EXTENDED ABSTRACT

Model of technical management of buildings based on life cycle cost - Case study of buildings facades in Alvalade neighborhood

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Abstract

Nowadays there is a great limitation in terms of the financial resources necessary for the maintenance and rehabilitation of facades. In this way, it is essential to manage these resources in an efficient way, trying to minimize the necessary expenses with these maintenances.

This study aims to contribute to the optimization of these resources, through an analysis of the degradation of building façades and the costs necessary to repair them. For that, a research was done on the history of interventions on facades of 49 buildings located in the Alvalade neighborhood, built at the same time and with the same architecture. After being defined and assigned 4 degradation levels to the facades analyzed, the collected data were modeled through Herz curves, transition matrix, ordinal logistic regression and multinomial logistic regression and analyzed from a financial point of view. From this analysis it was concluded that level 3 presents the best conditions for a facade intervention.

Future developments of this methodology, which analyzes homogeneous facade samples, will be necessary in order to understand how heterogeneity of a sample, used in several studies about facade degradation, can influence the prediction results of the degradation.

1. Introduction

Financial resources available for the maintenance and rehabilitation of infrastructures are always limited, creating a need for efficient resources management and for the ability to predict maintenance actions throughout the infrastructures service life (Costa et al., 2012). An option to optimize these maintenance plans is to understand how the different elements of the construction degrade and to identify the timing and the way in which they should be addressed (Talon, Boissier, Chevalier, & Hans, 2005) (Silva, Gaspar, & de Brito, 2014).

Using life-prediction methods, it is possible to define preventive maintenance plans, improving the performance of buildings and reducing costs (Dias et al., 2014).

For this same reason, in the last decades the models for predicting the service life of constructions and materials have been the object of investigations of several entities such as CIB (*Conseil International du Bâtiment*), RILEM (*Réunion Internationale des Laboratoires et des médecins des Matériaux, systèmes de construction et ouvrages*) or ISO *(International Organization for Standardization*).

One of the non-structural elements of a building that degrades over time is the exterior facing. The present dissertation aims to contribute to the study of interventions in facades of buildings and to the definition of the best moment to do it, from a technical and economic point of view.

For this, an analysis methodology will be developed, which will divide façades by levels of degradation and analyze, for each of these levels, the average period of years necessary for the facade to reach this degradation and also its cost of repair. In this way, it will be possible to determine whether it is more compensatory to intervene in shorter periods of time and at lower costs or whether it is preferable to prolong the period of deterioration of the facades and to carry out deeper and therefore more costly interventions.

2. Service life prediction

In recent years, the methods of predicting the service life of building materials and components have been given particular attention by various entities such as CIB in the W80 commission "*Prediction of service life of building materials and components*", RILEM, in partnership with CIB (CIB W080 / RILEM 71-PSL, CIB W080 / RILEM 100-TSL and CIB W080 / RILEM 175-SLM) or ISO (ISO 15686, Part 1 and Part 2).

The attention that has been given to the study of prediction mechanisms of service life, as mentioned above, mainly from the theoretical point of view, has resulted in a series of works to define technical criteria, such as Bourke and Davies (1997) or Abraham and Wirahadikusumah (1999). In this study, empirical models of determination of the useful life are approached. These can be function-based or data-based. Among these models are the Gompertz, Weibull and Potential curves, the factorial method, logistic regression, the artificial neural networks (ANN), and the Markov Model.

3. Case Study

The selected area is located in the Alvalade neighborhood and it involves 49 buildings. It was decided to restrict the study in both temporal and spatial terms to limit the variability of performance due to differences in materials and construction methods used and external requests.

3.1 Research Methodology

In the municipal archives the history of all buildings initially selected to identify the years of construction and interventions were consulted. This collected data was completed using a photographic register of facades, and a local survey.

3.2 Solar Orientation

In this identification, only the four main orientations - North (N), South (S), East (E) and West (W) were considered.

3.3 Degradation Levels

Four levels of degradation were defined to classify the façades under analysis.

