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Global Inspection, Diagnosis and Repair System for Buildings: Homogenising the Classification of Repair Techniques

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Abstract. *Building inspection systems are a useful tool for surveyors, standardising the collection of information. This research is framed within the development of a global inspection system based on twelve expert inspection systems for twelve types of building elements used in the envelope of current buildings. Homogenised classification lists replace the use of several records and unify designations used in fieldwork. A homogenised global classification list of repair techniques comprises, in a single component, all the techniques used to repair defects and eliminate their causes for different types of building elements. It includes curative and preventive repairs, as well as planned maintenance works. Well-defined criteria guided the harmonisation process of a large set of repair techniques in a user-friendly list. For instance, the association of different operations in a single repair technique took into account: similarities between procedures, applicability to one type of building element, solving identical defects and the use of similar repair materials. Considering data from the validation samples of the expert inspection systems, it is observed that techniques "R-A1 Cleaning" in painted façades and "R-A12 Application of a new (adequate) cladding/finishing coat over the existent/replacement" in wall renders are the most commonly prescribed. The provision of a homogenised classification list of repair techniques is expected to improve the quality of information collected on-site and give a comprehensive view of the most relevant repair techniques used in the envelope of current buildings.*

Keywords: *Building Pathology, Degradation, Inspection Systems, Maintenance, Repair Techniques.*

1 Introduction

Building inspection systems are useful for surveyors as they (i) help implementing uniform methodologies, (ii) guide the procedures through all the stages, and (iii) use standard designations. In this way, the collection of data on-site and inspection reports become methodic, hence standardising building inspections. This paper addresses the development of a global inspection system for the building envelope by a research team at Instituto Superior Técnico (IST), Universidade de Lisboa (UL), based on individual expert inspection systems (Pereira *et al.*, 2018).

The global inspection system under development at IST-UL is directed at current buildings. It is a broad tool including classification lists, correlation matrices, detailed information on degradation parameters, and an inspection form. It is based on existing expert inspection systems for individual building elements, which implies homogenising the system's components.

The homogenisation of classification lists simplifies the inspection process, replacing several lists with harmonised lists, more manageable to use. In this way, the identification of pathological phenomena in a painted façade or flat roof requires only one list of defects, for instance.

Additionally, standard designations may improve communication.

In this paper, the methodology of development of the harmonised list of repair techniques in the global inspection system is described, and the proposed classification list is presented. Then, using relative frequency results, the most common repair techniques are analysed. The paper ends summarising the research in concluding remarks.

2 Classification List of Repair Techniques

Following the structure of individual inspection systems, the global building inspection system includes a list of repair techniques. It contains techniques used to repair defects and eliminate their causes in the group of building elements taken into account in the inspection system. The particulars of each procedure are described in detail in files of repair techniques, out of the scope of this paper.

2.1 The Context of Developing a Global Inspection System

The development of the global building inspection system considered a well-defined range of building elements, corresponding to twelve expert inspection systems previously devised by researchers at IST-UL (Table 1). Those expert inspection systems have an identical structure and were all validated through the inspection of significant samples of building elements, hence providing a solid base for a new global system (Ferraz *et al.*, 2016).

All the selected individual expert inspection systems provide a classification list of repair techniques that may be recommended by surveyors following the detection and diagnosis of defects in visual and detailed building inspections. Those lists were based on the literature and experience, including curative and preventive techniques and planned maintenance works (Silvestre and de Brito, 2010). Curative repair techniques are those used to repair a defect directly, removing it. Preventive repair techniques refer to interventions on building elements that are not directly associated with a specific defect but, instead, act to eliminate the causes of potential issues. Curative and preventive repair techniques may include partial or complete replacement and changes in the characteristics of the building element (*e.g.* materials and geometry). Planned maintenance works are not intended to correct the behaviour of building elements, but to delay the natural ageing process and the resulting loss of performance and decrease of the service life.

2.2 Harmonisation Criteria

To achieve the goal of having a single list of repair techniques applying to different building elements within the global inspection system, all the expert classification lists had to be collected. Then, going through each list consecutively, the repair techniques referring to the same type of work were merged. For instance, ten out of twelve expert classification lists included cleaning works. Therefore, the global classification list comprises cleaning as one of the repair techniques. After that step, the list of repair techniques was still too long. So, similar techniques were grouped in a single repair technique considering equivalent scopes of intervention, identical procedures, and the resolution of the same kind of phenomena. For instance, different intervention techniques acting on the layers of cladding systems of flat roofs were gathered in a single and broader repair technique referring to the application, repair or replacement of the waterproofing system or separation layer in flat roofs (Conceição *et al.*, 2017). Despite the attempt of decreasing the extent of the global classification list of repair techniques, some specific techniques relating to only a type of building element were kept separately in the list, as no basis for merging applied.

