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Evaluation of the pathological manifestations of the Rio Negro Building in Anápolis-Goiás

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ABSTRACT

This paper shows the application of the methodologies GDE (Degree of Structure Deterioration) and GUT (Severity, Urgency, and Tendency) quantifying the pathological manifestations and determining the points of greatest need for maintenance. Thus, a quantitative perspective was used with the application of the previously mentioned methodologies and after building inspections and visual analysis with a photographic record, notes and mappings the methodologies were applied and it was obtained that most of the pathological manifestations that occur in the structure of the building have humidity as origin, resulting in efflorescence, spots or infiltration. Thus, this work defined the points that need priority, directing measures that can later be taken. The methodologies proved to be efficient and important for decision-making.
Keywords: pathology; GUT; GDE; buildings

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Evaluación de las manifestaciones patológicas del edificio Río Negro en Anápolis-Goiás

RESUMEN

Este trabajo muestra la aplicación de las metodologías GDE (Grado de Deterioro de la Estructura) y GUT (Gravedad, Urgencia y Tendencia) cuantificando las manifestaciones patológicas y determinando los puntos de mayor necesidad de mantenimiento. Así, se aplicó una perspectiva cuantitativa con la aplicación de las metodologías citadas y tras las inspecciones del edificio y un análisis visual con registro fotográfico, anotaciones y mapeos se aplicaron las metodologías y se obtuvo que la mayoría de las manifestaciones patológicas que se producen en la estructura del edificio tiene como origen la humedad, dando lugar a eflorescencias, manchas o infiltraciones. De este modo, este trabajo definió los puntos que necesitan prioridad, orientando las medidas que pueden tomarse posteriormente. Las metodologías demostraron ser eficaces e importantes para la toma de decisiones.

Palabras clave: patología; GUT; GDE; edificios.

Avaliação das manifestações patológicas do Edifício Rio Negro em Anápolis-Goiás

RESUMO

Este trabalho mostra a aplicação das metodologias GDE (Grau de Deterioração da Estrutura) e GUT (Gravidade, Urgência e Tendência) quantificando as manifestações patológicas e determinando os pontos de maior necessidade de manutenção. Dessa forma, foi aplicado uma perspectiva quantitativa com a aplicação das metodologias citadas e após inspeções prediais e uma análise visual com registro fotográfico, anotações e mapeamentos, foram aplicadas as metodologias e obtido que parte das manifestações patológicas que ocorrem na estrutura do edifício tem como origem a umidade, resultando em eflorescências, manchas ou infiltrações. Dessa forma, esse trabalho definiu os pontos que necessitam de prioridade, direcionando medidas que posteriormente podem ser tomadas. As metodologias se mostraram eficientes e importantes para tomadas de decisões.

Palavras-chave: patologia; GUT; GDE; edifícios.

