Discussion of proactive maintenance strategies in façades' coatings of social housing

Received (in revised form): 11th May 2009

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ABSTRACT Façades should meet the users' needs, assuring a good global performance during their service life. Proactive maintenance is becoming increasingly crucial to the rational management of buildings and to reducing global expenses. It offers clear advantages over reactive maintenance, that is interventions which take place after several complaints or in emergencies. Proactive maintenance of building elements helps to create mechanisms to prevent and/or control their deterioration, through the implementation of maintenance actions that are both reliable and economic. This paper discusses a technical and economic analysis that compares three proactive strategies (preventive, predictive and improvement) for two types of coatings typically used in maintenance interventions of façades of social housing units in Lisbon: emulsion, and elastomeric coatings. Finally, crucial parameters to reduce the uncertainty and ensure the reliability of technical and economic analyses for each maintenance strategy are established and discussed. This methodology, the result of 2 years' academic research (Flores, 2002), is intended to help clients, users, practitioners (especially maintenance managers) and decision-makers in their choice of façade intervention (type, frequency and cost estimate) at the buildings' design and post-occupancy phases.

Journal of Building Appraisal (2010) **5**, 223–240. doi:10.1057/jba.2009.21

Keywords: maintenance costs; painting; coating; building envelope; life-cycle cost

INTRODUCTION

As façades are the most visible part of a building, they are closely linked with the urban environment. International standards (ISO, 1984, 1986), European Construction Products Directive (CPD, 1989) and other publications, international (CSTB, 1989; Foliente, 2000;

Chew and Pin, 2003; ECBCS, 2003; Lacasse, 2003) and national (Alves and Sousa, 2003), have helped to establish performance parameters for façade elements that meet users' requirements. Table 1 summarizes façades' attributes and functions, on the basis of current technical standards.

Portuguese national statistics (INE, 2001) specify façades, structures and roofs as the building elements that are most often the focus of case studies owing to serious deterioration. Façades are constantly affected by the effects of climate and atmospheric pollution, which aggravate the degradation rate, with the likelihood of serious implications to user comfort and safety. A degraded facade is a source of non-functionality problems within the building, through damp and water leakage, and is also dangerous, thanks to the possibility of stone plates or ceramic tiles becoming detached.

The six most frequent sources of premature deterioration in exterior cladding systems (cementitious stucco, synthetic cladding and ceramic mosaic cladding) are: (1) faulty design; (2) inadequate application; (3) substandard quality of materials; (4) adverse climate or atmospheric conditions; (5) poor maintenance; and (6) intensive use (Shohet *et al*, 2002). The main causes of problems with building façades in Portugal are deficient detailing, a bad choice and application of materials, and lack of maintenance. The lack of maintenance may be because of the existence of inadequate rental policies for urban dwellings that hinder ongoing maintenance and rehabilitation (Flores, 2002). It is suggested that legislation proposed by the local municipal government and in principle useful in promoting adequate refurbishment policies for urban dwellings quite often remains unfulfilled.

A façade's overall performance will be improved with a sound knowledge of the durability of design solutions (long-term performance), so that appropriate materials are prescribed and reliable maintenance strategies implemented (Flores-Colen *et al*, 2004).

The assurance of long-term functional performance (that is durability) and maintenance efficiency imply compliance with functional requirements during the construction elements' life cycle under in-use conditions. In this context, the requisites that have to be met during the service life of each façade element (systems, assemblies and components of walls and glazed areas) must be stipulated, and acceptable limits defined for the performance requirements (for example deformability under the direct action of the wind, surface drying, permeability to air and water, thermal resistance, and durability) (estb. 1989).