Table 1. Expert inspection systems developed at IST-UL that were the basis of the global inspection system.

References	Building elements	Groups of repair techniques in the classification list	Validation sample	Average number of prescribed repair techniques per detected defect
(Garcez *et al.*, 2012b; a)	external claddings of pitched roofs (ECPR)	R-A Upper surface; R-B Inner surface; R-C Upper and inner surface; R-D Change of the ECPR; R-E Change of the bearing structure	207 surfaces 164 buildings	1.29
(Conceição *et al.*, 2017, 2019)	flat roofs (FL)	General; Specific	105 surfaces 105 buildings	0.63
(Silvestre and de Brito, 2010, 2011)	adhesive ceramic tiling (ACT) - walls and floorings	R-A ACT surface; R-B Tile bed; R-C Joints; R-D ACT; R-E Background; R-F Envelope	88 surfaces 46 buildings	2.26
(Neto and de Brito, 2011, 2012)	natural stone claddings (NSC) - walls and floorings	R-P Stone cladding surface (stone slab); R-A Bedding/anchoring/fixing material; R-J Joints; R-S Substrate; R-R Cladding system; R-E Envelope	128 surfaces 59 buildings	2.46
(Delgado *et al.*, 2013, 2018)	wood floorings (WF)	R-A WF covering; R-B WF surface; R-C WF substrate; R-D Joints between pieces of WF or with protruding elements	98 floorings 35 buildings	1.49
(Santos *et al.*, 2017a; b)	door and window frames (DWF)	R-A Accessories repair; R-F Fittings repair; R-P Profiles repair; R-V Glass repair	295 frames 96 buildings	1.11
(Garcia and de Brito, 2008)	epoxy resin industrial floor coatings (ERIFC)	R-A Current surface; R-B Flashings; R-C Joints	29 floorings 23 buildings	1.20
(Carvalho *et al.*, 2018, 2019)	vinyl and linoleum floorings (VLF)	R-A Superficial zones; R-B Whole flooring; R-C Substrate; R-D Flooring surrounding area	101 floorings 6 buildings	2.15
(Sá *et al.*, 2014, 2015)	wall renders (WR)	R-A Rendering surface; R-B Finishing layer; R-C Rendering system; R-D Envelope	150 surfaces 55 buildings	3.64
(Amaro *et al.*, 2013, 2014)	external thermal insulation composite systems (ETICS) - façades	TR-A Surface; TR-B Finishing coat; TR-C System	146 façades 14 buildings	1.61
(Pires *et al.*, 2015a; b)	painted façades (PF)	R-A Adherent pellicle cleaning; R-B Total/partial removal of existent pellicle; R-C Repainting	105 façades 41 buildings	3.09
(Silva *et al.*, 2017a; b)	architectural concrete surfaces (ACS) - walls	R-A Concrete surface; R-B Concrete; R-C Joints/discontinuities; R-D Periphery	110 surfaces 53 buildings	1.25

While merging and grouping repair techniques to obtain a more concise global list, balancing a simultaneously elaborate and succinct list is paramount for its broadness and user-friendliness. For instance, in the expert inspection system of wall renders (Sá *et al.*, 2014), five separate repair techniques were considered to express the idea of applying a new render with higher performance, namely: application of a reinforced rendering; execution of an external thermal insulation composite system (ETICS); execution of a reinforced render coating independent from the bearing wall; application of a render with higher thermal performance; and application of a drainage or corrective rendering. These five types of repair work refer to slightly different operations, but they are all based on the same concept: the existing render is not enough to prevent the occurrence of further defects and should be replaced or overlaid with a new one. Although separately considering each of these techniques may be reasonable in an inspection system only for wall renders, in a global building inspection system, it would hinder the ease of use of the classification list. For this reason, a single repair technique for the application of a higher performance render was proposed.

Still, other repair techniques could not be linked with any others, as they were too specific. For instance, executing a roof slab in pitched roofs is not comparable with other repairs. So, in the global classification list, it was considered separately, although not decreasing the list's complexity.

To guide the harmonisation of the global classification list of repair techniques, taking expert classification lists into account, a set of criteria was determined:

1. Building a **brief and concise** list of repair techniques without repetitions;

2. To decrease the extent of the list, coupling techniques in one repair technique considering:
    a. The **procedure** of the repair technique;
    b. The applicability of similar repair techniques to a **single type of building element**;
    c. Correcting **similar defects**;
    d. Using **repair materials** with **similar** properties;
3. Including all relevant repair techniques in the list, even though some may apply only to a single type of building element, so that the global classification list is **comprehensive**;
4. Grouping repair techniques into **categories** according to the intervention area within the cladding systems, namely: surface of the cladding, cladding system, change in the bearing structure/substrate and singularities.