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1. INTRODUCTION

The city of Anápolis, located in the Brazilian Central Plateau, in the state of Goiás - Brazil, is a centenary city, which was emancipated on July 31, 1907. As a result, there are old buildings, and more and more of these buildings are close to reaching the project life, because of this fact, it is important to highlight the need for investigations regarding the pathological manifestations and the performance of periodic inspections and maintenance as this makes it possible to prolong the useful life of the building and conserving buildings that are part of the history of the municipality.
The absence of preventive maintenance causes high costs in buildings over time, according to Sitter's law (1984) cited by Tutikian and Pacheco (2013) and also described by Souza and Ripper (2009), as the "law of fives", in which corrective interventions have a cost of 125 times the value of measures still in the design phase, while preventive maintenance has a cost of 25 times the same value.
Thus, as it is a more than 50-year-old building, besides its functional importance for the residents, it is an element that makes up the history of the city of Anápolis for being one of the first residential buildings in the city.
According to Souza and Ripper (2009), the pathology of structures is a branch of engineering that focuses on investigating the origins, forms, consequences, and mechanisms of the manifestations of failures in the structure. Similarly, Bolina, Tutikian, and Helene (2019) define that the "pathology of constructions" is a science, which through a systematic process seeks to investigate defects referring to the building as a whole, from materials to the elements that compose it, to know their origins and how they manifest themselves. The authors also differentiate the concept of pathology from constructions and from pathological manifestations, which are anomalies and defects present in the building that are characterized by being visible aspects indicative of possible problems.
Besides, according to NBR 16747 (ABNT, 2020), pathological manifestations are defined as the result of a degradation process that provides a reduction in the performance of the structure, which is manifested through symptoms.
During execution, other circumstances can lead to the emergence of pathological manifestations, whether in working conditions or related to the workforce, lack of quality control, and technical irresponsibility, a factor that is decisive, since an efficient inspection combined with qualified teams reduces the possibility of errors. Finally, no matter how correctly all the preceding steps are performed, it is possible that the emergence of pathological manifestations is related to improper use or lack of maintenance (Souza; Ripper, 2009). Authors such as Junior, Lima, and Balestra (2013), highlight the importance of periodic maintenance in order to prolong the useful life of the construction, providing better quality and performance of the building.
Furthermore, the concrete is subjected to the actions of the environment throughout the useful life of the building, so that reactions naturally occur that trigger the emergence of anomalies in the structure. In this way, care must be taken to ensure the conservation of the building so that it performs its function correctly over the time for which it was designed. With this in mind, it is essential to study the pathology in order to recognize the problems and their respective causes (Lopes, 2019).
In order to assist in this study, giving greater objectivity to the analysis and serving as a support for decision making, some techniques such as the GDE (Degree of Structure Deterioration) and GUT (Severity, Urgency, and Trend) methodologies can be applied, providing a quantification of the pathological manifestations obtained by the mathematical formulations proposed by the tools, which makes it possible to identify the state of a given structure and guarantee a more objective view for the analysis (Braga et al., 2019; Lima et al., 2019; Moura; Cavalheiros, 2019; Santana et al., 2019; Medeiros et al., 2020).

2. METHODOLOGY

The methodology applied in this work was the evaluation of pathological manifestations through the GDE (2007) and GUT (2014) methodologies. Data collection was carried out through building inspection through visual inspection, *in loco*, making photographic records of the identified pathological manifestations and mapping the anomalies in the plan of each inspected floor. The inspection was based on the descriptions of the National Building Inspection standard of the Brazilian Institute of Engineering Expert Assessments - IBAPE (2012), NBR 5674 (ABNT, 1999), NBR 16747 (ABNT, 2020) and the Technical Bulletin No. 1 of the Brazilian Association of Construction Pathology - ALCOPAT (2013). In addition, all information and documents regarding the building were collected.
Through the GUT methodology (2014) the pathological manifestations were quantified to posteriorly carry out a comparison and indicate the degree of priority for decision making. Through the methodology GDE/UnB (2007), also in order to quantify the pathological manifestations, the parameters of the degree of deterioration of elements, families, and structure were calculated, serving as a basis for the analysis and allowing the classification of the level of deterioration of elements and structure.
Subsequently, based on the literature and with the data obtained, comparison and analysis of the values obtained were carried out.
The tools used for the research were electronic spreadsheets for data organization, a smartphone for photographic records, a scalemeter, a fissurometer, and measuring tape.

2.1 GDE Methodology

Using the GDE methodology, the elements inspected were divided into groups of Pillars (P); Beams (V); Slabs (L); Stairs (E); Upper reservoir (R); Lower reservoir (R), and Expansion joints (J).
After this division, intensity factors (F_i) and weighting factors (F_p) were assigned for each manifestation present in the element, according to the tables present in the work by Fonseca (2007). Thus, it was possible to calculate the degree of damage, according to equations (1) and (2).

$$D = 0{,}8.F_p.F_i \qquad \text{To } F_i \leq 2{,}0 \qquad (1)$$
$$D = (12.F_i - 28)\,F_p \qquad \text{To } F_i \geq 3{,}0 \qquad (2)$$

Where:
D - Degree of damage
F_i - Intensity factor
F_p - Weighting factor

With the degree of damage (D) of each manifestation, the degree of deterioration of the element (G_{de}) is calculated according to equation (3).

$$G_{de} = D_{máx}\left[1 + \frac{\left(\sum_{i=1}^{n} D_i\right) - D_{máx}}{\sum_{i=1}^{n} D_i}\right] \qquad (3)$$

Where:
G_{de} - Degree of deterioration of the element;
D_i - Degree of damage “i”;
D_{max} - Highest degree of damage to the element;
n – Element damage numbers.

