Correlation analysis of pathological manifestations on facades of box buildings: case study in Jaboatão dos Guararapes-PE

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Análise de correlação das manifestações patológicas em fachadas de prédio caixão: estudo de caso em Jaboatão dos Guararapes-PE

RESUMO

Objetivo - Identificar e analisar as manifestações patológicas nas fachadas de prédio caixão com revestimento em pintura, bem como realizar uma análise de correlação para compreender as relações entre esses problemas estruturais.

Metodologia - A metodologia adotada incluiu inspeções visuais detalhadas, criação de mapas de danos, teste de aderência e análise estatística de correlação.

Originalidade/relevância - Identificação das manifestações patológicas através da execução de um mapa de danos e a análise dos dados utilizando estatística, verificando sua normalidade, representatividade de suas médias e a correlação entre as manifestações.

Resultados - Os resultados revelaram a distribuição espacial das manifestações patológicas, destacando áreas críticas e padrões de deterioração significativos.

Contribuições teóricas/metodológicas - A análise de correlação permitiu compreender as interações entre as variáveis estudadas, mostrando que a correlação entre fissura e deslocamento, por exemplo, indica que as fissuras surgem antes do deslocamento, comprovando a análise visual e servindo como um alerta precoce aos moradores.

Contribuições sociais e ambientais - A análise detalhada das manifestações patológicas e a aplicação de testes estatísticos são fundamentais para orientar ações de manutenção e conservação, visando a preservação do patrimônio arquitetônico e o bem-estar das comunidades locais.

PALAVRAS-CHAVE: Manifestações patológicas. Mapa de danos. Prédio caixão. Análise de correlação.

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ABSTRACT

Objective – Identify and analyze the pathological manifestations on box buildings with painted coatings facades, as well as carry out a correlation analysis to understand the relationships between these structural problems.

Methodology – The methodology adopted included detailed visual inspections, creation of damage maps, adhesion testing and statistical correlation analysis.

Originality/Relevance – Identification of pathological manifestations through the execution of a damage map and data analysis using statistics, verifying their normality, representativeness of their averages and the correlation between the manifestations.

Results – The results revealed the spatial distribution of pathological manifestations, highlighting critical areas and significant deterioration patterns.

Theoretical/Methodological Contributions – The correlation analysis allowed us to understand the interactions between the variables studied, showing that the correlation between cracking and spalling, for example, indicates that cracks appear before spalling, proving the visual analysis and serving as an early warning to residents.

Social and Environmental Contributions – The detailed analysis of pathological manifestations and the application of statistical tests are fundamental to guide maintenance and conservation actions, aiming to preserve the architectural heritage and the well-being of local communities.

KEYWORDS: Pathological manifestations. Damage map. Box building. Correlation analysis.

Análisis de correlación de manifestaciones patológicas en fachadas de edificios tipo caja: estudio de caso en Jaboatão dos Guararapes-PE

RESUMEN

Objetivo – Identificar y analizar las manifestaciones patológicas en las fachadas de edificios tipo cajón con revestimientos pintados, así como realizar un análisis de correlación para comprender las relaciones entre estos problemas estructurales.

Metodología – La metodología adoptada incluyó inspecciones visuales detalladas, creación de mapas de daños, pruebas de adherencia y análisis de correlación estadística.

Originalidad/Relevancia – Identificación de manifestaciones patológicas mediante la realización de un mapa de daño y análisis de datos mediante estadística, verificando su normalidad, representatividad de sus medias y la correlación entre las manifestaciones.

Resultados – Los resultados revelaron la distribución espacial de las manifestaciones patológicas, destacando áreas críticas y patrones de deterioro significativos.

Contribuciones Teóricas/Metodológicas – El análisis de correlación permitió comprender las interacciones entre las variables estudiadas, mostrando que la correlación entre agrietamiento y desconchado, por ejemplo, indica que las grietas aparecen antes del desconchado, comprobando el análisis visual y sirviendo como alerta temprana a los residentes.