Table 1: Façade attributes and functions

<i>Attributes</i>	<i>Functions</i>
<i>Integrity and security</i>	
Mechanical resistance and stability	Provide strength and rigidity
Safety in the event of fire	Control fire performance
Safety in use	Be safe and suitable for specified uses
<i>Habitability</i>	
Hygiene, health and the environment	Control rain penetration, water vapour flow and dampness
Protection against noise	Control noise
Energy economy and heat retention	Control heat flow, air flow, light, solar and other radiation
<i>Sustainability</i>	
Durability and serviceability	Be durable and fulfil user requirements during service life
Economy and global cost	Have an optimum total cost
Aesthetic quality	Be aesthetically pleasing
Maintainability	Be operationally effective in three aspects (end-user expectations, operation and maintenance)
Flexibility	Provide flexible and functionally adapted design solutions
Friendly environment	Generate a minimum environmental impact

These limits can be established on the basis of experience, testing and modelling (Lacasse, 2003; Flores-Colen *et al.*, 2006).

Maintenance is now a major phase in the life cycle of built assets and its management plays a major role in the performance of buildings (Lavy and Shohet, 2004). Maintenance may be defined as the combination of all technical and associated administrative actions undertaken during the service life to retain a building or its parts in a state in which it can perform its required functions (ISO, 2000).

Regular, planned maintenance is increasingly crucial to the rational management of buildings. It reduces the occurrence of emergency remedial actions in seriously degraded elements and helps cut overall expenses. This type of maintenance is known as 'proactive maintenance' (Brito and Branco, 2001) and it is clearly better than reactive maintenance (or curative or corrective maintenance) (Cabral, 1998), where intervention only occurs after several complaints or in emergencies.

For these reasons, maintenance planning must be included in the design phase, with the choice of durable technical solutions (appropriate technical solutions intended to provide for long-term performance), and it should be followed during the post-occupancy phase by the continuous evaluation of the results in terms of global costs and user satisfaction.

PROACTIVE MAINTENANCE STRATEGIES

Proactive maintenance strategies are crucial to intervention planning for building elements (structure, finishing and facilities). They are implemented in order to avoid failure and to control degradation by locally correcting the existing anomalies through the combination of several maintenance operations: inspection; cleaning; local repair; local replacement, or preventive treatment) (Flores, 2002).

Three different proactive maintenance strategies are proposed and discussed in this paper, viz., preventive, predictive and improvement strategies. These three strategies are then discussed in respect to both technical and economic aspects, the later focusing specifically on comparative maintenance costs.

Preventive maintenance strategies

Preventive maintenance strategies (PREVMS) are planned, cyclical maintenance actions that involve cleaning, local repairs, local replacements and/or preventive treatments (Figure 1). They reduce non-planned activities, with consequently less interference with the normal use of the building, and allow global costs to be estimated. They should start at the design phase by forecasting each element's performance over time based on technical and structured information related to degradation models, type of end-user and climate service conditions. Subsequent assessment of the elements post occupancy performance makes it possible to examine the interventions planned at the design phase (performance predicted) in the light of the elements' actual in-use needs.

Predictive maintenance strategies

Predictive maintenance strategies (PREDMS), also referred to as condition-based maintenance strategies (Cabral, 1998), include the planning of cyclic inspections. Further maintenance actions are planned after inspection depending on the elements' degradation level (condition state) (Figure 2).

These strategies are effective at reducing unexpected anomalies and are easier to implement in practice than the PREVMS. Regular inspections are carried out to monitor the performance of the design solutions over time and their performance after any

Figure 1: Example of a preventive strategy with two cleaning actions and one repair action, adapted from Perret (1995).

Figure 2: Example of a preventive strategy with two inspections, one cleaning action and one repair action.

intervention. This procedure contributes to the implementation of maintenance strategies that are more realistic and better adapted to the elements' in-use performance.

PREDMS will only succeed, however, if reliable diagnosis methods are used. These, in turn, are dependent on the level of technical knowledge and the extent of resources available. They are particularly suitable for elements made of non-traditional materials, for which the present lack of experience indicates a more conservative approach to planning maintenance operations (Flores, 2002).

Improvement maintenance strategies

Improvement maintenance strategies (IMPRMS) may be indicated after an inspection and generally arise when a certain element does not properly fulfil the pre-established requirements or when serious flaws are found in element design or installation (Figure 3). These strategies focus on replacing one or more existing elements with others more

Figure 3: Example of an improvement strategy after one inspection (Flores, 2002).

appropriate to certain in-use conditions (for example to improve an enclosed space's thermal insulation). Elements are improved as technological advances emerge with new materials and the adoption of alternative solutions, which at the same time meet existing users' expectations (more demanding requirements).