Table 1. Degradation Levels

Deg. Level	Defects	Repair Techniques	Cost (€/m^2)
Level 1	Runoff stains; Small cracks (<0.5 mm).	Washing; Application of primer and final paint.	12.50
Level 2	Runoff stains; Cracks.	Washing; Application of non-retractable mortars; Application of primer and final paint.	17.50
Level 3	Runoff stains; generalized cracking.	Washing; Rendering substitution; Application of primer and final paint.	20.00
Level 4	Runoff stains; Incomplete mortar surface.	Cleaning and passivation of reinforcements; Concrete repair; Substitution of rendering; Application of primer and final paint.	25.00 – 30.00

3.4 Mechanisms of Analysis

In this work, an ANOVA was initially performed to analyze the statistical relevance of façade orientations in their degradation. Subsequently, once the non-influence of the solar orientation was detected, Herz Curves, Transition Matrix and Multinomial Logistic Regression were performed.

3.5 Financial analysis

The financial analysis consists of an initial stage where the prices determined for the year 2017 are converted into the prices corresponding to the year in which this intervention is expected to take place.

The expected year for each of these interventions is calculated through the results obtained in the different statistical models developed in this study and according to two different scenarios:

- Scenario 1 - Considers the maximum transition values for the calculation of the financial indicators.
- Scenario 2 - Considers the average values between levels for the calculation of the financial indicators.

This price update is made through a geometric progression, which determines the cost of intervention in a given year t, using the cost of the same intervention in 2017, through the relation:

$$Cost_t = Cost_{2017}(1 + ta)^{t-2017} \quad (1)$$

The rate to be applied in this update is calculated from the price review formula, calculated for one year intervals.

Once the prices have been converted into the years corresponding to the transitions between levels of each model, the NPC and the EAC need to be determined, which will allow comparisons between the two scenarios.

4. Results

The data collected in the research allowed to make a first analysis of the number of years necessary for a facade to reach a certain level of degradation. These results are presented in the Figure below.

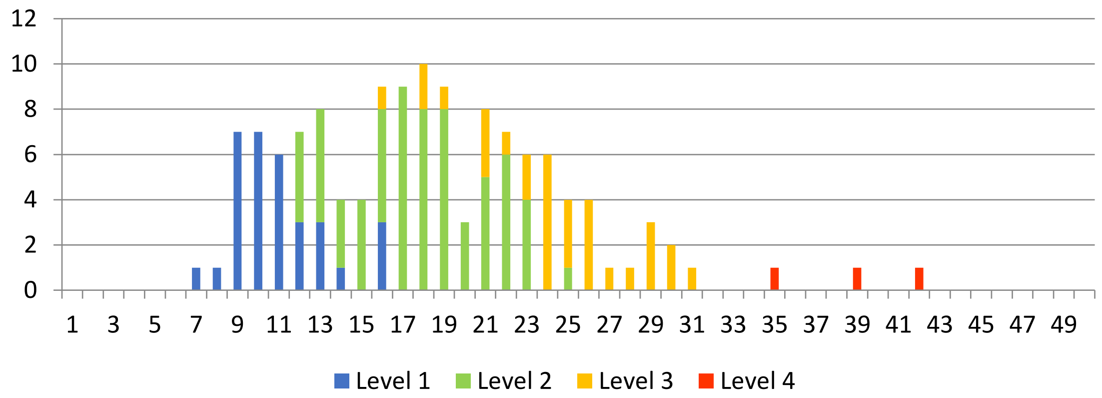

Figure 1. Number of interventions by age (divided by degradation levels)

4.1 ANOVA

Analyzing the results of the posteriori tests, particularly *Games-Howell*, that do not assume homogeneity of the variances, it is observed that there is a statistically significant difference between the ages of North and East oriented facades.

However, in general terms, and considering that the ages of facades may not correspond to the moments of transition between degradation levels, the sample does not show any statistically significant influence of the orientation on facades degradation.

4.2 Herz Curves

The results obtained in Herz curves can be analyzed in the following figure.

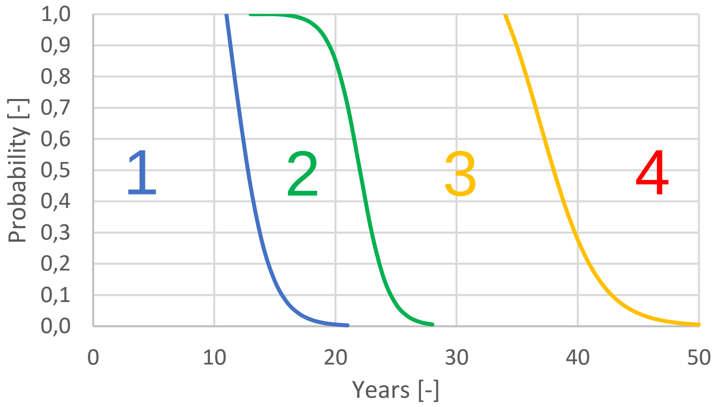

Figure 2. Herz Curves

It is verified that transition between level 1 and level 2 occurs in 10 years, between 11 and 21 years old, with a 50% probability of this transition happening until the age of 13 years. The transition between level 2 and 3 occurs in 15 years and half of the sample transits level up to 22 years. At the transition from level 3 to level 4, there is a 50% probability of this transition occurring up to 38 years.