Contribuciones Sociales y Ambientales – El análisis detallado de las manifestaciones patológicas y la aplicación de pruebas estadísticas son fundamentales para orientar las acciones de mantenimiento y conservación, con el objetivo de preservar el patrimonio arquitectónico y el bienestar de las comunidades locales.

PALABRAS CLAVE: Manifestaciones patológicas. Mapa de daños. Edificio caja. Análisis de correlación.

1 INTRODUCTION

Since the colonial period, the Metropolitan Region of Recife (RMR) has had a tradition of a construction model based on masonry for structural purposes, known as resistant masonry (Azevedo *et al.*, 2023; Mota, 2015). Box-shaped buildings, built using this technique, are characterized by blocks of up to four floors - the maximum number without elevators - which resemble a box on the ground (Branco, 2015). From the 1960s onwards, they became popular due to incentives from the National Housing Bank (BNH) and the growing demand for verticalization combined with cost reduction through the use of this type of masonry (Santos & Sobrinho, 2018; Verdum *et al.*, 2021). However, the lack of standardization led to the emergence of several pathological manifestations and, in some cases, the collapse of these buildings (Figueiredo *et al.,* 2017; Freitas *et al.*, 2024). On facades, mortar with a painted finish is used as a low-cost, quick-to-build, and easy-to-maintain option (Breitbach *et al.*, 2016; Verdum *et al.*, 2021).

The facade comprises the entire vertical external covering of a building and, therefore, most pathological manifestations are found in this area (Costa *et al.,* 2021). Climatic phenomena are one of the main agents of degradation, so that the lack of systemic understanding of these aspects affects the durability and, consequently, the useful life of the building (Freitas *et al.,* 2014; Rodrigues *et al.,* 2023). In addition to the climate, there are factors such as use, design, execution (Azevedo *et al*, 2023; Bauer *et al.,* 2015) or even the occurrence of one manifestation itself can cause the emergence of another (Freitas *et al*, 2024; Souza *et al.*, 2017). Each facade, therefore, can present different performances due to these variables. Junior *et al.* (2021) and Freitas et al. (2024) applied a correlation analysis in their studies on pathological manifestations in mortar coatings. The first compared the damage with the age of the buildings, identifying a strong correlation for detachments, a negative correlation for efflorescence and a weak correlation for cracks. The second investigated the factors that govern the service life, among which the orientation of the facade stood out as the most influential in the durability of this coating.

The mortar must be workable, waterproof, adhere to the substrate, be shock resistant and durable (Carvalho *et al.*, 2017; Freitas *et al.,* 2024), in order to fulfil its functions of regularization, finishing and protection of the substrate against the weather. Painting, in turn, can prolong the performance of the mortar coating, helping to reduce the passage of moisture and the proliferation of microorganisms (Freitas *et al.,* 2024; Neto, 2018). Bersch *et al.* (2021) identified a higher incidence of cracks and dirt in this type of coating, while Rodrigues *et al.* (2023) and Teixeira and Just (2019) observed moisture problems.

The study of damage maps in box-shaped buildings is of fundamental importance due to its relevance in identifying and understanding in detail the main irregularities found, in addition to highlighting the urgency required for intervention in the identified anomalies (Bersch *et al.*, 2021). A damage map can be defined as a graphic representation of the pathological manifestations observed in the buildings studied. These maps are prepared based on information collected during the technical inspection of the buildings, visually and in detail highlighting the location and nature of the problems identified in each element of the building

(Rodrigues *et al,* 2023; Tinoco, 2009). The damage mapping process ensures more precise identification of the manifestations, assisting in assertive decision-making in intervention, recovery, and maintenance activities of the buildings, also enabling a more effective and sustainable conservation process (Vanini & Oliveira, 2023).

The preservation of these buildings is essential, considering their prevalence in low-income areas where residents have limited financial resources. This ensures the safety and comfort of the local population, as well as promoting a better quality of life in less privileged communities.

2 OBJECTIVES

The present study aims to assess the conditions of the facades of a box building, establishing two main objectives: the identification of their pathological manifestations through the execution of a damage map and the analysis of the data using statistics, verifying their normality, representativeness of their averages and the correlation between the manifestation.