TECHNICAL-ECONOMIC ANALYSIS OF MAINTENANCE STRATEGIES

Interventions in social housing façades

Several interventions on façades of social housing stock were observed in the field in the last 6 months of 2001. Interventions were carried out on 59 buildings located in Lisbon, Portugal, in this period, in three sites: Boavista, Horta Nova (both in centre of Lisbon) and Flamengo (in the northern part of Lisbon) (Figure 4). The characteristics of the buildings that underwent maintenance interventions are summarized in Table 2.

These developments are managed by a municipal body, Gebalis. This organization claims that the rehabilitation and conservation of buildings' envelopes have improved the image of social housing in Lisbon and have helped improve user behaviour (Figure 5). A 2003 study of 374 housing units has discussed how the image, appearance and visual composition of buildings affect residents' attitudes to their environment. It concluded that user satisfaction is independent of the economic and education characteristics of the end-users (Reis and Lay, 2003).

The two main objectives of these interventions in the façades, roofs and internal areas were:

- Conservation, without changing the initial design, including removing peeling render; treating cracks wider than 1 mm with polymeric mortar (Figure 6); cleaning the façades with water jetting and brushing; treating the substrate with a primer to improve adherence between coats, and finally applying an elastomeric coating as finishing (coating with UV resistant, flexible, waterproof thermoplastic polymer); in Horta Nova the varnish applied in an intervention in 1998 was removed (Figure 7);
- Improvements, usually in older buildings, upgrading the initial design to improve habitability conditions, including earlier work, enclosing outside clothes-lines (Figure 8) and replacing window-frames and shutters.

Figure 4: Interventions in social housing building façades in three locations in the city of Lisbon, Portugal, managed by a municipal body, Gebalis.

Table 2: Characteristics of buildings having maintenance interventions

Characteristics	Social housing stock in Lisbon (centre and north)			
	Horta Nova	Flamenga	Boavista	
			Boavista 1	Boavista 2
Date of construction	1993	1980	1980	1990
Number of buildings intervened on	22	15	18	4
Average number of floors	6	5	5	5
Existing structure and walls	Concrete structure with non-load bearing wall (brick cavity wall)			
External walls finishing	Cementitious renders (made on-site and applied in three coats by hand) finished with resin emulsion coating (different colours). Façades of Flamenga housing site also have areas of concrete finishing. Façades of Horta Nova housing location façades have ceramic tile finishing in some areas at ground level.			
Previous maintenance interventions	Treatments of cracks with varnish (1998)	—	—	—
Degradation (anomalies)	Water leakage, cracks	Corrosion, cracks, insulation problems, water leakage	Balcony problems, insulation problems, water leakage	Cracks, water leakage problems

The data collected in the field revealed the relationship of different façade interventions and cost, loss of performance, degradation levels (extent of anomalies) and type of use. Among the conclusions were (Flores, 2002):

- Façade interventions account for a significant amount of the buildings' global interventions; an average of 25 per cent concerned conservation and 60 per cent involved improvement works; another study concluded that interventions in a

Figure 5: The comparison of two façades in Horta Nova social housing stock: before (left) and after (right) the intervention in 2001.

Figure 6: Treating cracks wider than 1 mm with polymeric mortar in Flamenga façades.

building's envelope (façades and roofs) represent in average of 66 per cent of the total costs (Pontes, 1990);

- The elastomeric coating represented a significant amount of the total costs for façades (Figure 9), but it was lower in improvement works (Flamenga and Boavista 1 housing stock); this type of coating improves the performance of an existing coating (emulsion coating) in terms of water and cracking resistance, providing better waterproofing of external walls (Veiga, 1996); this strategy is considered an IMPRMS.

Discussion of proactive scenarios

Proactive maintenance strategies depend on the specificity of each façade element analysed. The cases studied in this paper have come from a broad scoped study in which different proactive maintenance strategies were compared. Five façade finishes currently used in Portugal were studied: (i) cementitious renders, (ii) elastomeric coating, (iii) emulsion coating, (iv) ceramic tile mosaic, and (v) natural stone (Flores, 2002).

