0	0	0
A-A4	0	0	0	0	0	0
A-A5	0	0	0	0	0	0
A-A6	0	0	0	0	0	0

Note: refer to Table 3 and Table 1 for the designation of each defect and diagnosis method, respectively.

Table 5. Excerpt of the door and window frames' layer of the defects–repair techniques correlation matrix from the global inspection system developed by Pereira [12].

	Repair Techniques													
Defects	**R-A1**	**R-A2**	**R-A3**	**R-A4**	**R-A5**	**R-A6**	**R-A7**	**R-A8**	**R-A9**	**R-A10**	**R-A11**	**R-A12**	**R-A13**	**R-A14**
A-A1	1	1	1	0	0	0	1	0	0	0	1	0	0	1
A-A2	0	0	0	0	0	0	2	0	0	0	0	0	0	0
A-A3	2	2	0	0	0	0	0	0	0	0	0	1	0	1
A-A4	0	0	0	0	0	0	0	0	0	0	0	**1**	0	2
A-A5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A-A6	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: refer to Table 3 and Table 2 for the designation of each defect and repair technique, respectively.

The algorithm to determine the theoretical percentage correlation index is as follows (considering the diagnosis methods for demonstration purposes) [35,36]:

- For each detected defect (defect k), the corresponding row in the defects–diagnosis methods correlation matrix is read;
- For each second defect (defect j), the corresponding row in the defects–diagnosis methods correlation matrix is read;
- For each column, the product of the correlation indexes of both rows (for defects k and j) in the defects–diagnosis methods correlation matrix is calculated;
- To obtain the correlation index for each defect CI_{kj}, the products are summed up:

$$CI_{kj} = \sum_{i=1}^{N} C_{ki}C_{ji} \tag{1}$$

where N is the total number of diagnosis methods;
- To obtain the maximum theoretical percentage correlation index I_{Mk}, for each detected defect k, the corresponding row in the defects–diagnosis methods correlation matrix is read; the correlation indexes of defect k with the diagnosis methods are multiplied by 2 (which is the maximum index of correlation in the correlation matrices used as a basis to apply the described algorith;. three indexes are available: 0 (no correlation), 1 (indirect correlation), and 2 (direct correlation)), and then, those products are summed up:

$$I_{Mk} = \sum_{i=1}^{N} (C_{ki} \times 2) \tag{2}$$

where N is the total number of diagnosis methods;
- To determine the theoretical percentage correlation index between defect k and defect j, $CI_{\%kj}$, the quotient between the correlation index CI_{kj} and the maximum theoretical percentage correlation index I_{Mk} is calculated:

$$CI_{\%kj} = \frac{CI_{kj}}{I_{Mk}} \tag{3}$$

Following the described procedure, one can obtain correlation indexes between defects according to the possibility of prescription of the same type of diagnosis methods for different defects (based on the defects–diagnosis methods correlation matrix; Table 6) and according to the possibility of recommendation of the same type of repair techniques for different defects (based on the defects–repair techniques correlation matrix; Table 7). As such, two new three-dimensional inter-defect correlation matrices were built.

Table 6. Excerpt of the door and window frames' layer of the new inter-defects correlation matrix based on the defects–diagnosis methods correlation matrix from the global inspection system developed by Pereira [12].

	Defects					
Defects	**A-A1**	**A-A2**	**A-A3**	**A-A4**	**A-A5**	**A-A6**
A-A1	-	13%	8%	0%	0%	0%
A-A2	50%	-	33%	0%	0%	0%
A-A3	50%	50%	-	0%	0%	0%
A-A4	0%	0%	0%	-	0%	0%
A-A5	0%	0%	0%	0%	-	0%
A-A6	0%	0%	0%	0%	0%	-

Note: refer to Table 3 for the designation of each defect.

Table 7. Excerpt of the door and window frames' layer of the new inter-defects correlation matrix based on the defects–repair techniques correlation matrix from the global inspection system developed by Pereira [12].

	Defects					
Defects	**A-A1**	**A-A2**	**A-A3**	**A-A4**	**A-A5**	**A-A6**
A-A1	-	17%	37%	30%	0%	0%
A-A2	50%	-	10%	0%	0%	0%
A-A3	61%	6%	-	28%	0%	0%
A-A4	56%	0%	31%	-	0%	0%
A-A5	0%	0%	0%	0%	-	0%
A-A6	0%	0%	0%	0%	0%	-

Note: refer to Table 3 for the designation of each defect.

2.2. Analysing the New Inter-Defects Three-Dimensional Correlation Matrices

The information provided by the new inter-defects three-dimensional matrices was further analysed considering the prescription of diagnosis methods or repair techniques for different types of building elements/materials in roofs, façades, and floorings.

For that purpose, the most relevant correlations in each layer of the new inter-defects three-dimensional correlation matrices had to be determined. With that goal in mind, hypothesis testing was applied [37]. The null hypothesis H_0 was that by choosing threshold a, up to 35% of the most relevant correlations (b) would be obtained. The test may be summarised as follows:

H_0: $b \geq 35\%$;
H_1: $b < 35\%$;
Statistic: $\overline{X}$;
Rule form: accept H_0 if $\overline{X} \geq c$;
Significance level: $\alpha = 10\%$;
Result of threshold a: $a = \overline{x} + \gamma$, where $\overline{x}$ is the average of correlations higher than 0 in each layer of the matrix, and γ is the respective standard deviation.

By applying the described methodology in each layer of the new three-dimensional inter-defects correlation matrices (selecting the most relevant correlations), an auxiliary matrix within each layer is built, indicating whether the correlation between the defects is higher than or equal to a. If it is higher, the cell in the intersection between the given and the second defect in the auxiliary matrix is filled with 1.

Then, the relevant correlations are compared according to the type of building component—roof claddings, façade elements/claddings, and floorings. Such a comparison is made by stacking the auxiliary matrices per layer category. That is, the layers of external claddings of pitched roofs and flat roofs are piled up (roof claddings); the layers of wall renders, ETICS, painted façades, architectural concrete surfaces, door and window frames, adhesive ceramic tiling, and natural stone claddings are piled up (façade elements/claddings); and the layers of wood floorings, epoxy resin industrial floor coatings, vinyl and linoleum floorings, adhesive ceramic tiling, and natural stone claddings are piled up (floorings). According to these categories, the comparable cells of each layer (representing a relevant correlation between the same types of defects) are summed up.

Out of the obtained sums, the highest are highlighted. That means that, for roof claddings (Table 8), only sums equal to 2 were considered. For façade elements/claddings (Table 9), only sums higher than or equal to 3 were considered. For floorings (Table 10), only sums higher than or equal to 2 were considered. This applies to both correlations based on diagnosis methods and repair techniques.

The described process allows us to select the most relevant correlations per category—roof claddings, façade elements/claddings, and floorings. But it is also necessary to understand the diagnosis methods or repair techniques (according to the base matrix used) that led to such relevance. For that purpose, a survey of the diagnosis methods/repair techniques associated with the relevant correlations was performed. Out of those, the diagnosis methods/repair techniques considered in both external claddings of pitched roofs and flat roofs were identified (for roof claddings). For façade elements/claddings and floorings, a similar process was performed, considering the presence in three or two more building elements/materials, respectively.

Table 8. Excerpt of the roof claddings' sums matrix to highlight the most relevant correlations regarding diagnosis methods.

	Defects					
Defects	**A-A1**	**A-A2**	**A-A3**	**A-A4**	**A-A5**	**A-A6**
A-C1	1	1	0	0	0	0
A-C2	1	1	0	0	0	0
A-C3	2	2	0	0	0	0
A-C4	1	1	0	0	0	0
A-C5	0	0	0	0	0	0
A-C6	0	0	0	0	0	0
A-C7	0	0	0	0	0	0
A-C8	1	1	0	0	0	0
A-C9	0	0	1	0	0	0
A-C10	0	0	1	0	0	0
A-C11	0	0	0	0	0	0

Note: refer to Table 3 for the designation of each defect.

Table 9. Excerpt of the façade elements/claddings' sums matrix to highlight the most relevant correlations regarding repair techniques.

	Defects					
Defects	**A-A1**	**A-A2**	**A-A3**	**A-A4**	**A-A5**	**A-A6**
A-B1	2	3	4	2	0	0
A-B2	1	2	2	1	0	0
A-B3	1	3	2	3	1	1
A-B4	1	1	0	0	1	1
A-B5	1	0	0	0	0	0
A-B6	0	0	0	0	0	0

Note: refer to Table 3 for the designation of each defect.

Table 10. Excerpt of the floorings sums matrix to highlight the most relevant correlations regarding diagnosis methods.

	Defects										
Defects	**A-C1**	**A-C2**	**A-C3**	**A-C4**	**A-C5**	**A-C6**	**A-C7**	**A-C8**	**A-C9**	**A-C10**	**A-C11**
A-C1	0	3	1	0	0	0	0	0	0	0	0
A-C2	3	0	1	1	0	0	0	0	0	0	0
A-C3	1	2	0	1	0	0	0	1	0	1	0
A-C4	1	2	1	0	0	0	0	0	0	0	0
A-C5	0	0	0	0	0	0	0	0	0	0	0
A-C6	0	1	0	0	0	0	0	1	0	0	0
A-C7	1	1	0	0	0	1	0	0	0	1	0
A-C8	0	0	0	0	0	0	1	0	0	1	0
A-C9	0	0	0	0	0	0	1	0	0	0	0
A-C10	0	0	0	0	0	0	0	0	0	0	0
A-C11	0	0	0	0	0	0	1	0	0	0	0

Note: refer to Table 3 for the designation of each defect.

The materials and methods described in Sections 2.1 and 2.2 are outlined in Figure 2.

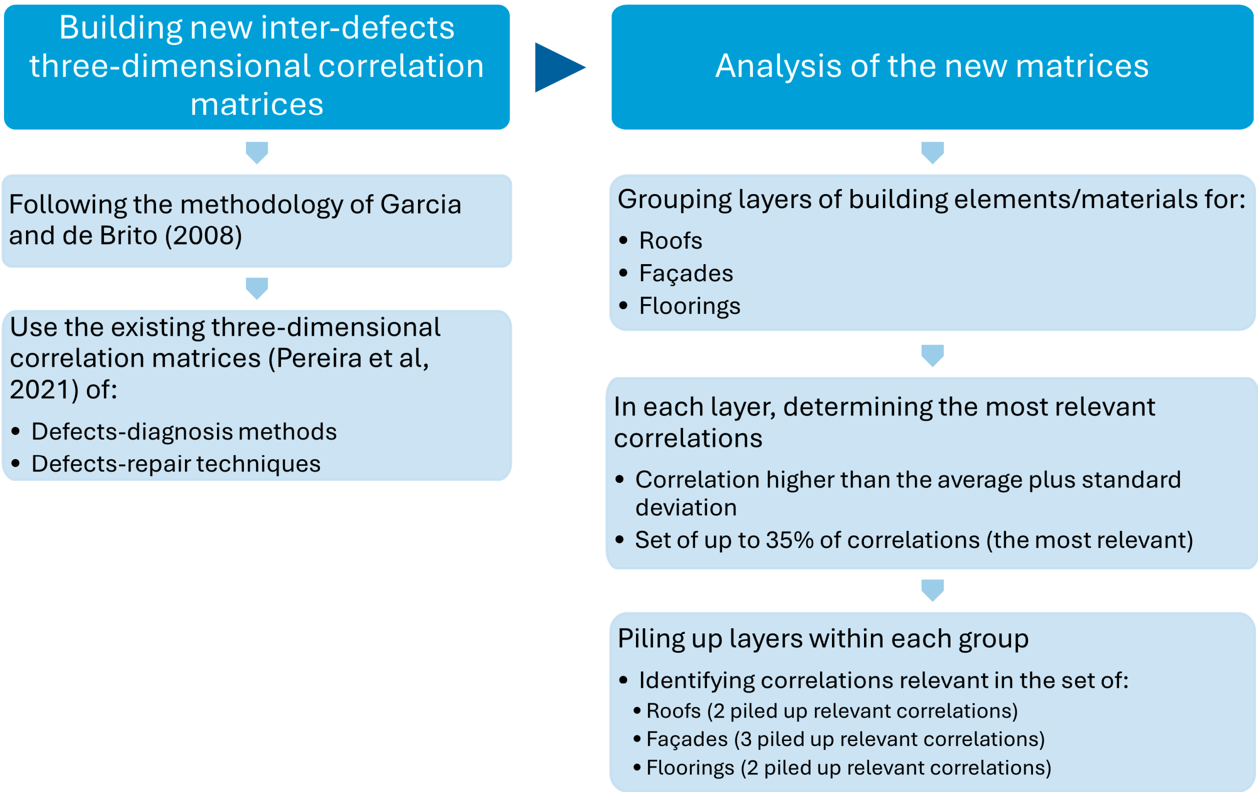

Figure 2. Methodology followed to build and analyse correlation matrices to reach the proposed goals (considering the information of Garcia and de Brito [35] and Pereira et al. [13]).