3 METHODOLOGY

3.1 Damage Map

The methodology adopted began with detailed visual inspections, during which several pathological manifestations were recorded, such as cracks, dirt, unwanted vegetation and displacement. Each incident was documented, including detailed information on the type of manifestation, location, affected area and date of observation. This data was then organized in an electronic spreadsheet and structured into columns representing the collected variables, which made it possible to create a damage map. The map clearly visualizes the spatial distribution of pathological manifestations on the facades, allowing the identification of critical areas and significant deterioration patterns. Given that there is no specific regulation that defines the criteria for creating damage maps in the country, it was decided to use a color legend in the drawings to represent the pathological manifestations identified (Figure 1).

Figure 1 – Color legend for the damage map

Legenda

Vegetação | Fissuras | Sujidades | Desplacamento do revestimento

Source: Authors, 2024.

3.2 Statistical Tests

A 0.25x0.25m mesh was superimposed on the damage maps prepared, with the aim of quantifying the occurrence of each pathological manifestation on the facades (Figure 2). The density of the mesh was determined based on the scale of the manifestations on the map, aiming to obtain adequate precision in data collection. Thus, the ratio between the quadrants

containing a manifestation and the total mesh resulted in the percentage of the manifestation per facade.

Figure 2 – Mesh superimposed on the damage maps
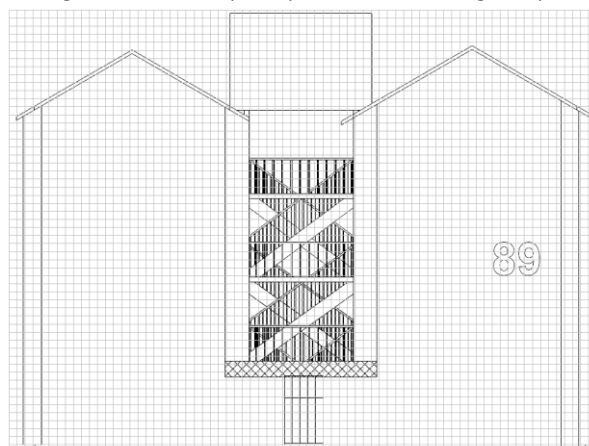
Source: Authors, 2024.

The values found were subjected to a chi-square goodness-of-fit test using the statistical software RStudio (RStudio Team, 2024), in order to identify whether the data distribution behaves normally. Next, the Student's T-test was performed to verify the representativeness of the averages, based on the null hypothesis that "the average of the pathological manifestation on a specific facade is equal to the overall average of the building for this manifestation", with a significance level of 0.05. Finally, the Pearson correlation test was used to measure the strength and direction of the linear relationship between two continuous variables. To analyze the results of the correlation tests, Table 1 was used, where the correlation varies from -1 to 1, and values close to these limits indicate a very strong correlation, positive or negative. A correlation close to 0 indicates the absence of correlation.

Table 1- Interpretation of correlation coefficients

P-value (+ or -)	Interpretation
0.00 a 0.19	Very weak
0.20 a 0.39	Weak
0.40 a 0.69	Moderate
0.70 a 0.89	Strong
0.90 a 1.00	Very strong

Source: Adapted from Hinkle *et al.* (2003)

4 RESULTS AND DISCUSSIONS

The box-shaped building known as Block 89 is located in the Curado 4 neighborhood in Jaboatão dos Guararapes. The block was built in 1978 by the Popular Housing Company of the State of Pernambuco (COHAB-PE), now called CEHAB (State Housing and Public Works Company) (Davidson, 2018). Located in the western part of the Metropolitan Region of Recife, it is

considered a Low Density Zone (ZAB) according to the Zoning Law of the city of Jaboatão dos Guararapes. In ZABs there are restrictions on construction, such as areas for low population density, lower-rise buildings, and it contains areas of environmental preservation. The building was chosen as a case study due to the urgency detected in its structure, since a notice was received from the Civil Defense requesting immediate repairs. Built more than four decades ago, over the years it has been affected by human interventions, lack of maintenance and natural events, resulting in pathological manifestations visible on its facades.