A technical and economic analysis was undertaken to compare various proactive strategies for two coatings used for the maintenance of social housing façades. These

Figure 7: Previous maintenance intervention in Horta Nova façades (treatments of cracks with varnish in 1998).

Figure 8: Enclosing outside clothes-lines and replacing window-frames and shutters, in Boavista façades.

Figure 9: Distribution of operations' costs as a percentage of façade maintenance interventions costs.

Table 3: Factors included in estimated service life

Coating type	Factor value								
	ESLC ^a	RSLC	A	B	C	D	E	F	G
Elastomeric coating	12	15	1.0	1.0	1.0	1.0	1.0	0.4	0.4
Emulsion coating	6	7	1.0	1.0	1.0	1.0	1.0	0.4	0.4

^aESLC=RSLC×A×B×C×D×E×F×G; where ESLC (estimated service life); RSLC (reference service life);

A (quality of component); B (design level); C (work execution level); D (indoor environment);

E (outdoor environment); F (in-use conditions); G (maintenance level).

Notes: A, B, C, D, E=1 (standard conditions); F, G=unfavourable conditions of use (social housing) and maintenance (lack of maintenance and/or inadequate repairs).

were an emulsion coating (existing coating, before intervention) and an elastomeric coating (coating used in maintenance intervention).

This analysis provided the following initial data (based on experience and on national and international research) that allow the characterization of three proactive maintenance strategy scenarios (preventive, predictive and improvement).

Service life values

The initial service life values were determined by applying the factorial method described in ISO 15686 (2000) to each coating, assuming a reference value for service life based on the manufacturer's data (technical catalogues). The estimated service life and specific factors' values are given in Table 3, based on information provided in ISO 15686 (2000), and related guides (AIJ, 1993).

Performance – degradation models

Coatings on façades have two purposes. First they must protect the walls (primary function), especially if the façades are exposed to harsh weather conditions. Second, they have a beneficially aesthetic effect on what are often not very attractive surfaces (Schmid, 1988).

Performance-degradation models are characterized according to the identification of current degradation mechanisms, anomalies and external agents (that is mechanical, electromechanical, thermal, chemical and biological agents (ISO, 2000). A field survey

helped to pinpoint patterns of long-term performance loss and deterioration based on a systematic evaluation of the physical and visual degradation of buildings' cladding systems. Four patterns were noted that were typical of the main mechanisms responsible for the symptoms observed in cladding systems, and these were convex, linear, s-shape, and concave patterns (Shohet *et al*, 1999).

In the analysis presented in this paper, the loss of performance over time is represented by qualitative curves that relate, for the first cycle of service life, the variation of the coatings' performance levels, the degradation rate and maintenance operations involved. These models (convex curves) are intended to characterize the loss of protective action of each coating, associated with physical and chemical degradation (first – formation of cracks, from fine hairlines to deep cracks; second – peeling and flaking of the coating and deterioration of appearance). The curves presented in this analysis are characterized by a degradation rate that increases slowly from the beginning (≈ 4.5 per cent) until the end (≈ 8.0 per cent) of the life cycle.

The end of service life is reached when the coating has a performance level of 20 per cent of the initial performance, considered here to be the level of quality that still meets the coating's essential functional requirements under maximum degradation.

Maintenance operations

In this analysis, four maintenance operations were considered for each coating, associated with different degradation levels and maintenance costs (Flores, 2002):

- No maintenance operations;
- Cyclic cleaning operations (frequency of $1/4 \times \text{SLR}$), SLR is the estimated service life for the minimum level of quality, that is 20 per cent of the initial performance;
- Cyclic minor repairs (frequency of $1/3 \times \text{SLR}$), interventions on 10 per cent of the whole façade area;
- Single extensive repair work (at $2/3 \times \text{SLR}$), interventions on 35 per cent of the whole façade area.

It was assumed that the cleaning operations did not affect the performance level but did slow the degradation rates, although the repairs improved the performance by about 15 per cent (minor repairs) and 40 per cent (extensive repairs).