2.3. *Studying the Resources Associated with the Most Common Types of Repair Techniques*

Considering some of the most common repair techniques that emerge from the analysis of results, a first approach to the resources needed to implement specific repair techniques was carried out. This narrow analysis can constitute the basis for the life-cycle assessment (LCA) of repair techniques in the future. In this case, the analysis was based on a cradle-to-gate approach of LCA [38]. The information about resources needed was collected from the CYPE Ingenieros S.A. website [39].

3. Results

3.1. *Most Common Diagnosis Methods to Prepare an Inspection*

Applying the methods described in Sections 2.1 and 2.2, it is possible to identify (i) the most relevant inter-defects correlations based on the recommendation of diagnosis methods and (ii) the most common diagnosis methods useful in roof claddings, façade elements/claddings, and floorings.

3.1.1. Diagnosis Methods in Roof Claddings

In Table 11, the most relevant inter-defects correlations in roofs are identified, referring to different relationships between defects "A-A1 Leakage damp", "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", "A-C3 Fracture or splintering on the current surface", "A-D1 Flaws in tail-end elements", and "A-D12 Ponding/insufficient or excessive slope in roofs". According to the data of Garcez et al. [40] adapted to the harmonisation of the classification of defects [33], none of these defects represent the top most detected defects in **external claddings of pitched roofs (ECPR)**. Nevertheless, some are commonly found, such as "**A-D12** Ponding/insufficient or excessive slope in roofs" (31.9%), "A-D1 Flaws in tail-end elements" (31.7%), and "A-A3 Dirt and accumulation of debris" (in 28.0% of inspected pitched roofs). As for **flat roofs (FR)**, according to the data of Conceição et al. [41], adapted to the harmonisation of the classification of defects [33], defect "**A-A3**

Dirt and accumulation of debris" is the most detected (in 74.3% of inspected flat roofs). Other than that, the defect "A-D1 Flaws in tail-end elements" (40.0%) is also common.

Table 11. Analysis of the results for claddings of roofs based on the new inter-defects correlation matrix considering diagnosis methods.

Building Element /Material	Defects That Can Be Diagnosed by the Same Methods	Diagnosis Methods Used in ECPR	Diagnosis Methods Used in FR	Diagnosis Methods Used in Both
Roof claddings—external claddings of pitched roofs (ECPR); flat roofs (FR)	A-A2 and A-A1	D-C1, D-C3	D-B2, D-B3, D-C3, D-E1, D-F1	D-C3
	A-A3 and A-D12	D-A3	D-A3	D-A3
	A-C3 and A-A1	D-C3	D-B2, D-B3, D-C3, D-E1, D-F1	D-C3
	A-C3 and A-A2	D-C3	D-B2, D-B3, D-C3, D-E1, D-F1	D-C3
	A-D1 and A-A1	D-C3	D-B2, D-C3, D-F1	D-C3
	A-D1 and A-A2	D-C3	D-B2, D-C3, D-F1	D-C3
	A-D1 and A-C3	D-C3	D-B2, D-C3, D-F1	D-C3

Note: refer to Table 3 and Table 1 for the designation of each defect and diagnosis method, respectively.

As for the severity of the set of defects included in the most relevant correlations in roof claddings, data from service life prediction methodologies may be considered. In the case of external claddings of pitched roofs, the severity implicitly associated with the degradation levels for defects by Ramos et al. [42] may be used. Of the mentioned set of defects, these authors only take into account "A-A2 Surface moisture" and "A-A3 Dirt and accumulation of debris", which comprise the defect "Staining, change in colour, or brightness of the tiles". This defect is admitted to affect 20% or less of the total area of the pitched roof cladding when it is in good condition (Level 1). On the other hand, if it affects more than 50% of the total area of the pitched roof cladding, then it should be considered moderately degraded (Level 3). Ramos et al. [42] use a five-level scale from Level 0 (Very good) to Level 4 (Generalised degradation).

Ramos et al. [42] also take into account the defect "A-C3 Fracture or splintering on the current surface", which is included in the defect "Cracking/fracture". If such a defect affects 10% or less of the total area of the pitched roof claddings, it should be considered slight degradation (Level 2). On the other hand, if it affects more than 30% of that area, then the roof has generalised degradation.

From the data of Ramos et al. [42], it is found that defect A-C3 is considered more severe than A-A2 and A-A3. Nevertheless, it is important to highlight that a roof in very good condition (Level 0) should not have any signs of either of these defects.

As for flat roofs, the same kind of analysis cannot be performed. Still, some literature [43] highlights the importance of "A-A1 Leakage damp", which may be associated with flashing details (between membranes) due to inadequate installation or improper detailing below the coping cap on parapet walls (where a moisture barrier is required). This cause is actually associated with the defect "A-D1 Flaws in tail-end elements". Moreover, "A-D12 Ponding/insufficient or excessive slope in roofs" may also be a common problem in flat roofs, according to Madsen [43], associated with the incorrect design of the required slope to promote drainage of rainwater. In any case, drains must be checked to guarantee that they are not clogged.

Also in Table 11, the results referring to the diagnosis methods associated with the most relevant correlations are presented. It is found that, for roof claddings' inspection, the most likely methods to be used, besides visual inspection, are "D-A3 Assessment of the slope, flatness, orthogonality, and alignments" and "D-C3 Infrared thermography".

D-A3 has the main purpose of checking whether the minimum slope values for roofs are being respected, taking into account the type of cladding, exposure, slope length, location, and construction layout. Furthermore, through D-A3, surveyors can also assess the planimetry of claddings, taking specifications into account. The results of this diagnosis method can point out the causes of ponding, for instance. A spirit level may be used, as well as an inclinometer.

As for D-C3, it is a diagnosis method with several applications, although it requires experienced professionals to analyse the results. Whether in pitched or flat roofs, thermography is more useful in cases where no thermal insulation is used. Nevertheless, infrared thermography may be used indoors or outdoors to assess watertightness and the occurrence of humidity issues and to pinpoint discontinuities in thermal insulation. An infrared camera is required, as well as a regular camera, to compare thermograms with the visible area of claddings. The technique consists of taking advantage of the heating caused by solar radiation, observing the thermographic images (thermograms) obtained through the infrared camera, identifying the areas where voids, cracks, infiltrations, and other discontinuities that are not visible to the naked eye can be observed; video record the images taken for later interpretation and diagnosis; when interpreting the results, it should be borne in mind that the flaws are warmer than the rest of the coating during the day, revealing a more intense red colour, and are cooler at night, corresponding to a light blue colour.

3.1.2. Diagnosis Methods in Façade Elements/Claddings

In Table 12, the most relevant inter-defects correlations in façades are identified, referring to different relationships between defects “A-A2 Surface moisture”, “A-A3 Dirt and accumulation of debris”, “A-B1 Biodeterioration/biological growth”, “A-C1 Mapped cracking”, and “A-C2 Oriented cracking on the current surface”. According to the data of Santos et al. [44] adapted to the harmonisation of the classification of defects [33], defect **A-B1** is the fourth most common in **door and window frames** (in 32.7% of inspected frames). Defect A-A3 is also common in door and window frames (24.1%). As for **wall renders**, according to the data of Sá et al. [45] adapted to the harmonisation of the classification of defects [33], defect “**A-A3** Dirt and accumulation of debris” is the most detected (in 90% of inspected wall renders). Defect A-C1 is much less common (6%). Defects A-C2 (41%) and A-B1 (35%) have an average incidence in wall renders. According to the data of Amaro et al. [46], adapted to the harmonisation of the classification of defects [33], defect **A-A2** is the most common in **ETICS** (in 59.4% of inspected surfaces). Defects A-A3 (24.4%), A-B1 (27.8%), and A-C2 (32.2%) are also common in ETICS, while defect A-C1 was only found in 7.5% of inspected surfaces. As for **painted façades**, according to the data of Pires et al. [47], adapted to the harmonisation of the classification of defects [33], defect “**A-A3** Dirt and accumulation of debris” is by far the most detected (in 91.4% of inspected painted façades). Defects A-B1 (40.0%) and A-C1 (35.2%) have an average incidence in painted façades. According to the data of Silva et al. [48], adapted to the harmonisation of the classification of defects [33], defect **A-C2** is the most common in **architectural concrete surfaces** (in 48.2% of inspected surfaces). Defects A-A2 (29.1%) and A-A3 (32.7%) are also common in architectural concrete surfaces, while defects A-B1 (11.8%) and A-C1 (12.7%) have a low incidence. As for **adhesive ceramic tiling**, according to the data of Silvestre et al. [49], adapted to the harmonisation of the classification of defects [33], defect “**A-A3** Dirt and accumulation of debris” is one of the most detected (in 28% of inspected surfaces). Defect A-B1 (3%) has one of the lowest incidences. Defects A-C1 and A-C2, together, are present in 50% of inspected tiled surfaces. Finally, according to the data of Neto and de Brito [50] adapted to the harmonisation of the classification of defects [33], none of the identified defects are among the top most detected in **natural stone claddings**. Nevertheless, defects **A-A3** (19.5%), A-B1 (7.8%), A-C1 17.6% and A-C2 17.6% have an average occurrence in natural stone claddings.

As for the severity of the set of defects included in the most relevant correlations in façade elements/claddings, data from service life prediction methodologies can also be considered. In the case of door and window frames, the severity implicitly associated with the degradation levels for defects by Fernandes et al. [51] may be used. Of the mentioned set of defects, these authors only take into account “A-A3 Dirt and accumulation of debris” and “A-B1 Biodeterioration/biological growth”, which comprise the defects “Accumulation of debris” and “Biological growth”, respectively. The accumulation of debris is admitted to affect 20% or more of the area of the element when it is in good condition (Level B). As for biological growth, if it affects up to 15% of the area of the element, it will be considered in Level C (slight degradation). On the other hand, if it affects between 15% and 30% of the total area of the element, then it should be considered moderately degraded (Level D). In case more than 30% of the area is affected, the element is considered to be under severe degradation (Level E). As such, biological growth is considered a severe defect in door and window frames. Fernandes et al. [51] use a five-level scale from Level A (Very good) to Level E (Severe degradation).