4.1 Damage Map

Based on the photographs obtained during the inspection carried out on the object of study, it is possible to note that all six facades exhibit a variety of structural problems. Due to the symmetry of the facades, their analyses will be organized in pairs, presented as follows: East-West, North-South and internal North-South.

4.1.1 East and West Facades

The pathological manifestations found on the west facade of the building can be seen in Figure 3 below.

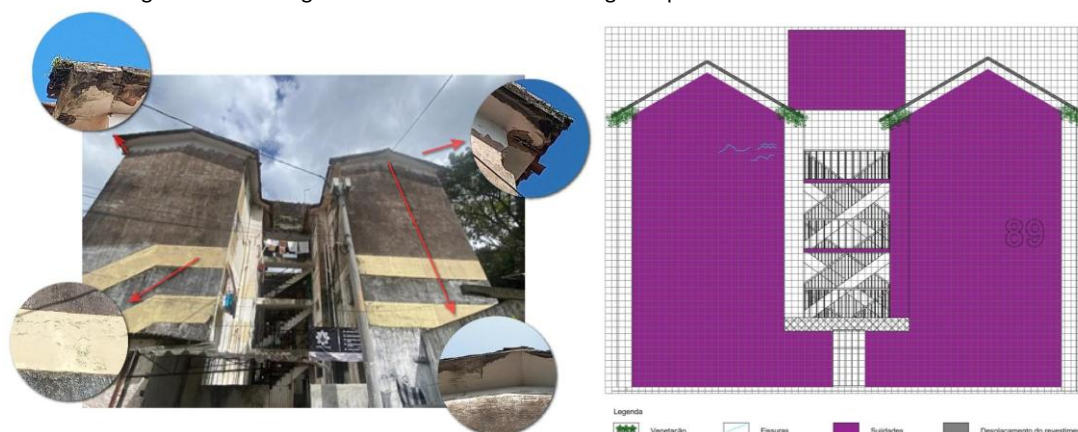Figure 3 – Pathological manifestations and damage map of the west facade of Block 89
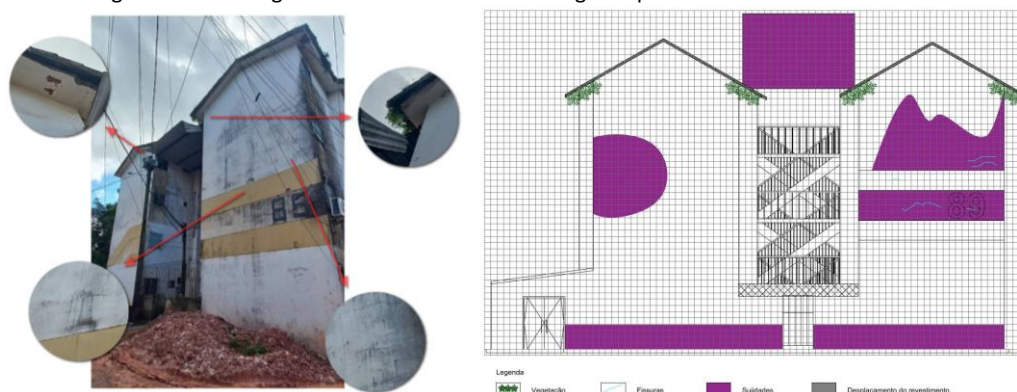
Source: Authors, 2024.

From the images, it is possible to observe a predominance of pathological manifestations in both the upper and lower parts of the facade, corroborating the statements of Bersch *et al.* (2021). The authors highlighted that these areas are frequently affected due to exposure to humidity and the greater incidence of rain and wind. The presence of vegetation, cracks and displacement can be observed in the upper part of the facade. The area serves as a shelter for birds, which leads to the presence of seeds carried by them, causing the emergence of vegetation - which is not considered a serious pathological manifestation, but over time causes infiltration and displacement of the coating (Kusumaningrum *et al.*, 2018; Verdum *et al.*, 2021).

The pathological manifestations found on the east facade are now analyzed, as can be seen in Figure 4.