Life-Cycle Cost analysis

The Life-Cycle Cost analysis is a relatively simple approach to minimizing coating maintenance costs. The total cost for a particular maintenance strategy is compared with the total cost of another strategy. The least cost strategy is considered to be the optimal maintenance strategy for the specific case (Zayed *et al*, 2002).

The costs are calculated for each strategy in current euros, that is, the cost in euros at the time of reference of the analysis (not necessarily today) to determine interventions at a future date. The basic formula used in life-cycle cost analysis can be found in any basic economic textbook (Flanagan *et al*, 1989), using the Equivalent Uniform Annual Cost Method (EUAC) also known as sinking fund, that combines all the costs into a single annual cost AC over the analysis period – equation (1)

$$\text{EUAC} = \sum_{t=0}^N \frac{C_t^{\text{est}_i} (1+e)^t}{(1+d)^t} \frac{d(1+d)^N}{(1+d)^N - 1} \quad (1)$$

where $C_t^{\text{est}_i}$ is the estimated cost for strategy i in year t ; e is the differential prices rate, d is the discount rate, and N is the analysis period in years.

The cost function $C_t^{\text{est}_i}$ includes some of the costs identified as a global cost function for bridges (Branco and Brito, 2004), such as initial costs, inspection, cleaning and repair costs, and replacement costs (repainting walls) – equation (2)

$$C_t^{\text{est}_i} = C_{\text{apl}} + \Sigma C_{\text{inps}} + \Sigma C_{\text{limp}} + \Sigma C_{\text{rep}} + C_{\text{repl}} \quad (2)$$

where C_{apl} represents the application costs, C_{inps} the inspection costs, if applicable, C_{limp} the cleaning costs, C_{rep} is the repair costs, and C_{repl} is the replacement costs. The estimation of various costs (application, maintenance and replacement) was based on average market values (€/m²).

Application of preventive strategies

Table 4 summarizes the values of EUAC and service life obtained for the preventive strategies for emulsion and elastomeric coatings, based on the hypotheses described above. Figure 10 represents the optimal maintenance strategies for the emulsion and elastomeric coatings: no maintenance strategy and cyclic light repairs. The very short service life and low replacement cost of emulsion coating indicate repainting at the end of the cycle without any cyclic maintenance.

Table 4: Values of EUAC (€/m²) and of service life (in years) for preventive strategies

Preventive strategies	Emulsion coating		Elastomeric membrane	
	€/m ²	Years	€/m ²	Years
No maintenance operations	1.85 ^a	5	1.18	10
Cyclic cleaning operations (frequency of 1/4×SLR)	2.23	6	1.35	12
Cyclic minor repairs (frequency of 1/3×SLR)	2.24	15	1.08 ^a	30
Single extensive repair work (at 2/3×SLR)	2.30	8	1.38	16

^aMost optimal strategies, with the lowest value of EUAC for the cases studied.

Figure 10: Preventive strategies: emulsion coating without maintenance (left) and elastomeric coating minor repairs (right).

Table 5 lists the techniques used in previous optimal maintenance strategies for the coatings in order to solve existing anomalies (cracking, swelling, loss of adhesion with scaling and deterioration of appearance).

Application of predictive strategies

The characterization of PREDMS was based on the following inspection frequency (Flores, 2002):

- Inspection a few years after construction to assess the elements' performance and detect premature anomalies (symptoms associated with changes in materials' characteristics);
- Additional inspections, as part of minor repairs strategies, to assess the expected performance and detect possible anomalies resulting from inadequate interventions/repairs;
- Inspection a few years before the end of the life cycle to assess the approach of the minimum level of quality ('imminent loss of functionality').