A level of deterioration is related to the value of the element's degree of deterioration and thus we obtain recommendations for actions to be taken. This relation can be seen in Table 1.

Table 1. Classification of the level of deterioration of the elements

Deterioration level	**G_{de}**	**Recommended actions**
Low	0-15	Acceptable state Preventive maintenance
Medium	15-50	Define deadline and nature of new inspection Plan long-term intervention (maximum 2 years).
High	50-80	Set deadline for specialized inspection Plan medium-term intervention (maximum 1 year)
Sufferable	80-100	Set deadline for rigorous expert inspection Plan short-term intervention (maximum 6 months)
Critical	>100	Immediate specialized intervention and emergency measures (load relief, shoring, etc). Plan immediate intervention.

Source: (Verly, 2015)

To determine the degree of deterioration of elements divided into similar groups, the degree of deterioration of the family (G_{df}) is calculated, which is a function of the degree of deterioration of the element (G_{de}) through equation (4).

$$G_{df} = G_{de,máx}\sqrt{1 + \frac{\left(\sum_{i=1}^{n} G_{de,i}\right) - G_{de,máx}}{\sum_{i=1}^{n} G_{de,i}}} \tag{4}$$

Where:
$G_{de,máx}$ – Highest degree of element deterioration
$G_{de,i}$ – Degree of element deterioration “i” (≥ 15)
m – Number of elements with $G_{de} \geq 15$

Finally, by obtaining the degree of deterioration of each family (G_{df}), the degree of deterioration of the structure (G_d) is calculated. The equation used for this calculation is expressed below, equation (5).

$$G_d = \frac{\sum_{i=1}^{k} F_{r,i}.G_{df,i}}{\sum_{i=1}^{k} F_{r,i}} \tag{5}$$

Where:
k – Number of families in the structure;
$F_{r,i}$ – Structural relevance factor of the family “i”;
$G_{df,i}$ – Degree of family deterioration “i”.

Thus, for the degree of deterioration of the structure, similarly to the degree of deterioration of the element (G_{de}), an association can be made to a level of deterioration and consequently measures that can be taken in this situation can be obtained. The table applied for this analysis is Table 1, p. 05.

2.2 GUT Methodology

The GUT methodology originated in the 1980s through the work of Kepner and Tregoe with the aim of creating a strategic planning tool to assist in decision-making (Fáveri; Silva, 2016). In civil construction, the work of Verzola, Marchiori, and Aragon (2014) proposed changes in the methodology in order to allow its application in building inspections and reduce the possibility of errors through subjectivity. The methodology uses the variables Severity (G), Urgency (U), and Tendency (T), in which weights ranging from 1 to 10 are assigned, with 1 being assigned to the least severe and 10 to the most severe. Thus, through the product of the variables (GxUxT), a classification is made according to how critical each situation is (Verzola; Marchiori; Aragon, 2014).

Some researchers such as Santana et al. (2019), Moura and Cavalheiros (2019), and Braga et al. (2019) applied the GUT methodology in their research to carry out inspections and identify the most critical points of the building, proving it to be practical and making it possible to define priority for decision-making. According to Verzola, Marchiori, and Aragon (2014), tables 2, 3, and 4 determine the grades to be assigned for each grade according to the variable.

Table 2. Severity (G) classification.

SEVERITY		
Degree	**Degree definition**	**Grade**
TOTAL	Risk of death, risk of punctual or generalized collapse/collapse. Very high financial loss.	10
HIGH	Risk of injury to users, reversible damage to the environment or to the building. High financial loss.	8
AVERAGE	Risk to users' health, discomfort in the use of systems. Average financial loss.	6
LOW	No risk to the physical integrity of users, no risk to the environment, minor aesthetic or usage inconveniences. Small financial loss.	3
NONE	No risk to health, physical integrity of users, the environment or the building.	1

Source: (VERzola; Marchiori; Aragon, 2014)

Table 3. Trend (T) classification

TREND		
Degree	**Degree definition**	**Grade**
TOTAL	Immediate progression. It is going to get worse quickly, it can get worse.	10
HIGH	Short-term progression. It will get worse soon.	8
AVERAGE	Medium term progression. It will get worse in the medium term.	6
LOW	Probable long-term progression. It will take time to get worse.	3
NONE	It won't progress. It will not get worse, stabilized.	1

Fonte: (Verzola; Marchiori; Aragon, 2014)

Table 4. Classification for Urgency (U).