Figure 4 – Pathological manifestations and damage map of the east facade of Block 89

Source: Authors, 2024.

The images show that the east facade contains more pathological manifestations compared to the west facade. Due to its position, dirt is present in almost the entire area, as it receives more sunlight, wind and rain. Geometrically, the facades are the same and have the same manifestations, differing only in quantity.

4.1.2 Fachada Norte e Sul

The pathological manifestations found on the south facade of the building can be seen in Figure 5 below. The image shows that this facade is significantly affected by the same pathological manifestations as the previous ones, starting with a large area of dirt over a large part of its area due to moisture from rainwater. The contrast of the upper part, which is protected by the roof, can be noted. There is also vegetation on the roof and displacement in the same area with the exposure of the structure's reinforcement.
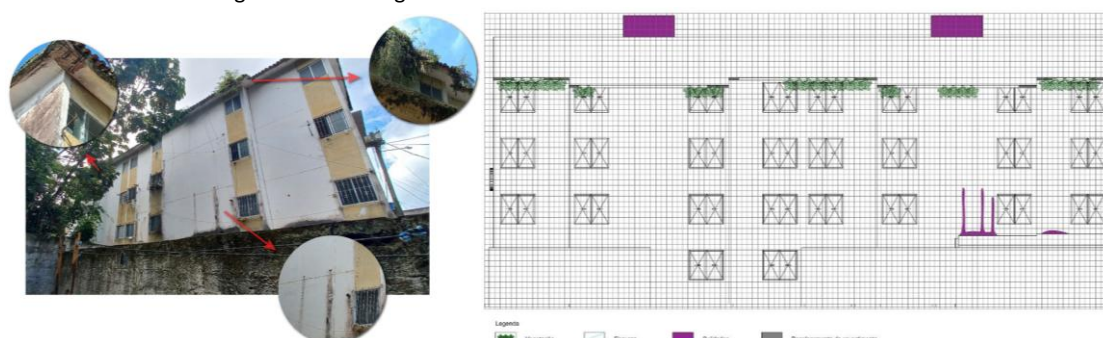
Figure 5 – Pathological manifestations and damage map of the south facade of Block 89

Source: Authors, 2024.

The pathological manifestations found on the north facade of the building can be seen in Figure 6 below.

Figure 6 – Pathological manifestations of the north facade of Block 89

Source: Authors, 2024.

The north facade contains few points of dirt, compared to the other facades studied, because it is in a location more protected from the sun and moisture from rainwater. This is a cleaner facade, but it does contain a build-up of vegetation on the roof. It is also possible to observe the displacement of the slab covering, exposing the reinforcement, cracks and infiltration points due to inadequate holes for fixing antennas on the facade.

4.1.3 North and South Internal Facades

The pathological manifestations found on the building's northern internal facade can be seen in Figure 7 below. Since it is a facade with a large area, it is arranged in four compiled images. It can be seen in the images that the pathological manifestations found on the other facades are repeated, with the presence of dirt, displacement, vegetation and cracks.

Figure 7 - Pathological manifestations of the northern internal facade of Block 89

Source: Authors, 2024.

Figure 8 below shows the southern internal facade. Since it is a large facade, it can be seen in the sequence of images. This facade has a section covered by a metal covering that was installed by the residents themselves. This is not part of the building's original design, but helps to protect the internal facades. It can be seen in the image that this facade has the same pathological manifestations as the others, such as dirt, cracks and displacement. It also shows the presence of vegetation on the roof and exposure of the structure's reinforcement.