The characterization of the predictive strategies was based on the models for the previous optimal maintenance strategies. Figure 11 shows two predictive strategies for emulsion

Table 5: Description of operations in preventive strategies in emulsion and elastomeric coatings

Strategy	Service life (years)	Plan of activities (first life cycle)	Interventions (years)
Emulsion coating – without maintenance	5	Façade painting with emulsion coating application (7.481 €/m ²) Cleaning and surface preparation at the end of the cycle (0.997 €/m ²)	0 5
Elastomeric coating – light repairs	30	Façade painting with elastomeric coating application (8.978 €/m ²) Water jetting the coating surface (0.998 €/m ²) Cracks (< 1 mm) treatment by applying the same product. In this case, the area to be treated is on average 10% of the whole façade area (10.974 €/m ²) Cleaning and surface preparation at the end of the cycle (0.997 €/m ²)	0 3, 7, 10, 13, 17, 20, 23, 26 3, 7, 10, 13, 17, 20, 23, 26 30

Figure 11: Predictive strategies: emulsion coating without maintenance (left) and elastomeric membrane with minor repairs (right).

coating (left) and elastomeric coating (right). In both cases it was assumed that a real degradation rate of the coatings' performance was observed on the first inspection (a few years after construction), and that this was 20 per cent lower than that initially assumed in the preventive strategy for each coating (curve T_k – dashed line) leading to an increase of the initial service life – $SLC_{initial}$ (curve T_m – solid line).

In the minor repairs strategy (Figure 11, right) this increases the interval between repairs and service life cycle and reduces overall costs, even with inspections costs included. It was also assumed that the in-use behaviour tendency observed on the first inspection would continue for future inspections (I_i , with $i > 1$). The end of life cycle is reached at the intersection of the degradation curve with the minimum level of quality (20 per cent of initial performance).

Table 6 summarizes the EUAC values and service life of two predictive strategies for emulsion and elastomeric coatings, taking into account the previous considerations. Table 7 shows the operations included in the two predictive strategies.

Application of improvement strategy

The improvement strategy under analysis corresponds to the intervention mentioned in the previous characterization of social housing interventions. In this context, two alternatives can be considered after inspection:

Table 6: Values of EUAC (€/m²) and of service life (in years) for two predictive strategies compared with the correspondent preventive strategies

Coatings	Preventive strategy		Predictive strategy		Strategy characterization
	€/m ²	Years	€/m ²	Years	
Emulsion coating	1.85	5	1.74 (– 7%)	6	Without maintenance
Elastomeric coating	1.08	30	1.04 (– 4%)	37	Minor repairs

Table 7: Description of predictive strategy operations for emulsion and elastomeric coatings

Strategy	Service life (years)	Plan of activities (first life cycle)	Interventions (years)
Emulsion coating – without maintenance, including inspections	6	Façade painting with emulsion coating application (7.481 €/m ²)	0
		Visual observation of degraded areas (cracks, swelling, scaling loss of adherence and degradation aspect) (0.50 €/m ²)	2, 3
		Cleaning and surface preparation at the end of the cycle (0.997 €/m ²)	6
Elastomeric coating – light repairs, including inspections	37	Façade painting with elastomeric coating application (8.978 €/m ²)	0
		Visual observation of degraded areas (cracks, swelling, scaling loss of adherence and degradation aspect) (0.50 €/m ²)	2, 7, 11, 15, 9, 23, 27, 31, 34
		Water jetting the coating surface (0.998 €/m ²)	4, 8, 12, 16, 20, 24, 28, 32
		Cracks (< 1 mm) treatment by applying the same product. In this case, the area to be treated is on average 10 per cent of the whole façade area (10.974 €/m ²)	4, 8, 12, 16, 20, 24, 28, 32
		Cleaning and surface preparation at the end of the cycle (0.997 €/m ²)	37

- Repair the existing coating, accepting a worse performance than initially predicted – emulsion coating (alternative A);
- Replace existing coating with a material with better in-use performance characteristics – elastomeric coating (alternative B); elastomeric membranes (a non-traditional material) are currently used as a corrective and preventive solution to control cracking in plastered and painted façades (Veiga, 1996); the success of this solution depends on the proper detailing, and special care is needed during the application of this material.

The choice of the best alternative should consider all the technical and economic parameters, as in the earlier examples. Alternative A involves applying the coating, its subsequent maintenance, inspection and replacement at the end of the cycle. Alternative B considers applying the initial coating, inspecting and removing the existing coating, applying a new coating, and its subsequent maintenance and replacement at the end of the cycle.