Table 12. Analysis of the results for façade elements/claddings based on the new inter-defects correlation matrix considering diagnosis methods.

Building Element/ Material	Defects That Can Be Diagnosed by the Same Methods	Diagnosis Methods Used in DWF	Diagnosis Methods Used in WR	Diagnosis Methods Used in ETICS	Diagnosis Methods Used in PF	Diagnosis Methods Used in ACS	Diagnosis Methods Used in ACT	Diagnosis Methods Used in NSC	Diagnosis Methods for 3 or More Materials
Façade elements and façade claddings—door and window frames (DWF); wall renders (WR); external thermal insulation composite systems (ETICS); painted façades (PF); architectural concrete surfaces (ACS); adhesive ceramic tiling (ACT); natural stone claddings (NSC)	A-A2 and A-B1	D-C1	D-C1, D-C3, D-F4, D-J1	D-C1, D-C3, D-F4	-	D-C1, D-C3, D-F4	-	-	D-C1, D-C3, D-F4,
	A-A3 and A-B1/ A-B1 and A-A3	D-A3, D-C1	D-C1, D-C3, D-F4, D-J1	D-C1, D-C3, D-F4	D-A2, D-B5, D-C1, D-C2	D-C1, D-C3, D-F4	-	D-C2	D-C1, D-C3, D-F4
	A-C1 and A-C2/ A-C2 and A-C1	-	D-A5, D-C1, D-D1, D-F4	D-A4, D-A5, D-C1, D-C3	-	D-A5, D-B4, D-J3	D-A4, D-A5, D-D2, D-G1	D-A4, D-A5, D-A6, D-D1	D-A4, D-A5

Note: refer to Table 3 and Table 1 for the designation of each defect and diagnosis method, respectively.

As for wall renders, the severity implicitly associated with the degradation levels for defects by Vieira et al. [52] may be used. Of the mentioned set of defects, these authors take all into account (“A-A2 Surface moisture”, “A-A3 Dirt and accumulation of debris”, “A-B1 Biodeterioration/biological growth”, “A-C1 Mapped cracking”, and “A-C2 Oriented cracking on the current surface”), which are mentioned as “damp”, “dirt”, microorganisms and algae”, and “cracking”, respectively. Damp is referred to in Level C of degradation (light degradation), as well as dirt. Microorganisms may eventually be present in Level B (good condition) and in dark patches (microorganisms and algae) in Level C. Cracking may occur in all levels of degradation, depending on the crack width to classify the level of degradation: in Level A (best condition), if the width is up to 0.1 mm; in Level B, if the width is between 0.25 mm and 1.0 mm, and in localised areas; in Level C, if the width is from 1.0 mm to 2.0 mm; and in Levels D (broad degradation) and E (worst condition), if the cracks have or are wider than 2 mm. Considering these data, cracking may be the most severe defect in this set of defects in wall renders. Vieira et al. [52] use a five-level scale from Level A (Best condition) to Level E (Worst condition).

In the case of ETICS, the severity implicitly associated with the degradation levels for defects by Ximenes et al. [53] may be used. Of the mentioned set of defects, these authors take into account “A-A2 Surface moisture”, “A-A3 Dirt and accumulation of debris”, and “A-B1 Biodeterioration/biological growth” under the defect “stains/colour changes”, and defects “A-C1 Mapped cracking” and “A-C2 Oriented cracking on the current surface”, considered as “loss of continuity/integrity defects”. None of these defects should be present in Level 0 (Unchanged). As for stains, in Level 1 (Good), only slight or few perceptible changes should be visible. In Level 2 (Slight degradation), they should be moderate or quite perceptible. In Level 3 (Moderate degradation), stains should be highly or strongly marked. In Level 4 (Generalised degradation), they should be very highly or quite strongly marked. As for cracking, in Level 1, cracks should be equal to or thinner than 0.2 mm and in a little or very little area of the cladding. In Level 2, they can be wider than 0.2 mm but only in a little or very little area or equal to or thinner than 0.2 mm in a moderate portion of the cladding. In Level 3, cracks can be wider than 0.2 mm but in a moderate portion of the cladding or equal to or thinner than 0.2 mm in a very large area. In Level 4, they can be wider than 0.2 mm in a very large area of the cladding. Both groups of defects can be present when severe degradation occurs in ETICS, depending on the intensity of the defects and the affected area. Ximenes et al. [53] use a five-level scale from Level 0 (Unchanged) to Level 4 (Generalised degradation).

As for painted façades, the severity implicitly associated with the degradation levels for defects by Chai et al. [54] may be used. Of the mentioned set of defects, these authors take into account "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", and "A-B1 Biodeterioration/biological growth", which are considered within the scope of "stains/colour change". "A-C1 Mapped cracking" is also taken into account as "cracking". Both for stains/colour changes and cracking, in Level 0, there should be no visible degradation. Stains/colour changes are classified from Level 0 to Level 4, considering the intensity of change and the type of visible signs of defects (Figure 3). So, in Level 1 (Good condition), only slight or little perceptible uniform surface dirt should be observed. In Level 2 (Slight degradation), moderate or quite perceptible uniform surface dirt may be observed. In Level 3 (Moderate degradation), moderate or quite perceptible humidity stains, biological growth, and localised surface dirt may be observed, or high or very perceptible uniform surface dirt may be observed. In Level 4 (Generalised degradation), high or very perceptible biological growth may be observed. Cracking is classified according to a visual scale of the density of cracks, from a small number of cracks (in Level 1) to a high number or density of cracks (in Level 4). Considering these data, biological growth and cracking may be the most severe defects in this set of defects in painted façades. Chai et al. [54] use a five-level scale from Level 0 (No visible degradation) to Level 4 (Generalised degradation).

(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 3. Levels of severity of stains/colour changes in painted façades: (**a**) Level 0; (**b**) Level 1; (**c**) Level 2; (**d**) Level 3; (**e**) Level 4.

In the case of architectural concrete surfaces, the severity implicitly associated with the degradation levels for defects by Serralheiro et al. [55] may be used. Of the mentioned set of defects, these authors take all into account. In Level A, there should be no visible degradation of any kind. In Level B (Good), dirt and moisture stains should account for less than 15% of the surface area and biological growth for less than 10%. In Level C (Slight degradation), dirt and moisture stains may affect 15–40% of the surface area and biological growth 10–30%. In Level C, oriented cracking (width up to 0.5 mm) cannot affect more than 20% of the surface. In Level D (Moderate degradation), dirt and moisture stains may affect more than 40% of the surface, while biological growth may be present in more than 30%. In Level D, mapped cracking may be present in less than 50% of the surface and oriented cracking with a width of 0.5–3 mm in 5% or more of the surface, while oriented cracking equal to or wider than 3 mm should only be found in less than 5% of the surface. In Level E (Generalised degradation), mapped cracking may be found in 50% or more of the surface, and oriented cracking equal to or wider than 3 mm may be found in 5% or more of the surface. As such, cracking is considered a more severe defect in architectural concrete surfaces. Serralheiro et al. [55] use a five-level scale from Level A (No visible degradation) to Level E (Generalised degradation).

As for adhesive ceramic tiling, the severity implicitly associated with the degradation levels for defects by Bordalo et al. [56] may be used. Of the mentioned set of defects, these authors take all into account. In Level 0, there should be no visible degradation. In Level 1 (Good), surface dirt and damp stains in 10% or less of the area of the surface are observed, while cracked glazing may be observed and markedly oriented cracking thinner than 0.2 mm without leakage may also be observed. In Level 2 (Slight deterioration), damp stains in 10–50% of the surface are present, as well as biological growth in 30% or less of the surface. Cracking with no predominant direction and markedly oriented cracking with 0.2 mm or wider is observed in 30% or less of the surface. In Level 3 (Moderate degradation), damp stains in more than 50% of the surface and biological growth in more than 30% of the surface are present. Cracking may occur with no predominant direction or markedly oriented cracking (wider than 1 mm) without leakage may occur in 30–50% of the surface. In Level 4 (Generalised degradation), cracking with no predominant direction and markedly oriented cracking wider than 5 mm may be observed in more than 50% of the surface. Considering these data, cracking is the most severe defect in this set of defects in adhesive ceramic tiling. Bordalo et al. [56] use a five-level scale from Level 0 (No visible degradation) to Level 4 (Generalised degradation).

In the case of natural stone claddings, the severity implicitly associated with the degradation levels for defects by Silva et al. [57] may be used. Of the mentioned set of defects, these authors take all into account. In Level 0, there should be no visible degradation of any kind. In Level 1 (Good), surface dirt may affect more than 10% of the surface; moisture and localised stains may affect up to 15% of the surface, and cracking of 1 mm or thinner may affect up to 20% of the surface. In Level 2 (Slight degradation), moisture and localised stains may affect more than 15% of the surface; moss, lichen, and algae growth may affect up to 30% of the surface; cracking of up to 1 mm wide may affect more than 20% of the surface, and cracking of 1–5 mm wide may affect up to 20% of the surface. In Level 3 (Moderate degradation), moss, lichen, and algae growth may affect more than 30% of the surface; cracking of 1–5 mm wide may affect more than 20% of the surface, and cracking of 5 mm wide or wider may affect up to 20% of the surface. In Level 4 (Generalised degradation), cracking wider than 5 mm may affect more than 20% of the surface. As such, cracking is considered a more severe defect, mainly when its width is larger, in natural stone claddings. Silva et al. [57] use a five-level scale from Level 0 (No visible degradation) to Level 4 (Generalised degradation).

To sum up, in general terms, in façade elements/claddings, and considering the variety of cladding types, cracking tends to be considered a more serious defect in more materials/elements, followed by biodeterioration/biological growth. It should be noted that, by using classification lists, not all materials are considered to be affected by detachment, as some are affected by loss of adhesion. In this way, cracking is a more transverse defect, which may also be associated with more severe mechanical issues in the building.

Also, in Table 12, the results referring to the diagnosis methods associated with the most relevant correlations are presented. It is found that for façade elements/claddings' inspection, the most likely methods to be used, besides visual inspection, are "D-C1 Measurement of the ambient and/or surface temperature and humidity", "D-C3 Infrared thermography", and "D-F4 Initial surface absorption test (ISAT) and Karsten-tube".

D-C3 was already described for roof claddings. In façades, it has the added advantage of enabling the detection of voids in the underlying layers of the cladding system.

D-C1 may be used to measure the ambient temperature close to the surface of the cladding, measure the relative humidity close to the surface of the cladding, measure the water content of claddings and measure the temperature on the cladding surface. For these purposes, a hygrometer or thermo-hygrometer, a portable moisture meter, a humidity and temperature sensor and an infrared thermometer may be necessary. To properly perform the required measurements, first, the reading points should be defined, considering the orientation of the cladding and the incidence of light, which can be assisted by designing a reference mesh for surface measurements. The equipment may require calibration. Then, the measuring equipment should be placed in the surroundings (ambient readings) or on (superficial readings) the cladding surface. The measurement equipment will show the reading values on its display. If the moisture meter values are presented as a percentage, it will correspond to the amount of water recognised by the device compared to the mass of material in a dry or wet state (varies according to the equipment, as defined in the user manual). The measurement should be performed at different points on the surface or in the surrounding environment.