2.3 Proposed Classification List of Repair Techniques

Table 2 presents the proposed classification list of repair techniques within a global inspection system. It is organised in four categories, according to the harmonisation criteria. Each technique is identified as constituting a curative (cr) or a preventive repair (pr) or planned maintenance work (pmw). Each category is linked to a code composed of letter R (for repair), a hyphen and a sequential capital letter (from A to D). Each repair technique also corresponds to a code, following that of its category, by adding a sequential number (*e.g.* R-A1, R-B2, R-C5 and R-D11).

Technique "R-D6 Application/repair/replacement/cleaning of drainage systems/plumbing" results from grouping similar repair techniques. R-D6 is a curative and preventive repair technique used in the drainage and plumbing equipment to eliminate or avoid clogging, accumulation of rainwater and leakages. In the expert system of flat roofs, the application, repair and replacement of the drainage system are mentioned (Conceição *et al.*, 2017), while the adhesive ceramic tiling expert system refers to the repair of defects in plumbing, separating embedded and exposed plumbing (Silvestre and de Brito, 2010). In turn, the classification list for natural stone claddings mentions the repair of defects in existing elements inside/outside the wall (Neto and de Brito, 2011). Plumbing is also mentioned for wood floorings (Delgado *et al.*, 2013), while, in door and window frames, the repair or execution of drains in the frames is pointed as a repair technique (Santos *et al.*, 2017b). In this context, technique R-D6 is an example of how conciseness influenced the development of the global classification list of repair techniques, as very similar techniques were harmonised in a single and broader repair technique.

Other techniques result from a direct transfer from the expert to the global classification lists. It is the case of "R-D9 Protecting or smoothing of protruding corners or edges", applying to adhesive ceramic tiling, natural stone claddings, wall renders, ETICS and architectural concrete surfaces.

3 Discussion

An analysis of the most frequently prescribed repair techniques may be performed using the data from the validation samples of the expert inspection systems (Table 1). To build Figure 1, the absolute frequency of recommendation of each repair technique was considered (Amaro *et al.*, 2014; Carvalho *et al.*, 2019; Conceição *et al.*, 2019; Delgado *et al.*, 2018; Garcez *et al.*, 2012a; Garcia and de Brito, 2008; Neto and de Brito, 2012; Pires *et al.*, 2015b; Sá *et al.*, 2015; Santos *et al.*, 2017a; Silva *et al.*, 2017b; Silvestre and de Brito, 2010), adapting the original repair techniques to the proposed global classification list. Then, those absolute frequencies were divided by the number of detected defects in each validation sample.

Table 2. Proposed classification list of repair techniques within a global inspection system.

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)
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)