4.3 Transition Matrix

Figure 4 represents the results obtained in the transition matrix, about the probability of a facade being at a certain level of degradation.

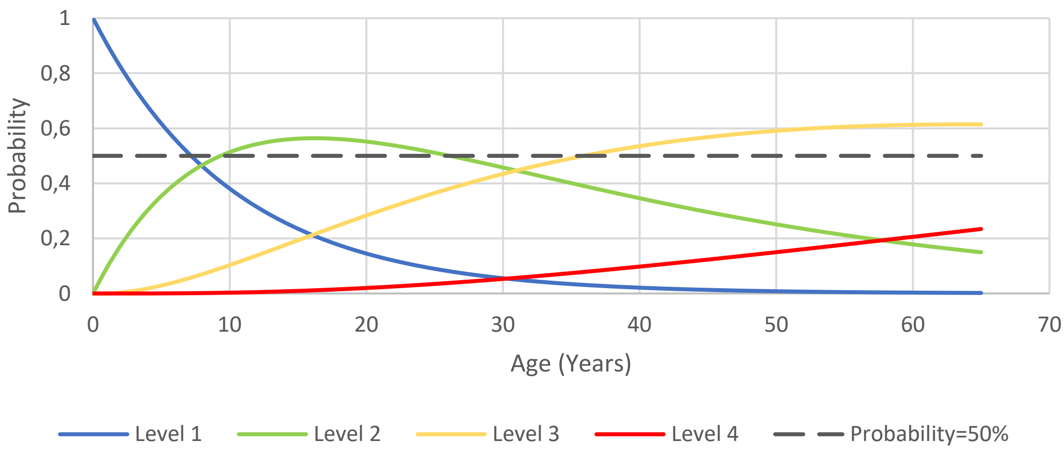

Figure 3. Transition probability (according to transition matrix)

By analyzing this graph, there is a 50% probability that a building will move from level 1 to level 2 after 10 years, from level 2 to level 3 after 36 years and the likelihood of a transition to level 4 never exceeds 50%.

4.4 Multinomial Logistic Regression

This model predicts the level of degradation for each façade analyzed. Comparing the results obtained with the actual results resulting from the research, there is a general success rate of

81.70%. In the table below the percentages of correctness at each level of degradation can be analyzed.

Table 2. Prediction of multinomial logistic regression

Observed	Predicted				
	1	2	3	4	Correct Percentage
1	25	7	0	0	78,10%
2	4	56	5	0	86,20%
3	0	8	23	0	74,20%
4	0	0	0	3	100,00%
Overall Percentage	22,10%	54,20%	21,40%	2,30%	81,70%

The figure below shows the results obtained in the multinomial logistic regression, from the point of view of the probability of a facade being at each level of degradation.