The method "D-F4 Initial surface absorption test (ISAT) and Karsten-tube" may be used to assess the water permeability of the cladding and to determine the porosity degree of the surface. The ISAT will require a clear acrylic cell (100 mm diameter), a transparent container (connected to the entry of the cell), a graduated capillary tube (connected to the exit of the cell), and a valve (to close the container). First, the capillary tube should be calibrated so that the cross-sectional area can be determined. Next, the cell area should be measured to determine the scale factor for the cell/tube combination. Then, the cell is attached to the surface and sealed to ensure uniform pressure. After filling the cell with water, the container is closed, and flow measurements are taken along the capillary tube (readings at 10, 30, and 60 min) after the first wetting of the surface. As for the Karsten tube test, it will require three (minimum) Karsten tubes (glass tubes graduated from 0 to 4 cm^3, shaped as pipes), silicone (or mastic, plasticine or putty) for fixing the tubes to the surface (included an application gun, if applicable), a water container, and nozzle. First, the surface is cleaned. Next, the edge of the tube is covered with silicone (or other adhesive material), and the tube is attached to the wall in the area to be tested, pressing it onto the wall. Silicone should dry for at least 20 min at room temperature. Then, the tubes are filled with water up to the maximum level (4 cm^3). After 5 min, the first reading is taken on each of the three tubes, based on the lowering of the water level observed in the tubes. The reading should be repeated at 10, 15, 30, and 60 min, registering the water level drop. For each time interval, an average value is considered (using the three readings) and using these values, a graph may be drawn of the water level drop as a function of time. The slope of the line corresponds to the absorption coefficient of the cladding.

3.1.3. Diagnosis Methods in Floorings

In Table 13, the most relevant inter-defects correlations in floorings are identified, referring to different relationships between defects "A-B4 Blistering/bulging", "A-C1 Mapped cracking", "A-C2 Oriented cracking on the current surface", "A-C3 Fracture or splintering on the current surface", "A-C4 Cracking and/or splintering adjacent to joints/edges", and "A-C10 Loss of adhesion". According to the data of Silvestre et al. [49] adapted to the harmonisation of the classification of defects [33], **defect A-C10** is the third most common in **adhesive ceramic tiling** (in 42% of inspected surfaces). As mentioned for façade claddings, defects A-C1 and A-C2 together were present in 50% of inspected adhesive ceramic tiled surfaces. Defect A-C4 (9%) has a low incidence on tiled surfaces. As for **natural stone claddings**, according to the data of Neto and de Brito [50], adapted to the harmonisation of the classification of defects [33], defects **A-C1** (17.6%), **A-C2** (17.6%), A-C4 (13.7%), A-C3 (10.2%), and A-C10 (6.3%) all have an average to low incidence in this type of flooring. According to the data of Delgado et al. [58], adapted to the harmonisation of the classification of defects [33], defect **A-C4** has an average incidence in **wood floorings** (in 13.8% of inspected floorings). Defects A-C2 (6.7%) and A-C3 (7.2%) are not very common in wood floorings. As for **epoxy resin industrial floor coatings**, according to the data of Garcia [59] adapted to the harmonisation of the classification of defects [33], defect "**A-C10** Loss of adhesion" is the most detected (in 51.7% of inspected floorings). Defects A-B4 (24.0%), A-C1, and A-C2 together (20.7%) have an average incidence in epoxy resin floorings. According to the data of Carvalho et al. [60], adapted to the harmonisation of the classification of defects [33]; defect **A-C2** is the fourth most common in **vinyl and linoleum floorings** (in 38% of inspected floorings). Defects A-C10 (16%), A-B4 (10%) and A-C3 (10%) have an average to low incidence in this type of flooring.

Table 13. Analysis of the results for floorings based on the new inter-defects correlation matrix considering diagnosis methods.

Building Element/ Material	Defects That Can Be Diagnosed by the Same Methods	Diagnosis Methods Used in ACT	Diagnosis Methods Used in NSC	Diagnosis Methods Used in WF	Diagnosis Methods Used in ERIFC	Diagnosis Methods Used in VLF	Diagnosis Methods for 2 or More Materials
Floorings—adhesive ceramic tiling (ACT); natural stone claddings (NSC); wood floorings (WF); epoxy resin industrial floor coatings (ERIFC); vinyl and linoleum floorings (VLF)	A-B4 and A-C10	-	-	-	D-A3, D-A8, D-C1, D-C2, D-G7, D-G8, D-G9	D-C1, D-C3, D-D2, D-G1, D-G7, D-J1	D-C1, D-G7
	A-C1 and A-C2/ A-C2 and A-C1	D-A4, D-A5, D-D2, D-G1	D-A4, D-A5, D-A6, D-D1	-	D-A3, D-A5, D-A6, D-G7, D-G8	-	D-A4, D-A5, D-A6
	A-C3 and A-C2	-	D-A4, D-A5, D-A6, D-D1	D-A5, D-A6, D-C1, D-G7	-	D-C3	D-A5, D-A6
	A-C4 and A-C2	D-A4, D-A5, D-D2	D-A4, D-A5, D-A6	D-A5, D-A6, D-C1, D-G1, D-G7	-	-	D-A4, D-A5, D-A6

Note: refer to Table 3 and Table 1 for the designation of each defect and diagnosis method, respectively.

As for the severity of the set of defects included in the most relevant correlations in façade elements/claddings, data from service life prediction methodologies can again be considered. Still, known studies refer only to wood floorings [61]. In this case, the weighting factor associated with each type of defect is considered. So, swelling is aggravated by a factor of 1.2 when calculating the severity of degradation, as well as cracking and broken or splintered elements. Subsequently, the defects considered in the observed correlations are all considered severe, as they aggravate the calculation of S_w.

Although the same kind of analysis cannot be performed for adhesive ceramic tiled floorings, the general literature about their defects can be analysed. Valente de Almeida [62] lists breaking, surface defects (dry spots, bumps and blisters), and crazing and cracks as some of the main problems in ceramic tiles. Son and Yuen [63] refer to similar problems, namely, arching, lifting, tile edge failure, and broken tiles, among others. In this sense, some of the defects considered in the correlations are among those most relevant in ceramic tiling floorings.

As for natural stone floorings, the specific literature is not abundant. Still, considering the general knowledge about the use of natural stone in buildings, the occurrence of cracking is highlighted as one of the consequences of frost attacks [64], which can result in the fragmentation of the stone slab. Additionally, freeze–thaw deterioration may cause a loss of bond between the bedding material and stone slabs [65]. In cold climates, when mortar is used as the bonding material, water may enter the system through the joints, and as it freezes, expands, and thaws, it causes a loss of adhesion in the flooring system. Debonding may also be caused by differential thermal movement between the stone material and the bedding [65].

In epoxy resin floorings, blistering is a serious concern. Osmotic blistering [66] may occur in the early stages of the service life of the flooring, which is a phenomenon not fully understood but mainly associated with design and execution measures.

Loss of adhesion can also be an issue in vinyl and linoleum floors, mainly associated with the presence of water in the bonding layer, which may break the bond [67], causing permanent damage.

Therefore, defects A-B4, A-C1, A-C2, A-C3, A-C4, and A-C10 affect varied types of floorings differently, but, in general terms, the defects that may result in some kind of flatness deficiencies are those considered more severe. All of these defects may have that effect.

Also, in Table 13, the results referring to the diagnosis methods associated with the most relevant correlations are presented. It is found that, for floorings inspection, the most likely methods to be used, besides visual inspection, are "D-A4 Tell-tale gauge and gypsum testimonies", "D-A5 Crack width ruler and crack-measuring microscope", and "D-A6 Mechanical strain gauge". All these methods are useful for measuring cracks or joints and they complement each other.

Method D-A4 is used to quantify and/or monitor the width of cracks, assess the stability of cracks, determine the movement trend through the analysis of readings over time, and provide evidence for establishing cause–effect relationships according to the actions or occurrences to which the building is subjected. The tell-tale gauge is a small piece of equipment applied on the surface of floorings or claddings. First, the measuring points are defined with traces of about 20 cm, and each one is numbered. Next, to monitor displacements parallel to the test plane, the two acrylic glass plates that make up the tell-tale gauge are well attached to each side of the crack along the direction closest to the perpendicular direction to the crack so that the centre of the grid coincides with the centre of the crack and with the previously marked line. Then, the width of the crack is monitored by directly reading the displacement and observing the relative position of the crosshairs (reference traces, usually red) compared to the grid. Finally, the observed values are recorded, and the defect can be mapped using location and orientation data, as well as the progression information. As for gypsum testimonies, they help determine the degree of stabilisation of cracks through monitoring over time. For that purpose, a mortar of pure gypsum with 70% water is used to execute a patch centred on the crack and fixed to both sides. The patch should be detached from the crack itself using paper tape. Afterwards, periodic verification should check the occurrence of breakage in the patch, revealing the degree of activity of the crack.

"D-A5 Crack width ruler and crack-measuring microscope" refers to the use of these two instruments to quantify the width of cracks. The crack width ruler is used for direct readings of the width of cracks, placing the instrument over the building element and matching the lines with the crack under analysis, running the lines from smallest to largest until one matches the width of the crack, thus finding the corresponding value. After reading, the values should be recorded, and the crack can be mapped. The use of the crack measuring microscope is similar but for thinner cracks. The crack microscope is placed over the crack, peering through the eyeglass and focusing using the appropriate handle. As the lens is graduated, one can read the crack opening in millimetres. Then, the cracks observed can be mapped according to width values, location, orientation, and severity.

The mechanical strain gauge (D-A6) can assess, quantify, and monitor even small displacements in joints and cracks with high accuracy. To use this method, first, the locations for measurements need to be selected and marked. Then, the metal bases (5 mm diameter) are glued to the building element, where the gauge is placed. The values are registered during the monitoring period, and then the crack can be mapped.

3.2. Most Common Types of Repair Techniques

As performed for diagnosis methods, if the methods described in Sections 2.1 and 2.2 are used, the most relevant inter-defects correlation based on the prescription of repair techniques are revealed, and the most common repair techniques used in roof claddings, façade elements/claddings, and floorings can be identified.

3.2.1. Repair Techniques in Roof Claddings

In Table 14, the most relevant inter-defects correlations in roofs are presented, namely, different relationships between defects "A-A1 Leakage damp", "A-A3 Dirt and accumulation of debris", "A-B1 Biodeterioration/biological growth", "A-B2 Vegetation growth", "A-C1 Mapped cracking", "A-C2 Oriented cracking on the current surface", "A-C3 Fracture or splintering on the current surface", "A-D7 Absence/loss of filling material in connecting elements or current joints", and "A-D9 Insufficient or excessive overlap of the claddings elements in roofs". According to the data of Garcez et al. [40], adapted to the harmonisation of the classification of defects [33], defects **A-B1 and A-B2**, together, are the most common in **external claddings of pitched roofs** (in 72.5% of inspected roofs). Then, defects A-C1, A-C2, and A-C3, all together, also have a high incidence (46.4%). Defect A-A3 (28.0%), as highlighted in Section 3.1, moderately affects claddings of pitched roofs, and defects A-D7 (6.8%) and A-D9 (12.6%) only affect a few pitched roofs. As for **flat roofs**, according to the data of Conceição et al. [41], adapted to the harmonisation of the classification of defects [33], as mentioned in Section 3.1, defect "**A-A3** Dirt and accumulation of debris" is the most detected (in 74.3% of inspected flat roofs). Defects A-C1, A-C2, and A-D7, all together, have a median incidence in flat roofs (21.9%). Then, defects A-D9 (13.3%), A-C3 (11.0%), and A-A1 (9.5%) only affect a small number of inspected roofs.