cr - curative repair; pr - preventive repair; pmw - planned maintenance works

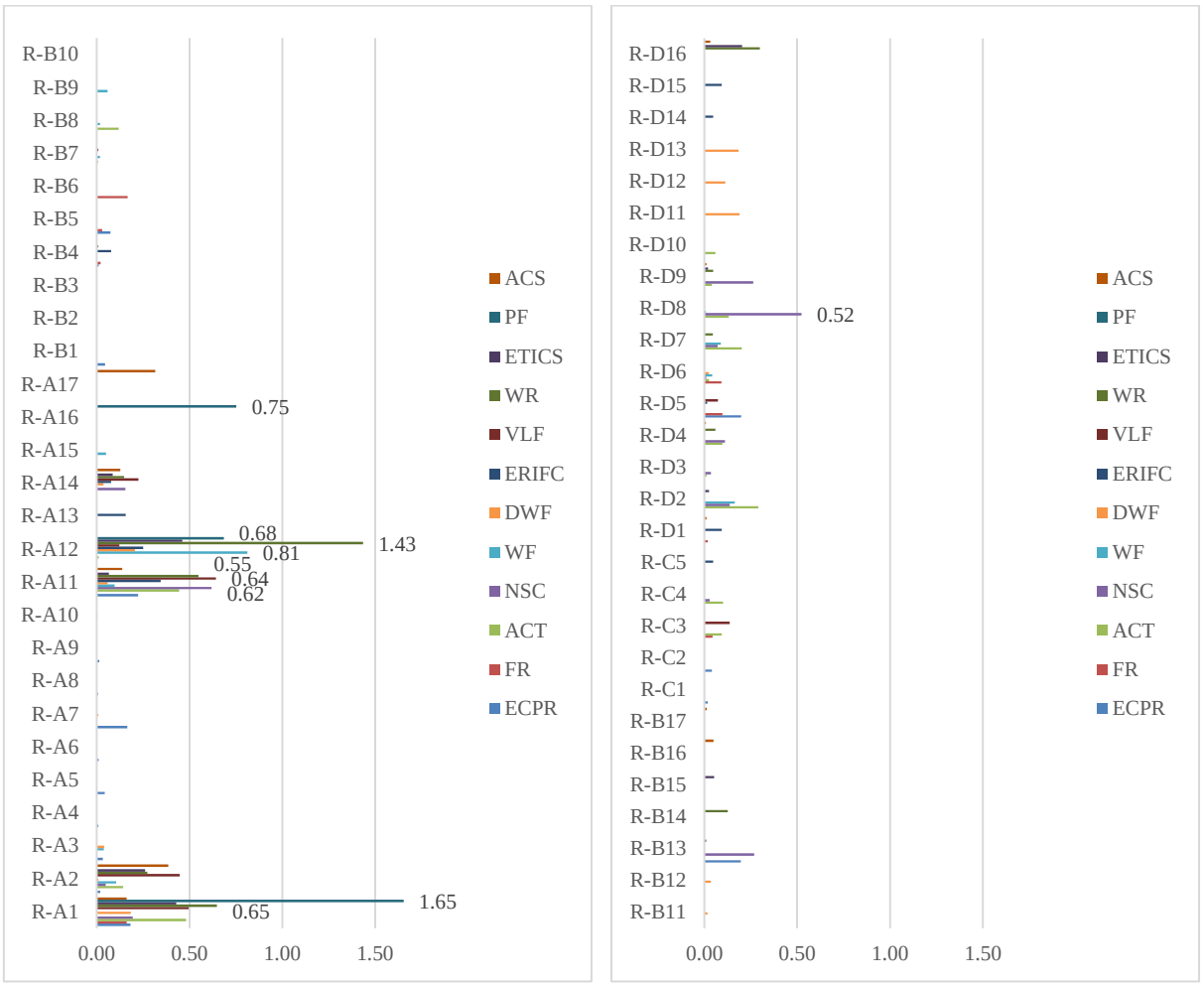

Figure 1. Relative frequency of prescribed repair techniques for detected defects in each expert inspection system.

Due to the adaptation to the global classification list, Figure 1 values may result from the sum of absolute frequencies, referring to the union of repair techniques from each expert classification list.

The highest relative frequency in Figure 1 refers to the prescription of "R-A1 Cleaning" in painted façades. R-A1 corresponds to four specific techniques in the expert inspection system of painted façades, which divide the act of cleaning in different operations, namely (Pires *et al.*, 2015a): scrubbing/dusting, manual washing with water and a sponge, washing with a low-pressure water jet, and chemical cleaning. As the result in Figure 1 (1.65) comes from the sum of four absolute frequencies, it exceeds the number of detected defects. It may be interpreted that, in many occurrences, more than one type of cleaning operation was prescribed considering (i) the combination of different activities for better results, or (ii) the prescription of different types of cleaning operations allowing the selection of the best method by decision-makers taking the available equipment and staff into account. Additionally, in the sample of Pires *et al.* (2015b), the category of anomalies referring to stains represents about 46% of all detected defects, partially explaining the recommendation of a high number of cleaning operations. Finally, cleaning a painted surface may frequently be considered as preliminary work to prepare the surface for further repairs.

"R-A12 Application of a new (adequate) cladding/finishing coat over the existent/replacement" is highly recommended in wall renders. Again, the value in Figure 1 (1.43) results from the sum of the absolute frequency of three repair techniques from the wall renders' expert classification list: full/partial replacement of the finishing coat, application of a new finish coat over the existing render, and application of cladding over the existing render (Sá *et al.*, 2014). Considering that inspected renders were protected with a paint coating, and the average age of the sample of buildings is 27 years (Sá *et al.*, 2015), many likely lacked maintenance or repainting according to the standard service life of paint coatings in façades—an average of 8.5 years, according to Chai *et al.* (2015). Additionally, in the sample of Sá *et al.* (2015), the cause referring to an irregular repainting periodicity was the most often identified among the group of wear and maintenance faults.

In general, observing Figure 1, it may be concluded that repair techniques in category "R-A Surface of the cladding" are the most commonly prescribed. The outer layer of a building element is the most exposed to aggressive agents. Furthermore, its integrity is of high importance to protect the conditions of the building element and the whole building.

4 Conclusions

The use of a single list of repair techniques in the context of building inspections is user-friendly for surveyors and contributes to the standardisation of inspection procedures and the improvement of communication between players in the construction sector. Such a single list of repair techniques may also be useful as it determines the general scope of repair techniques that should be expected within a maintenance plan, namely for this selection of twelve materials used in the building envelope. Additionally, analysing frequency data on the prescription of repair techniques allows building owners and maintenance managers to prepare the staff for the execution of the most common procedures, training workers and acquiring adequate equipment while balancing costs and benefits.

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