Figure 12 illustrates the scenario for the application of the elastomeric coating ('elastic membrane') instead of repairing the existing emulsion coating ('plastic paint'). In this scenario a real degradation rate of the emulsion coating was detected after the first inspection (I_1) that was 20 per cent higher than the one initially assumed, which corresponds to a shorter SLR (4 rather than 5 years).

Table 8 summarizes the EUAC and service life values for alternatives A and B. Table 9 describes the maintenance operations, costs and frequency for each alternative.

Discussion of results

This analysis has proposed initial data to allow a technical and economic comparison of different proactive maintenance strategies (preventive, predictive and improvement).

The results show that defining preventive strategies for two different coating solutions allows a better characterization of the alternatives in terms of durability, maintenance

Figure 12: Improvement strategy: emulsion coating without maintenance (alternative A) and elastomeric membrane with minor repairs (alternative B).

Table 8: Values of EUAC (€/m²) and of service life (in years) for improvement scenario compared with the correspondent preventive strategy

Existing coating	Preventive strategy (P_p)		Alternative A (P_p)		Alternative B (improvement strategy) (E_m)	
	€/m ²	Years	€/m ²	Years	€/m ²	Years
Emulsion coating	1.85	5	2.28	4	1.42	31.5

Note: P_p – emulsion coating ('plastic paint'); E_m – elastomeric coating ('elastic membrane').

Table 9: Description of operations in improvement strategy

<i>Alternatives</i>	<i>Service life (years)</i>	<i>Plan of activities (first life cycle)</i>	<i>Interventions (years)</i>
A – Emulsion coating	4	Façade painting with emulsion coating application (7.481 €/m ²)	0
		Cleaning and surface preparation at the end of the cycle (0.997 €/m ²)	4
B – Elastomeric coating	31,5	Façade painting with emulsion coating application (7.481 €/m ²)	0
		Visual observation of degraded areas (cracks, swelling, scaling loss of adherence and degradation aspect) (0.50 €/m ²)	1
		Façade painting with elastomeric membrane application (8.978 €/m ²)	2
		Water jetting the coating surface and cracks (< 1 mm) treatment by applying the same product to average of 10% of the whole façade area (11.972 €/m ²)	5, 8, 12, 15, 18, 22, 25, 28
		Cleaning and surface preparation at the end of the cycle (0.997 €/m ²)	31.5

needs and overall costs. These data also help to establish inspection and maintenance plans (crucial for proactive maintenance practice) that include the determination of decision-making, the priority and periodicity of interventions, maintenance operations, and cost estimates (Flores-Colen, 2003).

The results also showed that, compared with the preventive strategies, the predictive strategies lead to an increase of service life and lower EUAC values if, as is often the case, the in-use performance of the coating is better than that initially predicted at the design stage (theoretical performance). This analysis is only viable when it is possible to define the real degradation rate of coating, based on inspection results.

In this analysis, the improvement strategy (alternative B) – replacement of the existing emulsion coating by elastomeric coating – was better than maintaining the existing coating with a worse in-use performance (alternative A). Alternative A indicates a 24 per cent rise in estimated costs in relation to the preventive strategy (emulsion coating without maintenance) and should not be chosen in this case.

The above situation also demonstrated that the initial theoretical performance (preventive strategy) and its inherent costs were totally inadequate in their failure to reflect reality. The cost of replacement with an elastomeric coating would have been avoided if this was the initial design option, particularly if the likelihood of severe service conditions (for example high risks of cracking) was known at an early stage. In conclusion, the choice of appropriate solutions at the design stage can forestall future interventions, extra costs and functional problems, and help to ensure the end-users' satisfaction.

The analysis has shown that the advantages and disadvantages of these strategies depend on the initial hypotheses (structured information and performance knowledge), decision criteria and technical and economic characteristics of each intervention technique.

Finally, Table 10 summarizes the parameters that influenced the uncertainty and reliability of the technical and economic analysis for each proactive maintenance strategy.

Other parameters could be included, depending on initial data and type of analysis. For example, a qualitative assessment of public housing in Singapore identified four categories of factors that affect the service life of external paint finish on plastered facades – weather, material composition of paint used, quality of workmanship, and building characteristics/attributes (Teo *et al.*, 2005).