Figure 8 - Pathological manifestations of the southern internal facade of Block 89
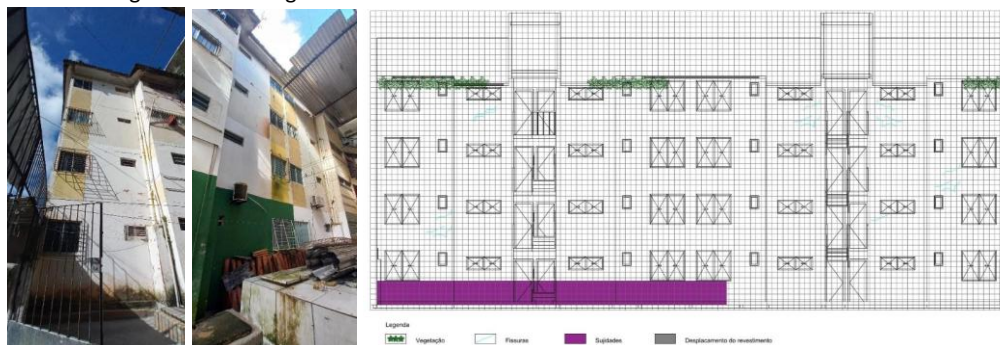
Source: Authors, 2024.

4.2 Statistical Tests

4.2.1 Adherence Test

Based on the mesh superimposed on the damage maps, it was possible to count the occurrence of each pathological manifestation on the facades of Block 89. The results obtained can be seen in Table 1.

Table 1 – Percentage of pathological manifestations per facade

Facade	Vegetation	Crack	Dirt	Displacement
East	1,49%	0,47%	64,61%	2,84%
West	1,58%	0,60%	21,22%	2,52%
North	3,28%	0,00%	2,53%	0,65%
Soutb	3,24%	1,16%	60,31%	0,62%
Internal North	2,40%	1,09%	26,80%	1,42%
Internal South	2,03%	1,29%	5,01%	0,68%

Source: Authors, 2024.

To test the normality of data distribution, the chi-square test of adherence was applied in the RStudio statistical software. Adopting a significance level of 0.05 and starting from a null hypothesis that the data follow a normal distribution and the alternative hypothesis that they do not follow a normal distribution, the p-values were analyzed.

The p-values found for the manifestations were 0.4743 for vegetation, 0.748 for cracks, 0.4924 for dirt and 0.535 for displacement. All data sets have p-values significantly greater than 0.05, and therefore, the null hypothesis that they follow a normal distribution is not rejected.

4.2.2 T-Test

The T-Test was run in RStudio to verify whether the overall mean of the pathological manifestations of the facades represents the mean of the manifestations for the building, as shown in Table 2.

Table 2 - T-Test Results

	VEGETATION	CRACK	DIRT	DISPLACEMENT
Mean	2,34%	0,77%	30,08%	1,45%
T-Test – P-value	1	1	1	1

Source: Authors, 2024.

The observed mean of vegetation (2.34) is within the confidence interval of [1.51, 3.16]. The p-value of 1 indicates that there is insufficient evidence to reject the null hypothesis. Therefore, we can conclude that the mean of vegetation on each facade is not significantly different from the total mean of the building.

The observed mean of dirt (30.08) is within the confidence interval of [1.99, 58.17]. A p-value of 1 indicates that there is insufficient evidence to reject the null hypothesis. Therefore, we can conclude that the mean soiling on each facade is not significantly different from the overall building mean.

The observed mean crack (0.77) is within the confidence interval of [0.25, 1.29]. A p-value of 1 indicates that there is insufficient evidence to reject the null hypothesis. Therefore, we can conclude that the mean crack on each facade is not significantly different from the overall building mean.

The observed mean displacement (1.45) is within the confidence interval of [0.41, 2.50]. A p-value of 1 indicates that there is insufficient evidence to reject the null hypothesis. Therefore, we can conclude that the mean displacement on each facade is not significantly different from the overall building mean.

The t-tests for all pathological manifestations indicate that the observed means on the facades are significantly equal to the overall building means.

4.2.3 Correlation Analysis – Pearson Test

Table 3 presents the results of the Pearson correlation test, organized based on the results of the RStudio software.

Table 3 - Result of the Pearson correlation test

Manifestation	Vegetation	Crack	Dirt	Displacement
Vegetation	1,00000	-0,07130	-0,13240	-0,82870
Crack	-0,07130	1,00000	0,14900	-0,28650
Dirt	-0,13240	0,14900	1,00000	0,40880
Displacement	-0,82870	-0,28650	0,40880	1,00000

Source: Authors, 2024.