URGENCY		
Degree	**Degree Definition**	**Grade**
TOTAL	Incident in occurrence, immediate intervention subject to interdiction of the property. Intervention deadline: None	10
HIGH	Incident about to occur, urgent intervention. Deadline for intervention: Urgent	8
AVEREGE	Incident expected soon, short-term intervention. Deadline for intervention: As soon as possible	6
LOW	Indication of future incident, scheduled intervention. Deadline for intervention: You can wait a little	3
NONE	Unforeseen incident, indication of follow-up and scheduled maintenance. Deadline for intervention: No rush	1

Fonte: (Verzola; Marchiori; Aragon, 2014)

The grade corresponds to the value assigned to each pathological manifestation according to the associated degree, that is, in total degree, a grade of 10 is assigned, a high degree is grade 8, an average degree gets a grade of 6, a low degree is grade 3 and no degree gets a grade of 1. Thus, the grade is assigned for each variable of the manifestation, and using the product of these values, it is possible to list the problems that have higher priority. Those with greater value deserve special attention, as they are the most serious, and urgent and tend to get worse (Periard, 2011).

3. RESULTS AND DISCUSSIONS

3.1 Pathological manifestations

Mapping was carried out on each inspected floor to facilitate the identification of the elements. Furthermore, the evaluated elements were divided into families as proposed by the GDE methodology (2007). Then, the pathological manifestations identified were presented according to this division.

In the column family, only one element, P01, was identified, and it was possible to notice a great exposure of the reinforcements in the process of corrosion, identifying stains along the reinforcements and detachment of the concrete due to the expansion of the reinforcement, as can be seen in Figure 1.

Figure 1. Detachment of concrete and corrosion of reinforcement in element P01

In the slabs family, elements L01 to L08 were identified, as shown in Figure 2, in which stands out the constant presence of moisture, generating dark spots in element L01, detachment of the paint in element L02, formation of calcium carbonate stalactites, due to efflorescence in element L04, small stains and cracks in elements L05 and L08 and wear of waterproofing in element L03. There are also cracks in elements L06 and L07 due to additional loads applied by a telephone antenna over the roof.