Table 14. Analysis of the results for claddings of roofs based on the new inter-defects correlation matrix considering repair techniques.

Building Element/ Material	Defects Associated with the Same Repair Technique	Repair Techniques Considered in ECPR	Repair Techniques Considered in FR	Repair Techniques Considered for Both
Roof claddings—external claddings of pitched roofs (ECPR); flat roofs (FR)	A-A3 and A-B1	R-A1	R-A1	R-A1
	A-A3 and A-B2	R-A1	R-A1	R-A1
	A-B1 and A-B2/ A-B2 and A-B1	R-A1, R-A2, R-A7	R-A1	R-A1
	A-C1 and A-C2/ A-C2 and A-C1	R-A2, R-A3, R-A4, R-A6, R-A7, R-A8, R-A9, R-A11	R-B6	-
	A-C1 and A-C3/ A-C3 and A-C1	R-A2, R-A3, R-A4, R-A6, R-A7, R-A8, R-A9, R-A11	R-B6	-
	A-C2 and A-C3 / A-C3 and A-C2	R-A2, R-A3, R-A4, R-A6, R-A7, R-A8, R-A9, R-A11	R-B6	-
	A-D7 and A-D9	R-A5, R-C2	R-B6	-
	A-D9 and A-A1	R-A5, R-A11, R-B13, R-C2	R-B6	-

Note: refer to Table 3 and Table 2 for the designation of each defect and repair technique, respectively.

As for the severity of the set of defects included in the most relevant correlations in roof claddings, data from service life prediction methodologies may be considered. In the case of external claddings of pitched roofs, the severity implicitly associated with the degradation levels for defects by Ramos et al. [42] may be used. Out of the nine mentioned defects, these authors only take into account "A-A3 Dirt and accumulation of debris", "A-B1 Biodeterioration/biological growth", "A-B2 Vegetation growth", "A-C1 Mapped cracking", "A-C2 Oriented cracking on the current surface", and "A-C3 Fracture or splintering on the current surface", which comprise the defects "Staining, change in colour or of brightness of the tiles", "Development of parasitic vegetation/biological colonisation", and "Cracking/fracture". The first one was already considered in Section 3.1.1, and it is considered to affect moderately degraded roof claddings. Biological colonisation and vegetation growth, together, are admitted to affect up to 10% of the total area of the cladding when it is in good condition (Level 1). On the other hand, if they affect more than 50% of the pitched roof cladding, then it should be considered moderately degraded (Level 3). Cracking/fracture was also considered in Section 3.1.1, and it affects roofs from slight degradation (Level 2) to generalised degradation (Level 4). Ramos et al. [42] use a five-level scale from Level 0 (Very good) to Level 4 (Generalised degradation). From this data, defects A-C1, A-C2, and A-C3 are the most severe.

As for flat roofs, the same kind of analysis cannot be performed. Still, as mentioned in Section 3.1.1, the importance of "A-A1 Leakage damp" is highlighted in the literature [43].

Also, in Table 14, the results referring to the repair techniques associated with the most relevant correlations are presented. It is found that, for the repair of roof claddings, the most likely technique to be used is "R-A1 Cleaning". It is actually common knowledge that, together with the biannual inspections of roofs, cleaning procedures should be carried out (checking the drainage system for clogging and cleaning any debris).

Furthermore, given the future assessment of the life cycle of repair techniques, a superficial analysis of the resources associated with each repair technique can be performed. This is a seminal approach to the topic.

In the case of Table 15, "R-A1 Cleaning" refers to (i) in external claddings of pitched roofs, cleaning gutters manually (removal of any accumulated dirt, including debris, nests and leaves), and cleaning ceramic roof tiles manually and applying an adequate cleaning agent for the removal of mould, fungus and grease stains; (ii) in flat roofs, using a blower to remove debris from the current surface and gutters, manually removing any vegetation, using a water jet to wet the surface, brushing the roof surface and rinsing the surface thoroughly with running water.

Table 15. Resources involved in the use of repair technique "R-A1 Cleaning" from category "R-A Surface of the cladding" in the scope of roof claddings—an approach based on a cradle-to-gate approach of LCA [38]; resources data from CYPE Ingenieros S.A: [39].

Life-Cycle Stage	**External Claddings of Pitched Roofs**			**Flat Roofs**		
	Applicable?	**Resource**	**Amount**	**Applicable?**	**Resource**	**Amount**
Raw material extraction and processing, processing of secondary material input	Gutters: No	-	-	No	-	-
	Ceramic roof tiles: Yes	Depends on the ingredients of the cleaning agent	Depends on the formula of the cleaning agent			
Transport to the manufacturer	Gutters: No	-	-	No	-	-
	Ceramic roof tiles: Yes	Transportation using a vehicle and the respective energy	Depends on the location of the ingredients and the factory			
Manufacturing	Gutters: No	-	-	No	-	-
	Ceramic roof tiles: Yes	Processed raw materials, energy, and auxiliary materials to produce the cleaning agent	Depends on the formula of the cleaning agent			
Transport to the building site	Gutters: Yes	Transportation of construction workers	Depends on the location of the construction site	Yes	Transportation of construction workers and cleaning equipment	Depends on the location of the construction site
	Ceramic roof tiles: Yes	Transportation of construction workers and the cleaning agent	Depends on the location of the construction site			

Table 15. *Cont.*

Life-Cycle Stage	External Claddings of Pitched Roofs			Flat Roofs		
	Applicable?	Resource	Amount	Applicable?	Resource	Amount
Installation into the building	Gutters: Yes	Labour of construction workers	0.274 h/m	Yes	Energy for the blower and water jet	Depends on the efficiency of the equipment
	Ceramic roof tiles: Yes	Cleaning agent for the removal of mould, fungus, and grease stains	0.130 L/m^2		Water	10 L/m^2
		Labour of construction workers	0.547 h/m^2		Labour of construction workers	0.547 h/m^2

3.2.2. Repair Techniques in Façade Elements/Claddings

In Table 16, the most relevant inter-defects correlations in façades are identified, referring to different relationships between defects "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", "A-A4 Colour changes", "A-A6 Cohesion loss/disaggregation and chalking", "A-B1 Biodeterioration/biological growth", "A-B2 Vegetation growth", "A-B3 Efflorescence/cryptoflorescence and carbonation", "A-C1 Mapped cracking", and "A-C2 Oriented cracking on the current surface". According to the data of Santos et al. [44], adapted to the harmonisation of the classification of defects [33], defects **A-B1** (32.7%) and A-A3 (24.1%) are common in **door and window frames**, while A-A4 (8.6%) and A-A2 (2.7%) only occur sparsely.

As for **wall renders**, according to the data of Sá et al. [45], adapted to the harmonisation of the classification of defects [33], defect "**A-A3** Dirt and accumulation of debris" is the most detected (in 90% of inspected wall renders). Defects A-A4 (46%), A-C2 (41%) and A-B1 (35%) have an average incidence in wall renders, while defects A-A2 (15%), A-B3 (9%), A-C1 (6%), A-A6 (4%), and A-B2 (3%) are not very common.

According to the data of Amaro et al. [46], adapted to the harmonisation of the classification of defects [33], defect **A-A2** is the most common in **ETICS** (in 59.4% of inspected surfaces). Defects A-C2 (32.2%), A-B1 (27.8%), A-B2 (27.8%), A-A3 (24.4%), and A-A4 (20.3%) are also common in ETICS, while defects A-C1 (7.5%) and A-B3 (1.4%) are rare.

As for **painted façades**, according to the data of Pires et al. [47], adapted to the harmonisation of the classification of defects [33], "**A-A3** Dirt and accumulation of debris" is by far the most detected (in 91.4% of inspected painted façades). Defects A-A4 (47.6%) and A-B1 (40.0%) are also common, while A-C1 (35.2%) has an average incidence in painted façades. Defects A-B3 (8.6%) and A-A6 (5.7%) occur sparsely.

According to the data of Silva et al. [48], adapted to the harmonisation of the classification of defects [33], defect **A-C2** is the most common in **architectural concrete surfaces** (in 48.2% of inspected surfaces). Defects A-A3 (32.7%), A-A2 (29.1%), and A-A4 (29.1%) are also common in architectural concrete surfaces, while defects A-C1 (12.7%), A-B1 (11.8%), A-B3 (7.3%), and A-A6 (0.9%) have a low to very low incidence.

As for **adhesive ceramic tiling**, according to the data of Silvestre et al. [49], adapted to the harmonisation of the classification of defects [33], defect "**A-B3** Efflorescence/cryptoflorescence and carbonation" is one of the most detected (in 40% of inspected surfaces). Defects A-B1 and A-B2, together (5%), have one of the lowest incidences. Defects A-A3 and A-A4, together (55%), are commonly detected in this type of cladding. Defects A-C1 and A-C2, together, are present in 50% of inspected tiled surfaces.

Table 16. Analysis of the results for façade elements/claddings based on the new inter-defects correlation matrix considering repair techniques.

Building Element/ Material	Defects Associated with the Same Repair Technique	Repair Techniques Considered in DWF	Repair Techniques Considered in WR	Repair Techniques Considered in ETICS	Repair Techniques Considered in PF	Repair Techniques Considered in ACS	Repair Techniques Considered in ACT	Repair Techniques Considered in NSC	Repair Techniques Considered for 3 or More Materials
Façade elements and façade claddings—door and window frames (DWF); wall renders (WR); external thermal insulation composite systems (ETICS); painted façades (PF); architectural concrete surfaces (ACS); adhesive ceramic tiling (ACT); natural stone claddings (NSC)	A-A2 and A-A3/ A-A3 and A-A2	R-D11	R-A1, R-A2, R-B14, R-D16	R-A1, R-A2, R-A12	-	R-A1, R-A2, R-A11, R-D1, R-D16	-	-	R-A1, R-A2
	A-A6 and A-C1	-	R-A11, R-A12, R-B14	-	R-A12	R-A11	-	R-A11, R-A14, R-D9	R-A11
	A-B1 and A-A2	R-D11	R-A1, R-A2, R-A11, R-A12, R-D16	R-A1, R-A2, R-A12, R-D16	-	R-A1, R-A2, R-D16	-	-	R-A1, R-A2, R-D16
	A-B1 and A-A3	R-A1, R-A2, R-A12, R-A14, R-D6, R-D11, R-D12	R-A1, R-A2, R-A12, R-D16	R-A1, R-A2, R-A12	R-A1, R-A12	R-A1, R-A2, R-D16	R-A1, R-D6	R-A1, R-A2, R-D8	R-A1, R-A2, R-A12,
	A-B1 and A-B2/ A-B2 and A-B1	-	R-A1, R-A2, R-A11, R-A12, R-D16	R-A1, R-A2, R-A12, R-D16	-	-	R-A1, R-D2, R-D3, R-D6	R-D3, R-D8	R-A1
	A-B3 and A-A2	-	R-A1, R-A11, R-A12, R-B14	R-A1, R-A12	-	R-A1, R-A2	-	-	R-A1
	A-B3 and A-A4	-	R-A1, R-A11, R-A12	R-A1, R-A12	R-A1, R-A12, R-A16	R-A1, R-A2	R-D6	R-A11	R-A1, R-A12
	A-B3 and A-B1	-	R-A1, R-A11, R-A12	R-A1, R-A12	R-A1, R-A12	R-A1, R-A2	R-A1, R-D2, R-D6	-	R-A1, R-A12
	A-C1 and A-C2	-	R-A11, R-A12, R-A14	R-A12, R-A14, R-D2	-	R-A2, R-A11	R-A11, R-A12, R-B8, R-C4, R-D4, R-D7, R-D9	R-A11, R-A14, R-D4, R-D9	R-A11, R-A12, R-A14

Note: refer to Table 3 and Table 2 for the designation of each defect and repair technique, respectively.