The strongly negative correlation (-0.8287) between vegetation and displacement suggests that the presence of vegetation is strongly associated with a lower incidence of displacement. In contrast, the moderate positive correlation (0.4088) between dirt and displacement indicates that dirtier surfaces tend to present higher levels of displacement. This can be explained by the fact that dirt often retains moisture, which can accelerate the degradation and displacement processes of paint and plaster.

On the other hand, the weak negative correlation (-0.2865) between cracks and displacement suggests a slight tendency for surfaces with more cracks to present less displacement. This can be interpreted as an indication that cracks can form before displacement occurs, serving as a possible early indicator of structural problems.

When observing the correlations between vegetation, cracks and dirt, we note that: Vegetation and Cracks, Vegetation and Dirt, Cracks and Dirt: The very weak correlations (-0.0713, -0.1324 and 0.149, respectively) between these pairs of manifestations indicate that there is no significant relationship between these factors. This means that the presence of vegetation or dirt is not directly associated with the appearance of cracks, and vice versa.

5 CONCLUSION

Through visual inspection analysis, it can be concluded that the predominance of pathological manifestations found occurred due to the lack of regular maintenance, which allowed the facades to be exposed to dirt, wind and weather for a long time. Exposure to the sun contributes to the appearance of peeling, resulting from the degradation of paint and coatings, making the affected areas vulnerable to the appearance of vegetation. The pathological manifestations found with the highest incidence on the building's facades were the presence of vegetation, displacement and dirt. The presence of cracks was also identified in smaller quantities.

The use of the damage map proved to be of utmost importance in the precise identification of the abnormalities present in the structure under analysis, helping to ensure that sustainable choices are made in its conservation. The analysis of statistical correlations provides important insights into the interrelationships between different pathological manifestations on the facades of box-shaped buildings.

The positive correlation between soiling and displacement highlights the importance of keeping surfaces clean to avoid more severe degradation. Furthermore, the weak negative correlation between cracks and displacement may indicate that cracks appear before displacement, serving as a possible early warning.

This information is valuable for guiding more effective and targeted maintenance and conservation interventions, promoting more sustainable preservation of buildings. By understanding the extent and severity of damage, it is possible to mitigate potential risks, protecting not only the architectural heritage, but also the safety and well-being of occupants and the community in general. Therefore, studying the damage map using correlation is a crucial step in the process of preserving and properly maintaining these historic structures and housing.

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STATEMENTS

AUTHOR CONTRIBUTIONS

- **Study Conception and Design**: Rayssa Valéria da Silva.
- **Data Curation**: Rayssa Valéria da Silva.
- **Formal Analysis**: Rayssa Valéria da Silva and Mariana Lissa Saruhashi.
- **Grant Obtainment**: None.
- **Investigation**: Rayssa Valéria da Silva.
- **Methods**: Rayssa Valéria da Silva and Mariana Lissa Saruhashi.
- **Writing - First Draft**: Rayssa Valéria da Silva and Mariana Lissa Saruhashi.
- **Writing - Review**: Rayssa Valéria da Silva and Mariana Lissa Saruhashi.
- **Review and Final Editing**: Rayssa Valéria da Silva and Mariana Lissa Saruhashi.
- **Oversight**: Eliana Cristina Barreto Monteiro, Willames de Albuquerque Soares and Bianca M. Vasconcelos.

CONFLICTS OF INTEREST STATEMENT

We, **Rayssa Valéria da Silva, Mariana Lissa Saruhashi, Eliana Cristina Barreto Monteiro, Willames de Albuquerque Soares and Bianca M. Vasconcelos**, hereby state, regarding the paper entitled " **Correlation analysis of pathological manifestations on facades of box buildings: case study in Jaboatão dos Guararapes-PE**":

1. **Financial Interests**: This work does not involve any financial interests that could influence its results or interpretations.
2. **Professional Relationships**: This work does not involve any professional relationships that could affect its analysis, interpretations, or the display of results.
3. **Personal Conflicts**: This work does not involve any personal conflicts of interest related to its contents.