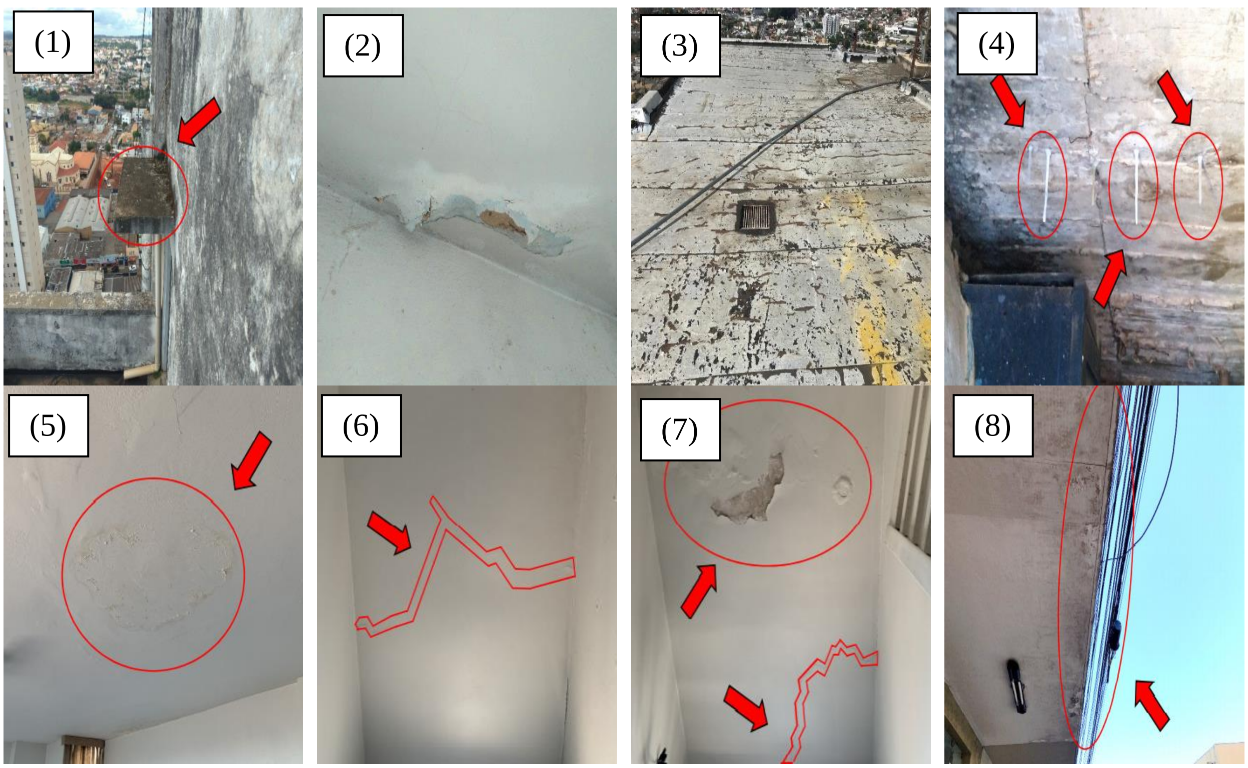

Figure 2. Pathological manifestations identified in the slabs. (1) Dark spots on element L01. (2) Detachment of the ping in element L02. (3) Wear of waterproofing on element L03. (4) Efflorescence with formation of stalactites in element L04. (5) Small moisture spots on the L05 element. (6) and (7) Cracks due to additional loading on the cover, on elements L06 and L07. (8) Dark spots of moisture on element L08.

The upper reservoir family and the lower reservoir family showed possible flaws in their waterproofing, identified by the characteristic appearance of light efflorescence stains on elements R01 and R02.

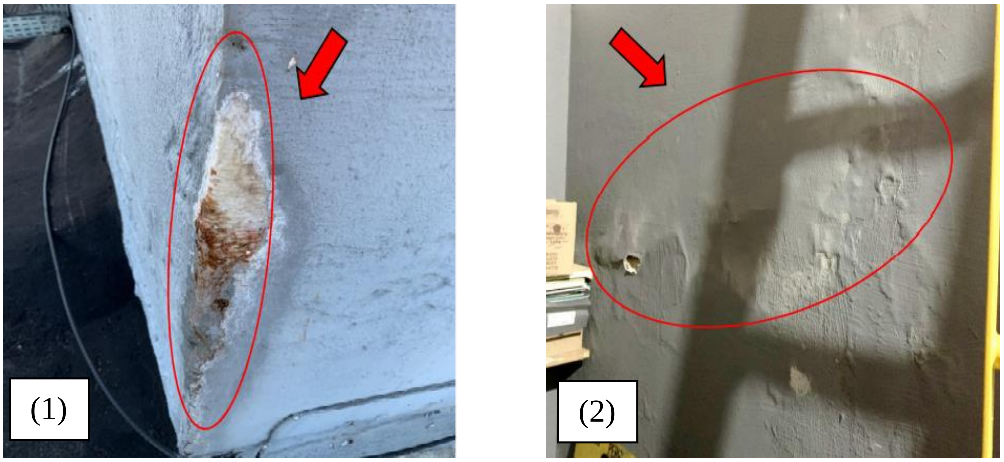

Figure 3. Efflorescence spots in the reservoir. (1) R01. (2) R02.

It is noted that the beam family did not present any element that demonstrated the development of pathological manifestations.
The elements of the family of stairs and expansion joints were E01 for the stairs and J01 and J02 for the expansion joints, as can be seen in Figure 4. In it, it is noted that the element E01 showed only wear on its steps due to the weather over the years and in elements J01 and J02, the constant presence of humidity resulted in the dark spots identified.