Table 10: Parameters that influence the uncertainty and reliability of technical and economic analysis for the proactive maintenance strategies

<i>Parameters</i>	<i>PREVMS</i>		<i>PREDMS</i>		<i>IMPRMS</i>	
	<i>Design</i>	<i>Post-occupancy</i>	<i>Design</i>	<i>Post-occupancy</i>	<i>Design</i>	<i>Post-occupancy</i>
Estimated service life values	•	○	—	•	—	•
Models of performance-degradation over-time	•	○	•	•	—	•
Required minimum level of quality	•	○	•	•	—	•
End-user expectations	•	•	•	•	—	•
Maintenance operations						
Cleaning	•	○	—	•	—	•
Repairs	•	○	—	•	—	•
Inspections	○	•	•	•	•	—
Models of maintenance costs	•	○	—	•	—	•
Diagnostic methods	—	—	•	•	•	—
Non-traditional materials	—	—	•	○	—	—
New technologies	—	—	•	○	•	—
In-use environment	•	•	○	•	—	•
In-use performance assessment methods	—	•	—	•	—	•
Construction flexibility	—	—	—	—	•	•

• (primary parameter); ○ (secondary parameter); — (n/a).

CONCLUSIONS

A proactive maintenance strategy reduces the need for subsequent remedial action on elements suffering serious degradation and inadequate repairs/replacement, where poor materials and techniques are chosen and used. This paper has described a technical and economic analysis of three different proactive maintenance strategies for two different façade coatings applied on social housing façades: emulsion and elastomeric. The strategies in question are preventive, predictive and improvement. The methodology, used here for coating materials, is nonetheless suitable, from an academic point of view, for any other construction element.

Preventive strategies should be based on planned cyclic maintenance actions, which include cleaning, local repairs, local replacements and/or prevention treatments, and should take the coating's theoretical performance into account. These strategies reduce non-planned activities and help the calculation of global costs; valid supporting data are required at the design stage (information on performance over time).

Predictive strategies are based on planned cyclic inspections, with further maintenance actions being planned after each inspection. These strategies are extremely helpful at reducing unexpected anomalies and assist the implementation of solutions that are more realistic and appropriate. The strategies adopted at design stage (preventive strategies) are also assessed. The success of predictive strategies does however depend on the diagnostic methods being reliable in terms of technical knowledge and analytical resources. They are particularly useful for coatings made with non-traditional materials, for which the present lack of experience recommends a more conservative attitude to maintenance operations planning.

Improvement strategies tend to involve the replacement of existing elements with others that perform better under specific in-use conditions, and which remedy serious design and execution flaws. These strategies can be adopted when a coating's in-use performance is significantly worse than initially predicted. However, their success requires accurate information about the new material's performance and construction

flexibility, as well as the end-users' expectations. The demand for better performance (for example thermal comfort (Dabija, 2005)) along with technological innovation in façade systems have led to the use of new construction solutions that are more durable and exhibit improved behaviour.

Finally, the choice of the best maintenance strategy must consider certain characteristics of the coating under analysis, such as its in-use performance (anomaly types, degradation mechanisms and service life) and inherent costs. Decision-makers must have as much information as possible about appropriate corrective/preventive techniques, users' expectations and current regulations so that scenarios with real in-use characteristics can be simulated to aid the decision process.

This type of analysis can help clients, users, practitioners and decision-makers working in the building maintenance industry to choose the type and frequency of façade intervention and estimate its cost at a building's design and post-occupancy stages. It can also be applied, with the necessary adaptations, to any of a building's construction elements, thus contributing to a better characterization of its global performance and, therefore, to the optimization of the overall costs. These theoretical modulations of maintenance strategies are, in fact, being used by other authors (Silva and Falorca, 2004) to develop an inspection and maintenance planning model for external thermal insulation composite systems used in the extensive façades of the new buildings of the University of Coimbra, Portugal.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of the ICIST Research Institute from IST, Technical University of Lisbon and the financial contribution of the Foundation for Science and Technology of Portugal towards the doctoral studies of the first author.

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