Finally, according to the data of Neto and de Brito [50], adapted to the harmonisation of the classification of defects [33], defect "**A-A4** Colour changes" is the most common in **natural stone claddings** (in 93.0% of inspected surfaces); the remaining defects have an average to low incidence in natural stone claddings—A-A3 (19.5%), A-C1 (17.6%), A-C2 (17.6%), A-B3 (12.5%), A-B1 (7.8%), A-A6 (5.5%), A-B2 (3.1%).

As for the severity of the set of defects included in the most relevant correlations in façade elements/claddings, data from service life prediction methodologies can also be considered in the case of window frames [61]. The severity implicitly associated with the degradation levels for defects by Fernandes et al. [51] may be used. Of the mentioned set of nine defects, these authors only take into account "A-A3 Dirt and accumulation of debris", "A-A4 Colour changes", "A-B1 Biodeterioration/biological growth", and "A-C1 Mapped cracking". The accumulation of debris may affect more than 20% of the elements in Level B (Good). There can be colour changes in the element coating in up to 10% of the element in Level B (Good), but if it affects more than 50% of the area, then the element is in Level D (Moderate degradation). Biological growth can affect up to 15% of the element in Level C (Slight degradation), but in Level E (Severe degradation), biodeterioration needs only to affect 10% or more of the door/window frame. As for mapped cracking, it may affect up to 10% of the element coating in Level B (Good) and more than 50% in Level D (Moderate degradation). In this case, biodeterioration is considered the most severe defect in door and window frames. Fernandes et al. [51] use a five-level scale from Level A (Very good) to Level E (Severe degradation).

As for wall renders, the severity implicitly associated with the degradation levels for defects by Vieira et al. [52] may be used. Of the mentioned set of defects, these authors take the following into account: "A-A2 Surface moisture"; "A-A3 Dirt and accumulation of debris"; "A-A4 Colour changes"; "A-B1 Biodeterioration/biological growth"; "A-C1 Mapped cracking"; and "A-C2 Oriented cracking on the current surface". They are mentioned as "damp", "dirt", "changes in the colour of the surface", "microorganisms and algae", and "cracking", respectively. Damp and dirt are referred to in Level C (light degradation). Colour changes may be visible in Level B (good condition). Microorganisms may be present in Level B (good condition) and dark patches (microorganisms and algae) in Level C (light degradation). Cracking may occur at all levels of degradation, depending on the crack width. In Level A (best condition), cracks may be up to 0.1 mm wide. In Level E (worst condition), cracks may be 2 mm or wider. Considering these data, cracking may be the most severe defect in this set of defects in wall renders. Vieira et al. [52] use a five-level scale from Level A (Best condition) to Level E (Worst condition).

In the case of ETICS, the severity implicitly associated with the degradation levels for defects by Ximenes et al. [53] may be used. Of the mentioned set of defects, these authors take into account "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", "A-A4 Colour changes", "A-B1 Biodeterioration/biological growth", and "A-B3 Efflorescence/cryptoflorescence and carbonation" under the defect "stains/colour changes", and defects "A-C1 Mapped cracking" and "A-C2 Oriented cracking on the current surface", considered as "loss of continuity/integrity defects". The severity of these defects has already been detailed in Section 3.1.2, finding that both groups of defects can represent severe degradation in ETICS depending on the intensity and affected area.

As for painted façades, the severity implicitly associated with the degradation levels for defects by Chai et al. [54] may be used. Of the mentioned set of defects, these authors take into account "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", "A-A4 Colour changes", "A-B1 Biodeterioration/biological growth", and "A-B3 Efflorescence/cryptoflorescence and carbonation", which are considered within the scope of "stains/colour change". "A-C1 Mapped cracking" is also taken into account as "cracking". The severity of these defects has already been detailed in Section 3.1.2, determining that biological growth and cracking may be the most severe defects within this set in painted façades.

In the case of architectural concrete surfaces, the severity implicitly associated with the degradation levels for defects by Serralheiro et al. [55] may be used. Of the mentioned set of defects, these authors take into account "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", "A-A6 Cohesion loss/disaggregation and chalking", "A-B1 Biodeterioration/biological growth", "A-B3 Efflorescence/cryptoflorescence and carbonation", "A-C1 Mapped cracking", and "A-C2 Oriented cracking on the current surface". The severity of most of these defects has already been discussed in Section 3.1.2, but for A-A6 and A-B3, it is missing. Disaggregation may be present in less than 10% of surfaces with slight degradation (Level C). If the surface has generalised degradation (Level E), then disaggregation may be present in more than 30% of its area. As for efflorescence, it may be present in less than 10% of a surface in good condition (Level B), while if it takes up more than 30% of the surface, it may be considered with moderate degradation (Level D). Although disaggregation is a severe defect, cracking of more than 0.5 mm wide is still more severe in architectural concrete surfaces. Serralheiro et al. [55] use a five-level scale from Level A (No visible degradation) to Level E (Generalised degradation).

As for adhesive ceramic tiling, the severity implicitly associated with the degradation levels for defects by Bordalo et al. [56] may be used. Of the mentioned set of defects, these authors take into account "A-A2 Surface moisture", "A-A3 Dirt and accumulation of debris", "A-A4 Colour changes", "A-B1 Biodeterioration/biological growth", "A-C1 Mapped cracking", and "A-C2 Oriented cracking on the current surface". Out of these, only the severity of A-A4 has not been discussed in Section 3.1.2. The change in colour may occur in up to 10% of tiled surfaces in good condition (Level 1). If it affects more than 50% of the area, then the surface is under moderate degradation (Level 3). So, cracking is still the most severe defect in this set of defects in adhesive ceramic tiling. Bordalo et al. [56] use a five-level scale from Level 0 (No visible degradation) to Level 4 (Generalised degradation).

In the case of natural stone claddings, the severity implicitly associated with the degradation levels for defects by Silva et al. [57] may be used. Of the mentioned set of defects, these authors take all into account. The severity of A-A2, A-A3, A-B1, A-C1, and A-C2 was discussed in Section 3.1.2. As for "A-A4 Colour changes", it may occur in up to 15% of the area of the stone cladding in good conditions (Level 1), but if it affects more than that area, then the surface is considered with slight degradation (Level 2). As for "A-A6 Cohesion loss/disaggregation and chalking", it is classified according to the thickness of the stone slab that is affected. Material degradation in up to 1% of the thickness may occur in claddings in good conditions (Level 1), regardless of the affected area. But material degradation in up to 10% of the thickness of the stone slab is limited to 20% of the area of the stone claddings for it to be considered in good condition (Level 1). In cladding under generalised degradation (Level 4), material degradation may affect more than 30% of the thickness of the stone slabs in more than 20% of the surface of the stone cladding. In the case of "A-B2 Vegetation growth", it may be observed in claddings with slight degradation (Level 2) in up to 30% of the surface. If it is more than that, then the surface is considered moderately degraded (Level 3). Efflorescence (A-B3) follows the same criteria as A-B2. Cracking is the most severe defect in the set, according to its width, closely followed by disaggregation. Silva et al. [57] use a five-level scale from Level 0 (No visible degradation) to Level 4 (Generalised degradation).

Also, in Table 16, the results referring to the repair techniques associated with the most relevant correlations are presented. It is found that for the repair of façade elements/claddings, the techniques that may solve a broader number of types of defects are "R-A1 Cleaning", "R-A2 Application of a protective coat (paint, varnish, water-repellent, antifungal, biocide)", "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)", "R-A12 Application of a new (adequate) cladding/finishing coat over the existent/replacement", "R-A14 Treatment of cracks or other holes in the cladding", and "R-D16 Correction of geometrical construction details". These repair techniques tend to have very broad designations, and the particular works that are involved for each building material may be quite different.

Concerning the resources used, two repair techniques are analysed, namely, R-A1 and R-A2. In the case of Table 17, "R-A1 Cleaning" in façade claddings refers to manual cleaning of the surface with mould stains or dampness through the application of water and bleach solution at 10% and rinsing with abundant clean water.

In the case of Table 18, "R-A2 Application of a protective coat (paint, varnish, water-repellent, antifungal, biocide)" in natural stone claddings refers to a water-repellent surface treatment for natural stone façades, using colourless water-repellent and oil-repellent impregnation applied in successive coats until the element is saturated.

Table 17. Resources involved in the use of repair technique "R-A1 Cleaning" from category "R-A Surface of the cladding" in the scope of façade elements/claddings—an approach based on a cradle-to-gate approach of LCA [38]; resource data from CYPE Ingenieros S.A: [39].

Life-Cycle Stage	Façade Claddings		
	Applicable?	Resource	Amount
Raw material extraction and processing, processing of secondary material input	Yes	Sodium hypochlorite	0.0025 L/m^2
Transport to the manufacturer	Yes	Transportation using a vehicle and the respective energy	-
Manufacturing	Yes	Bleach	0.1 L/m^2

Table 17. *Cont.*

Life-Cycle Stage	Façade Claddings		
	Applicable?	Resource	Amount
Transport to the building site	Yes	Transportation of construction workers and bleach	Depends on the location of the construction site
Installation into the building	Yes	Water and bleach solution at 10%	0.3 L/m^2
		Water	1 L/m^2
		Construction worker 1	0.055 h/m^2
		Construction worker 2	0.055 h/m^2

Table 18. Resources involved in the use of repair technique "R-A2 Application of a protective coat (. . ., water-repellent, . . .)" from category "R-A Surface of the cladding" in the scope of façade elements/claddings—an approach based on a cradle-to-gate approach of LCA [38]; resources data from CYPE Ingenieros S.A: [39].