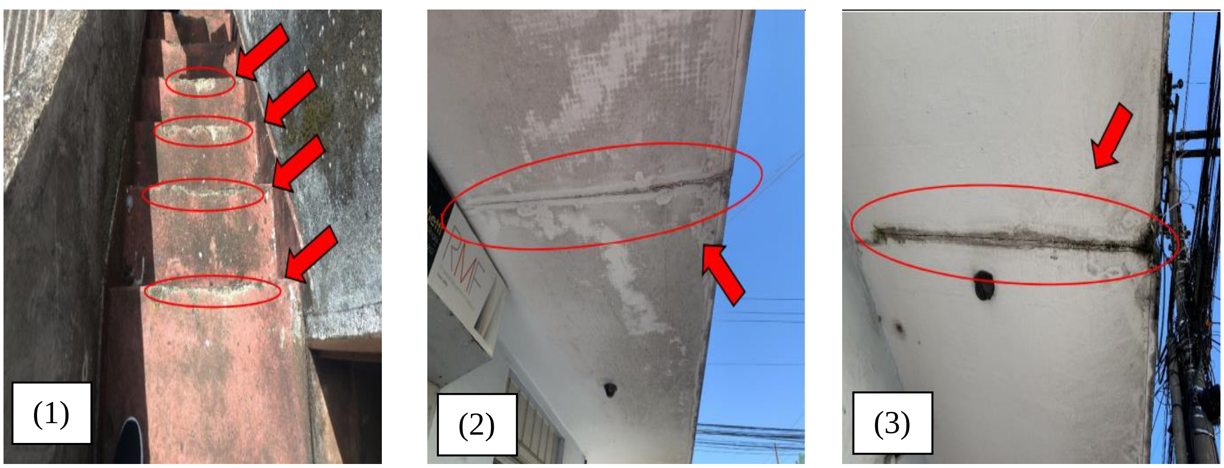

Figure 4. Efflorescence spots in the reservoir. (1) Wear of stair treads on element E01. (2) and (3) Stains due to humidity in elements J01 and J02.

3.2 Application of methodologies and analysis of results

First, it was observed that the family that has the largest number of elements that present pathological manifestations is the slab family, with 57.14% of the identified anomalies, as can be seen in Figure 5.

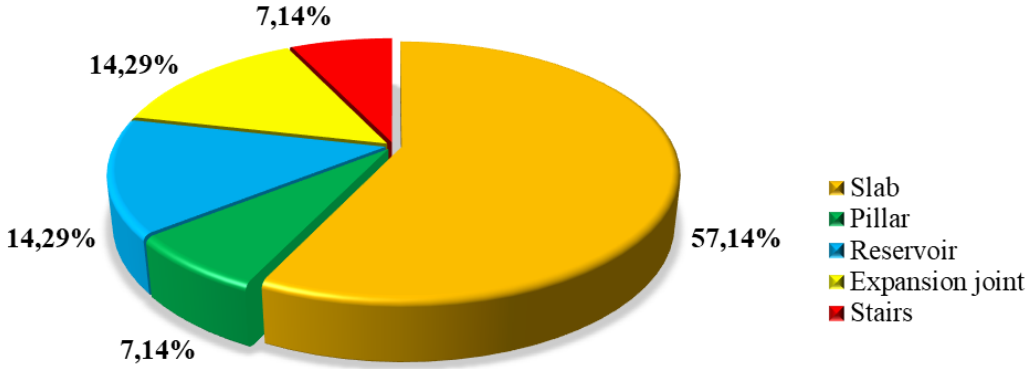

Figure 5. Graph of the frequency of pathological manifestations by family of elements.

Through the mapping of the pathological manifestations that affect the building, it was noticed that in the 14 structural elements inspected, 35.29% of the pathological manifestations are originated due to the infiltration of humidity as we can see in Figure 6. In addition, other pathological manifestations such as efflorescence (17.65%) and dark spots (11.76%) also have a similar cause.