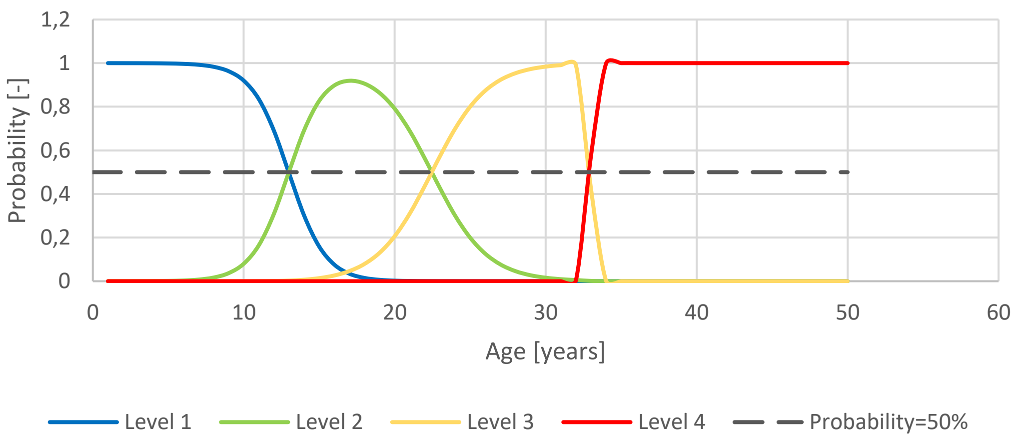

Figure 4. Multinomial Logistic regression

This graph shows that the transition from level 1 to level 2 occurs after age 12, level 2 to level 3 occurs after age 22, and transition to level 4 occurs after age 32.

4.5 Comparative Analysis Between Models

From the results obtained in each model, the following years for the maximum age of each level were determined.

Table 3. Comparative analysis between models

Level	Herz Curves	Transition Matrix	Multinomial Logistic Regression
1	13	8	12
2	22	27	22
3	38	-	32

As shown above, it is possible to see that the transition matrix presents more dispersed results than the Herz curve and the multinomial logistic regression, transitioning earlier from level 1 to level 2 (8 years) and later from level 2 to level 3 (27 years).

It is also possible to verify that there is a convergence of values between the results of Herz curves and the results of multinomial logistic regression. The results of these models differ only in the transition from level 3 to level 4, which can be explained by the reduced number of level 4 facades in the sample.

4.6 Financial analysis

Scenario 1

In this scenario, and based on the results of the different statistical models previously calculated, the following years are used as the maximum transition years. It was considered 45 years old as the maximum age for level 4.

Table 4. Maximum transition years per model

Level	Herz Curves	Transition Matrix	Multinomial Logistic Regression
1	13	8	12
2	22	27	22
3	38	40	32
4	45	45	45

In this way, the NPC and the EAC were determined for each model. The EAC results are expressed in Figure 6.

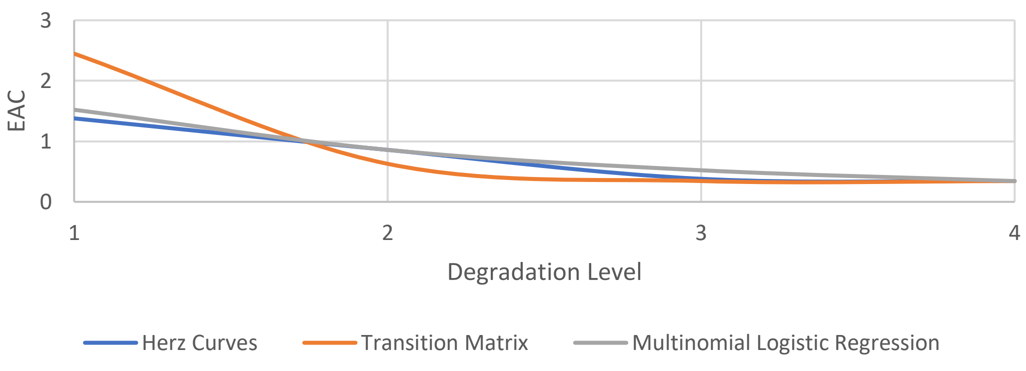

Figure 5. EAC (Scenario 1)

Considering that the cost is always lower for deeper degradation states, and if we only want to choose the ideal moment to intervene a facade that is already in these advanced states, the initial variability verified in the annual cost of the transition matrix acquires a reduced importance and this model becomes the most stable and most appropriate from the financial point of view.

Scenario 2

In this scenario, and based on the results of the different statistical models previously calculated, the following years are used as the average years of each level of degradation:

Table 5. Average years per model

Level	Herz Curves	Transition Matrix	Multinomial Logistic Regression
1	7	4	6
2	18	18	17
3	30	34	27
4	42	43	39

The determined EAC is expressed in Figure 7. Analyzing data on equivalent annual cost, it can be seen that only in level 1 there is a marked difference between the annual costs of performing a facade intervention. In level 2, these values not only approximate considerably in all three models, but have a very low rate of variation, with only a few cents per square meter variation between the intervention in level 3 or level 4.

In this scenario it is verified that, although there is a time when the annual cost is lower in the transition matrix, the low variability between models from level 2 makes the Herz curves model the more favorable since it is the one which presents lower costs in the only phase in which the models vary more between each other.