Life-Cycle Stage	Natural Stone Claddings		
	Applicable?	Resource	Amount
Raw material extraction and processing, processing of secondary material input	Yes	Depends on the ingredients of the colourless water and oil repellent	Depends on the formula of the colourless water and oil repellent
Transport to the manufacturer	Yes	Transportation using a vehicle and the respective energy	-
Manufacturing	Yes	Colourless water and oil repellent	Depends on the formula of the colourless water and oil repellent
Transport to the building site	Yes	Transportation of construction workers and the colourless water and oil repellent	Depends on the location of the construction site
Installation into the building	Yes	Water-repellent, colourless, water-based alkyl alkoxysilane impregnation, without solvents, with an average penetration depth of 6.8 mm, repellent to water and dirt, with thixotropic properties, permeable to water vapour, anti-bark and anti-green, with efflorescence prevention effect and resistant to UV rays and alkalis.	0.2 L/m^2
		Painter	0.197 h/m^2

3.2.3. Repair Techniques in Floorings

In Table 19, the most relevant inter-defects correlations in floorings are presented, namely, between defects "A-A3 Dirt and accumulation of debris", "A-A4 Colour changes", "A-A5 Spalling/peeling/exfoliation and pop-outs", "A-A6 Cohesion loss/disaggregation and chalking", "A-C1 Mapped cracking", "A-C2 Oriented cracking on the current surface", "A-C4 Cracking and/or splintering adjacent to joints/edges", "A-C6 Scratches/grooves and deep wear", "A-C9 Detachment", "A-D6 Degradation of the filling material of current joints", and "A-D7 Absence/loss of filling material in connecting elements or current joints". According to the data of Silvestre and de Brito [49], adapted to the harmonisation of the classification of defects [33], defect **A-D6** is the most common in **adhesive ceramic tiling** (in 57% of inspected elements). Then, defects **A-A3 and A-A4** (55%), together, represent the second most common occurrence (staining, change in colour or brightness). Moreover, cracking (**A-C1 and A-C2**) is present in about 50% of inspected surfaces. As for **natural stone claddings**, according to the data of Neto and de Brito [50], adapted to the harmonisation of the classification of defects [33], by far, defect A-A4 (93%) is the most common in the inspected surfaces. Defects **A-C1 and A-C2** (36%), together, also have a significant incidence in this type of flooring, as well as A-A3 (32%). According to the data of Delgado et al. [58], adapted to the harmonisation of the classification of defects [33], defect A-C6 (85%) is by far the most relevant one in **wood floorings**. As for **epoxy resin industrial floor coatings**, according to the data of Garcia [59], adapted to the harmonisation of the classification of defects [33], defects "A-A4 Colour changes" (31%) and "A-C6 Scratches/grooves and deep wear" (31%) are within those most common. According to the data of Carvalho et al. [60], adapted to the harmonisation of the classification of defects [33], defect A-C6 (in 75% of inspected surfaces) is the most common in vinyl and linoleum floorings. Defects A-D6 and A-D7 together (54%) and A-A4 (43%) are also relevant in this type of flooring.

As for the severity of the set of defects included in the most relevant correlations in floorings, data from service life prediction methodologies can also be considered. In the case of wood floorings, the severity implicitly associated with the degradation levels for defects by Coelho et al. [61] may be used. These authors take into account the complete set of nine defects considered by Delgado et al. [68]. The one considered more severe is the loss of wood elements (detachment), whose degradation starts at level 3 (slight degradation), even if the area affected is low (0–30%). As for weighting factors associated with each defect to calculate the flooring's S_w, all functional defects are aggravated with a factor of 1.2, including "A-A6 Cohesion loss/disaggregation and chalking", "A-C2 Oriented cracking on the current surface", "A-C4 Cracking and/or splintering adjacent to joints/edges", and "A-D7 Absence/loss of filling material in connecting elements or current joints". So, most of the defects considered in Table 19 are considered severe in wood floorings.

The same analysis cannot be carried out for the other types of floorings, but the general literature about their typical pathology can be analysed. Ventura et al. [69] identify cracking, detachment, crushing and chipping, wear and/or scratching, swelling, colour loss, blistering, staining, fungi, and xylophagous organisms as the most recurrent in floorings. Of this group, only swelling, blistering, and fungi and xylophagous organisms are not in Table 19. Furthermore, Valente de Almeida [62] lists "A-A5 Spalling/peeling/exfoliation and pop-outs" (surface defects), "A-C1 Mapped cracking", "A-C2 Oriented cracking on the current surface" (crazing and cracks), and "A-C4 Cracking and/or splintering adjacent to joints/edges" (breaking) as some of the main problems in ceramic tiles. Although the specific literature on natural stone floorings is scarce, the general knowledge refers to the effects of pollutants in staining and the risks of design, specification, and construction errors, which may lead to cracking, general decay, and more rapid decay. For instance, in public areas paved with natural stone elements, the design issues are critical to avoid cracking and premature end-of-life [65]. Cracking is also a major concern in epoxy resin floorings, mainly associated with the substrate conditions (screeds or concrete slabs) depending on the layers of the epoxy coating system [70]. In vinyl and linoleum floorings, joint defects (A-D7, mainly) may assume larger proportions if not corrected, as they are prone to water leakages, which, in place, may lead to the detachment of the flooring system.

To sum up, A-A3, A-A4, A-A5, A-A6, A-C1, A-C2, A-C4, A-C6, A-C9, A-D6, and A-D7 affect several types of floorings in various manners, but those more severe are associated with mechanical causes. Nevertheless, depending on the level of requirements, visual defects (e.g., stains) may also obtain graver proportions if not tackled in the earlier stages.

Table 19 also presents the results referring to the repair techniques associated with the most relevant correlations. It is found that for floorings rehabilitation, the most likely techniques to be used are "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)", "R-A12 Application of a new (adequate) cladding/finishing coat over the existent/replacement", and "R-A14 Complete/partial removal of the existing coat in painted façades". R-A11 is the most relevant and is considered next to identify the resources for its execution.

In the case of Table 20, "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)" refers to the following: (i) in adhesive ceramic floorings, outdoor glazed porcelain stoneware mosaic flooring, polished finish, with 25 × 25 × 5 mm tiles mounted on a mesh, medium range, water absorption capacity E < 0.5%, group BIa, according to NP EN 14411, with slip resistance greater than 45 according to ENV 12633, the substrate consisting of cement mortar, filling with a thin layer with cementitious adhesive, C1 TE, according to NP EN 12004, with reduced slip and extended setting time, and joint filling with improved cementitious grout, with reduced water absorption and high resistance to abrasion type CG 2 W A, white colour, in 2 mm thick joints; (ii) in wood floorings, outdoor deck flooring, made up of 21 × 95 × 1600/2400 mm Swedish pine solid wood boards, fixed using the hidden fixing system on 65 × 38 mm autoclave-treated Pinus pinaster wood clapboards, risk class 4 according to NP EN 335, 40 cm apart and resting on adjustable polyolefin supports with a flat round base, for heights between 30 mm and 50 mm; brushing and subsequent application of two coats of quick-drying water-based interior and exterior floor polish, Pino colour, satin finish, yield of 0.083 L/m^2 each coat as a protective and decorative treatment, including stainless steel clips and screws for fixing the boards to the battens and special pieces.

Table 19. Analysis of the results for floorings based on the new inter-defects correlation matrix considering repair techniques.

Building Element/ Material	Defects Associated with the Same Repair Technique	Repair Techniques Considered in ACT	Repair Techniques Considered in NSC	Repair Techniques Considered in WF	Repair Techniques Considered in ERIFC	Repair Techniques Considered in VLF	Repair Techniques Considered for 2 or More Materials
Floorings—adhesive ceramic tiling (ACT); natural stone claddings (NSC); wood floorings (WF); epoxy resin industrial floor coatings (ERIFC); vinyl and linoleum floorings (VLF)	A-A3 and A-A4	R-A2, R-A11, R-A12, R-D6	R-A1, R-A11, R-D8	R-A2, R-A11, R-A12, R-D6, R-D8	-	R-A1, R-A2, R-A11, R-A12	R-A2, R-A11, R-A12, R-D6, R-D8
	A-A4 and A-C6/ A-C6 and A-A4	R-A11, R-A12	R-A11	R-A11, R-A12, R-B9	R-A12, R-A13	R-A1, R-A2, R-A11, R-A12	R-A2, R-A11, R-A12
	A-A5 and A-C1	R-A11, R-A12	R-A11, R-A14, R-D9	-	-	-	R-A11
	A-A5 and A-C2	R-A11, R-A12	R-A11, R-A14, R-D9	-	-	-	R-A11
	A-A5 and A-C6/ A-C6 and A-A5	R-A11, R-A12	R-A11, R-A14, R-D9	-	-	-	R-A11
	A-A6 and A-C6/ A-C6 and A-A6	-	R-A11, R-A14, R-D9	R-A11, R-A12, R-B9	-	-	R-A11
	A-C1 and A-C2/ A-C2 and A-C1	R-A11, R-A12, R-B8, R-C4, R-D4, R-D7, R-D9	R-A11, R-A14, R-D4, R-D9	-	R-A11, R-A13, R-A14	-	R-A11, R-A14, R-D4, R-D9
	A-C1 and A-C6/ A-C6 and A-C1	R-A11, R-A12	R-A11, R-A14, R-D9	-	R-A11, R-A13, R-A14	-	R-A11, R-A14
	A-C2 and A-C6/ A-C6 and A-C2	R-A11, R-A12	R-A11, R-A14, R-D9	R-A11, R-A12, R-B9	R-A11, R-A13, R-A14	R-A2, R-A11	R-A11, R-A12. R-A14
	A-C6 and A-A3	R-A11, R-A12	R-A11	R-A11, R-A12	-	R-A1, R-A2, R-A11, R-A12	R-A11, R-A12
	A-C6 and A-C4	R-A11, R-A12	R-A11	R-A11, R-A12, R-B9	-	-	R-A11, R-A12
	A-C9 and A-C4	-	R-A11, R-D7, R-D8	R-A11, R-B7, R-B8	-	-	R-A11
	A-D7 and A-D6	R-D2, R-D7	R-D2	R-D2	-	R-A2, R-A11, R-D5	R-D2

Note: refer to Table 3 and Table 2 for the designation of each defect and repair technique, respectively.

Table 20. Resources involved in the use of repair technique "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)" from category "R-A Surface of the cladding" in the scope of floorings—approach based on a cradle-to-gate approach of LCA [38]; resources data from CYPE Ingenieros S.A: [39].

Life-Cycle Stage	Adhesive Ceramic Tiling			Wood Floorings		
	Applicable?	**Resource**	**Amount**	**Applicable?**	**Resource**	**Amount**
Raw material extraction and processing, processing of secondary material input	Yes	Raw materials for the production of cementitious adhesive, ceramic tiles, and grouting	Depends on product formula	Yes	*Pinus pinaster* wood	Depends on log radius
					Swedish pine wood	
					Raw materials for the production of adjustable supports, fastening elements, and wood wash	Depends on product formula
Transport to the manufacturer	Yes	Transportation using a vehicle and the respective energy	Depends on ingredients and factories' location	Yes	Transportation using a vehicle and the respective energy	Depends on ingredients and factories' location
Manufacturing	Yes	Cementitious adhesive	Depends on product formula	Yes	Clapboard of *Pinus pinaster* wood	Depends on product formula
					Adjustable support	
		Ceramic tiles			Solid Swedish pine wood boards	
					Fastening elements in stainless steel	
		Grouting			Quick-drying water-based floor polish	
Transport to the building site	Yes	Transportation of construction workers, cementitious adhesive, ceramic tiles, and grouting	Depends on construction site location	Yes	Transportation of construction workers, clapboards, adjustable supports, wood boards, fastening elements, and floor polish	Depends on construction site location
Installation into the building	Yes	Cementitious adhesive, C1 TE (NP EN 12004), with reduced slip and extended laying time, white, based on high-strength cement, selected aggregates, additives and synthetic resins, for laying all types of ceramic tiles in a thin layer on exterior floors	4 kg/m^2	Yes	Clapboard with a section of 65 × 38 mm, made from *Pinus pinaster* wood, autoclave-treated, risk class 4, according to NP EN 335, brushed finish, with humidity of less than 20%.	2.6 m/m^2