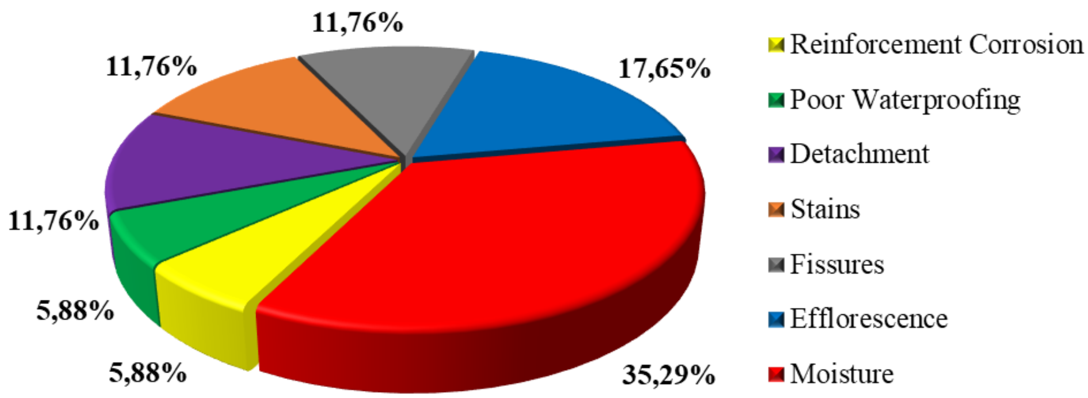

Figure 6. Graph of the frequency of pathological manifestations in the elements.

Regarding the GDE/UnB (2007) methodology, it is possible to raise some analysis based on the graphic model used by Medeiros et al. (2020). In the slab family, elements L06 and L07 are the ones that most influence the calculation of the degree of deterioration of the family, as can be seen in figure 7. In addition, it is worth noting that element L05 is not taken into account for the G_{df} calculation for presenting G_{de} less than 15.

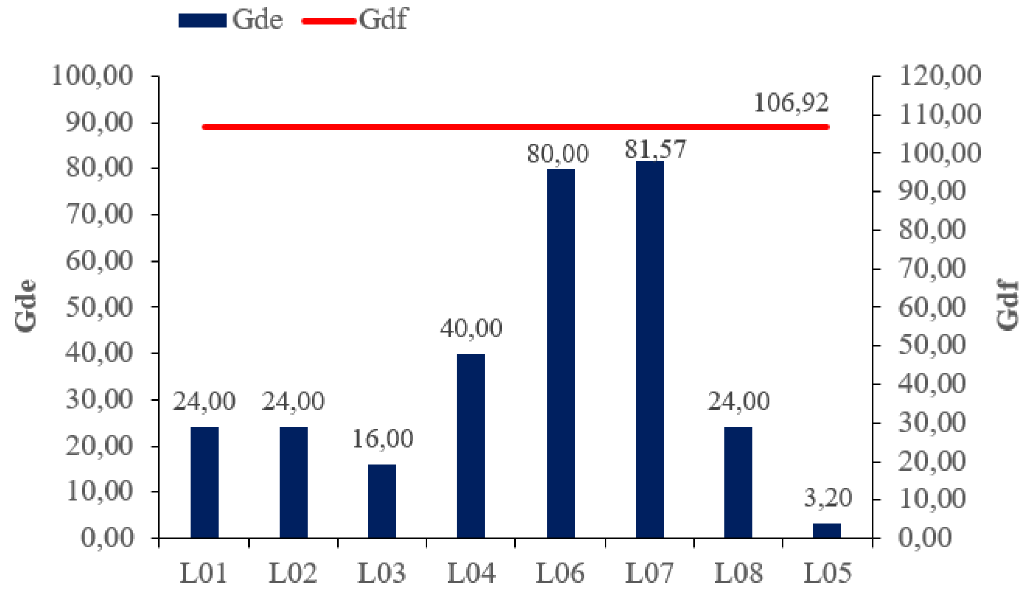

Figure 7. Degree of deterioration of the slabs.