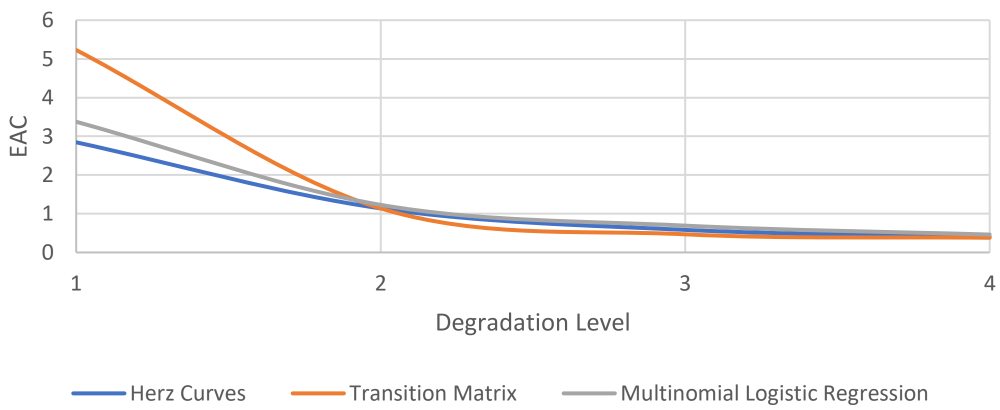

Figure 6. EAC (Scenario 2)

Transition Matrix (Scenario 1) vs. Herz Curves (Scenario 2)

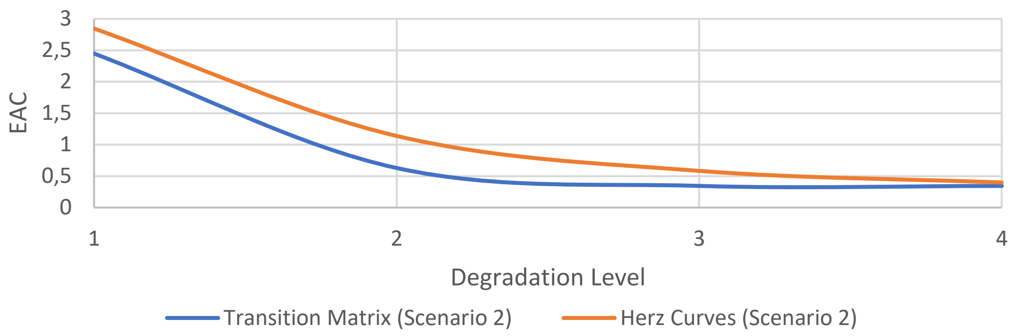

Figure 7. Comparative approach of both scenarios

Analyzing Figure 8, and taking into account that there is a slight stabilization of the curves of the EAC calculations from level 3, it is considered that, combining the aesthetic point of view with the financial criteria underlying this analysis, the level 3 is the one that presents itself as the most favorable to perform an intervention. Degradate for a longer time translates into a slight decrease in the annual cost of intervention, but in a considerable architectural and functional deterioration of the building.

5. Conclusion

The main objective of this study was to contribute to the analysis of the life cycle cost of buildings in the service period, namely in the definition of the most appropriate moments to perform interventions in facades from a technical and economic point of view.

To support this decision, a facade analysis methodology was proposed based on the definition of degradation levels and the determination of the intervention costs associated with them. These elements were supported by a collection of information on the buildings examined, in particular the history of their interventions.

In this study, it was aimed to analyze a group of buildings with similar characteristics and identical construction years. This selection criteria allows to reduce the uncertainty associated with the possible influence of the building materials on the facade degradation, since, assuming small differences in the materials used, this should not be significant, given the identical construction period and the same geographic location.

After comparing the advantageous models in the two final scenarios, and considering a slight stabilization of the curves associated to the calculation of the EAC starting at the third degradation level, it was considered that the buildings in level 3 were in the best moment to be intervened.

This study intends, through a more careful selection of the facades to be analyzed, to determine how the heterogeneity of facades influences the estimated degradations in the different studies carried out in the past. In the future, and as a continuation of the work developed in this dissertation, buildings located in other places and with other construction ages must be studied, always maintaining the homogeneous character of the sample. In this way, and after analyzing several heterogeneous groups composed of homogeneous buildings, it will be possible to assess the possible influence of the heterogeneity of facades in degradation prediction.

References

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