Table 20. *Cont.*

Life-Cycle Stage	Adhesive Ceramic Tiling			Wood Floorings		
	Applicable?	Resource	Amount	Applicable?	Resource	Amount
Installation into the building	Yes	Glazed porcelain stoneware mosaic, with 25 × 25 × 5 mm tiles mounted on a mesh, with a 2 mm separation joint between tiles, medium range, water absorption capacity E < 0.5%, group BIa, according to NP EN 14411, with slip resistance greater than 45 according to ENV 12633	1.05 m^2/m^2	Yes	Adjustable support, made of polyolefin, with added mineral filler, in black colour, with 750 kg mechanical compression capacity and flat round base, for heights between 30 and 50 mm; thermal stability from −25 °C to 110 °C; imputrescible, resistant to ageing and weathering	7 units/m^2
		Kit of PVC crosses to guarantee a joint thickness between tiles of 2 mm in ceramic flooring.	3.2 units/m^2		Solid Swedish pine wood boards, 21 × 95 × 1600/2400 mm, untreated, for brushing and application of a protective and decorative treatment on site, with assembly accessories. According to EN 13810-1 and EN 14342	1.05 m^2/m^2
					Assembly kit for decking, comprising a stainless-steel omega-shaped clip for assembly of the boards and a stainless steel screw for fixing the clip to the slat	25 units/m^2
		Improved cementitious grout, with reduced water absorption and high resistance to abrasion, type CG2 W A, according to EN 13888, white colour, for joints of 2 mm, based on high-strength cement, quartz, special additives, pigments and synthetic resins, for filling joints in all types of ceramic tiles	1.34 kg/m^2		Quick-drying water-based floor polish for interior/exterior use, Pino colour, satin finish, based on hybrid acrylic resins and polyurethane copolymers, with a biocide agent, against blue stain fungi and moulds, weather-resistant, applicable by brush, roller or spray gun to exterior wooden floors (protective and decorative treatment)	0.166 L/m^2
					Sanding machine for wooden floors, equipped with sanding rollers and suction system	0.174 h/m^2
		Construction worker 1	0.496 h/m^2		Construction worker 1 (installation of flooring)	0.594 h/m^2
					Construction worker 1 (installation of flooring)	0.594 h/m^2
		Construction worker 2	0.248 h/m^2		Painter 1	0.356 h/m^2
					Painter 2	0.059 h/m^2

4. Discussion

4.1. Most Common Diagnosis Methods to Prepare an Inspection

Section 3.1 establishes separately the relevant diagnosis methods to be used while inspecting roof claddings, façade elements/claddings, and floorings. In roof claddings, "D-C3 Infrared thermography" is helpful in the detection of several defects, with the added advantages of (i) not requiring direct access to the roof, provided the angle of inspection is within limits mentioned in the literature [71] and (ii) also allowing for the inspection of the top area of the façades, where eventual leakages or water runoff (from the roof) can be detected. In façade elements/claddings, "D-C1 Measurement of the ambient and/or surface temperature and humidity", "D-C3 Infrared thermography", and "D-F4 Initial surface absorption test (ISAT) and Karsten-tube" seem to be more useful, considering the high relevance of humidity-related defects (superficial moisture, dirt, biological colonisation). As for floorings, "D-A4 Tell-tale gauge and gypsum testimonies", "D-A5 Crack width ruler and crack-measuring microscope", and "D-A6 Mechanical strain gauge" are the highlighted methods, as mechanical defects have a higher prevalence (cracking, fracture and splintering). Given these results, an essential kit to inspect the building envelope could involve these six diagnosis methods (D-A4, D-A5, D-A6, D-C1, D-C3, D-F4), given that they are useful for elements, and even more in specific building elements/materials.

Other authors also advise the use of an electronic moisture-reading meter or an electronic hygrometer (included in D-C1) and thermography (D-C3) in long lists of useful equipment for professionals dedicated to building surveys [5,72,73]. It should be noted that surprisingly, in the case of Douglas and Noy [72], testing equipment for crack assessment is not advised to prepare for the inspection. On the other hand, the Structural Engineering Institute and the American Society of Civil Engineers [5] highlight the importance of testing cracks in the context of air infiltration and long-term testing of movements in the building envelope. Wilson [73] also highlights the advantages of properly measuring cracks, as they are a relevant indicator of structural issues. Son and Yuen [63] also include crack-measuring equipment (callipers and gauges) in the set of basic equipment for building inspections, as well as electrical resistance meters for measuring moisture content. These authors consider thermography a specialised test. In 1993, with different equipment costs (higher), that could be justifiable, but not nowadays.

4.2. Most Common Types of Repair Techniques

Section 3.2 establishes separately significant repair techniques to prescribe while rehabilitating roof claddings, façade elements/claddings and floorings. In roof claddings, "R-A1 Cleaning" is relevant for many common defects, mainly associated with dirt accumulation and biological growth, both on the current surface and drainage system, which are very frequent and of paramount importance for the good performance of the building envelope. In façade elements/claddings, "R-A1 Cleaning", "R-A2 Application of a protective coat (paint, varnish, water-repellent, antifungal, biocide)", "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)", and "R-A12 Application of a new (adequate) cladding/finishing coat over the existent/replacement" were identified as the most transversal repair techniques, all mostly referring to the outer layers of the cladding system, considering the prevalence of superficial defects (moisture, dirt, disaggregation, cracking, biological colonisation, vegetation growth, efflorescence/cryptoflorescence). As for floorings, "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)" is highlighted, particularly because it can solve a large span of common defects in these elements/materials.

Given these results, it is worth noting that repair techniques have specific needs in terms of materials, workload, and process of application depending on the building element/material. Nevertheless, given the categorisation of Pereira et al. [32], some repair techniques seem to heal a lot of the most frequent defects. Those techniques are cleaning (R-A1), application of a protective coat (R-A2), partial or complete replacement/reapplication of the cladding/flooring (R-A11), and replacement or application of a more suitable cladding/flooring (R-A12).

Furthermore, the specificity of repair techniques according to building elements/materials makes it more complex to perform a full analysis of the use of involved resources. To perform a preliminary framework for that kind of analysis, the application procedures for some materials were analysed according to freely available data [39]. These data were adapted to an LCA-based cradle-to-gate approach [38]. This is the first analysis of the kind in the literature, since usually, LCA uses standard data about the service life of materials, not specifically considering the maintenance procedures involved. The relevance of such an analysis is attested by some of the results presented in Section 3.2.3. For instance, to properly clean a flat roof, 10 L/m^2 must be used, which, in larger buildings, may refer to an annual expenditure of more than 70,000 L of water (a rough estimate based on the size of Portugal's largest hospital). Besides the expenditure of water, its eventual contamination during cleaning procedures should be considered, as well as methods to prevent it from reaching public mains. Additionally, the cost of cleaning a roof may also be high, taking into account that such a procedure should preferably be performed bi-annually (for the drainage system) and yearly (for the whole roof) in a proactive preventive approach [74]. If the same example is considered, but with a metallic pitched roof, the cost would have to comply with 191 h of labour of construction workers to clean gutters (EUR 4202), plus 910 l (EUR 23,831) of cleaning agent, plus 3829 h of labour of construction workers to clean the current surface of roof tiles (EUR 84,238) (costs based on data from CYPE Ingenieros S.A: [27] and retail prices in Portugal in April 2024). An annual cost of more than (not all costs are considered) EUR 8404 to clean gutters and EUR 112,271 to clean the whole roof are impactful in the service life cost of a building, thus affecting the economic component of life-cycle assessment.

In different orders of magnitude, cleaning procedures are also impactful in terms of cost and resource use per intervention in façades. Still, façade cleaning does not require annual implementation, and the most reasonable approach (proactive predictive) is to clean when inspection data advise that procedure. Consequently, depending on the performance requirements defined by the owners and users, cleaning may be performed in 5, 10, or 30-year intervals [75]. Still, according to the height of the building, the area to be cleaned can be much larger than that of flat or pitched roofs. Additionally, protective coatings should be applied after cleaning to prevent the severity of graffiti or other aggressive agents, which increases both the use of resources and costs.

In floorings, the replacement of materials is considered. The operations are more complex, including several types of products and stages of application. Even the application of a renewable material like wood decking boards implies the use of non-renewable materials like adjustable supports in polyolefin (700 units), stainless steel omega-shaped clips and screws (2500), and floor polish based on hybrid acrylic resins and polyurethane copolymers (166 L) (numbers for a 100 m^2 wood deck, which is relatively small). Even though one could argue that the replacement of floorings may occur only every 38 years (estimated service life of a wood flooring system exposed to moisture) [61], if non-functional factors are taken into account to determine when to replace the flooring, this interval can be drastically lower.

In this sense, in the future, LCA should consider the requirements in terms of the performance of claddings because that is very relevant to determining the periodicity of maintenance and repair operations, thus affecting the number of resources used and costs. Performance levels during the service life should be part of LCA's functional unit.

Moreover, some costs and resources are not specified in Tables 15, 17, 18 and 20, namely, energy costs, which are impactful in some procedures using electric tools, as well as due to transportation, depending on the source of materials used.

Nevertheless, it is the authors' conviction that a detailed LCA of maintenance and repair operations would highlight their advantages when compared with a total refurbishment of buildings, not considering functional adaptations due to changes in use.

5. Conclusions

This study introduces a novel approach by applying an established methodology to a parallel context, creating inter-defect correlation matrices based on diagnosis methods and repair techniques within the domain of building pathology research. This approach is based on fieldwork data complemented by expert knowledge [34], while the literature generally presents information only based on the experts' professional opinions. Furthermore, the research process had the purpose of performing an analysis of defects that could be investigated or solved by using the same means—diagnosis methods or repair techniques, respectively. In the first case, an essential kit of equipment/procedures for the diagnosis of claddings of the building envelope was determined, while, in the second case, the analysis went a little further, scrutinising the resources used to carry out some of the most transversal repair techniques in the building envelope. Such an analysis may be the starting point for a more extensive line of research regarding LCA of maintenance and repair operations in buildings, even more if the LCA of diagnosis methods is also dealt with.

The diagnosis methods considered in the referred essential kit are "D-A4 Tell-tale gauge and gypsum testimonies", "D-A5 Crack width ruler and crack-measuring microscope", "D-A6 Mechanical strain gauge", "D-C1 Measurement of the ambient and/or surface temperature and humidity", "D-C3 Infrared thermography", and "D-F4 Initial surface absorption test (ISAT) and Karsten-tube". They are all applicable to several materials and building elements and focus on some of the most common defects and causes of defects in the claddings of the building envelope.

As for repair techniques, those more transversal to several building elements/materials are "R-A1 Cleaning", "R A2 Application of a protective coat (paint, varnish, water-repellent, antifungal, biocide)", "R-A11 Replacement or reapplication of the cladding/glazing (partially or completely)", and "R-A12 application of a new (adequate) cladding/finishing coat over the existent/replacement". This set of techniques comprises procedures mostly applicable to the surface of the cladding, but if applied timely, they may avoid further deterioration of the underlying layers of the cladding system, as well as the substrate and bearing structure.

Although the authors dedicated all their efforts to base their conclusions on unbiased and reliable data, some limitations should be mentioned. The expert knowledge that led to the creation of the inter-defect data is mainly based on Portuguese construction methods and samples of Portuguese buildings. Although some of those methods are very common in the Western world, some regional specificities may affect the results. Furthermore, the dimensions, typologies, and use of buildings and cities in the Portuguese context require adequate caution when transposing the results to other contexts.

In any case, the provided information may be useful to researchers in the fields of LCA and LCC. In more general terms, this study is important for any practitioner in the field of architecture, engineering, and construction, but specifically for architects, engineers, and contractors dedicated to the rehabilitation of the building stock.

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