The beam families have a null degree of deterioration, as no pathological manifestation was identified in the elements that compose them, in the family of stairs, the only identified element has G_{de} less than 15. Thus, for both, G_{df} equal to zero was calculated. As for the families of columns and upper and lower reservoirs, it is observed that they are composed of only one element, so the value of the degree of deterioration of the family corresponds to the value of the degree of deterioration of the element itself, this can be seen, respectively, in figures 8, 9 and 10.

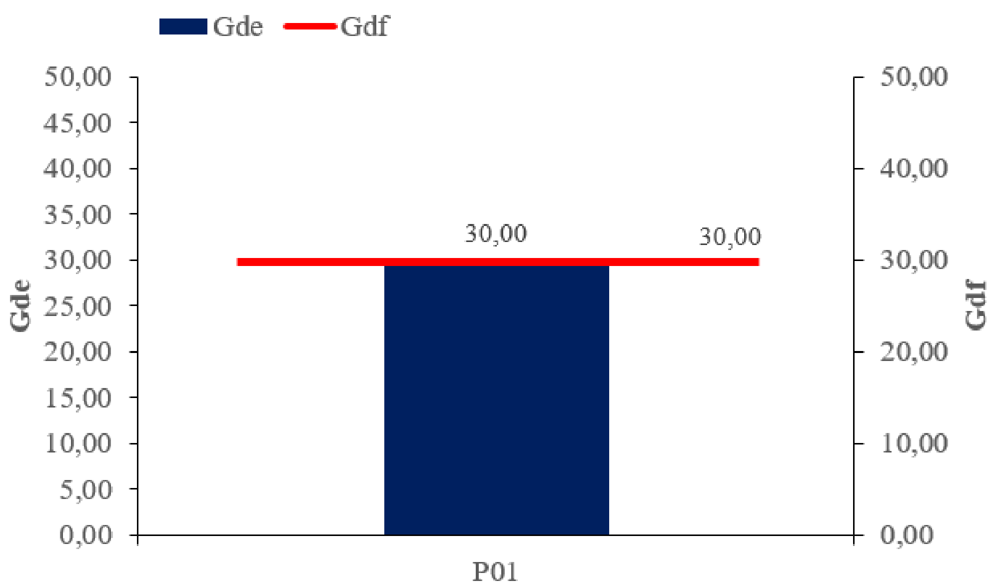

Figure 8. Degree of deterioration of the pillars.

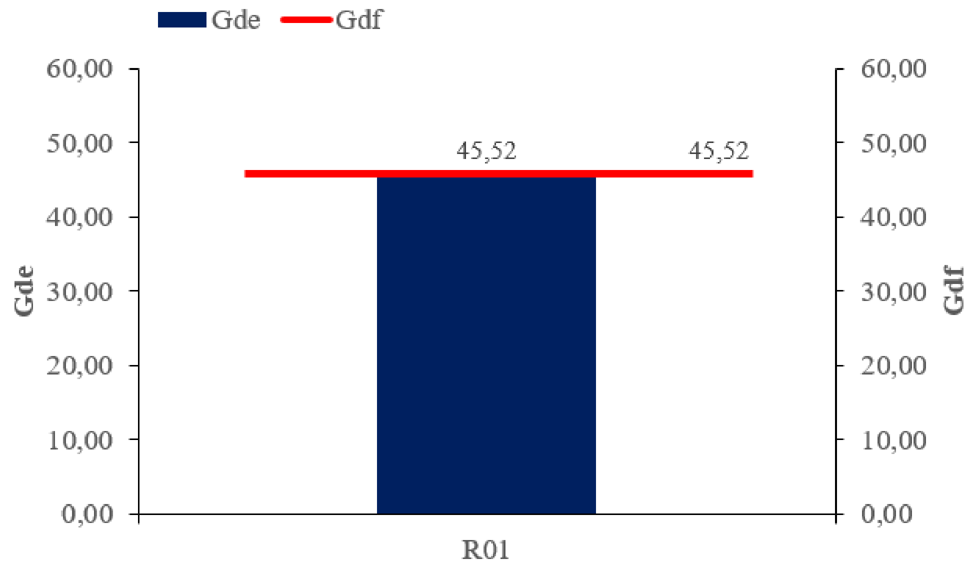

Figure 9. Degree of deterioration of the upper reservoir.

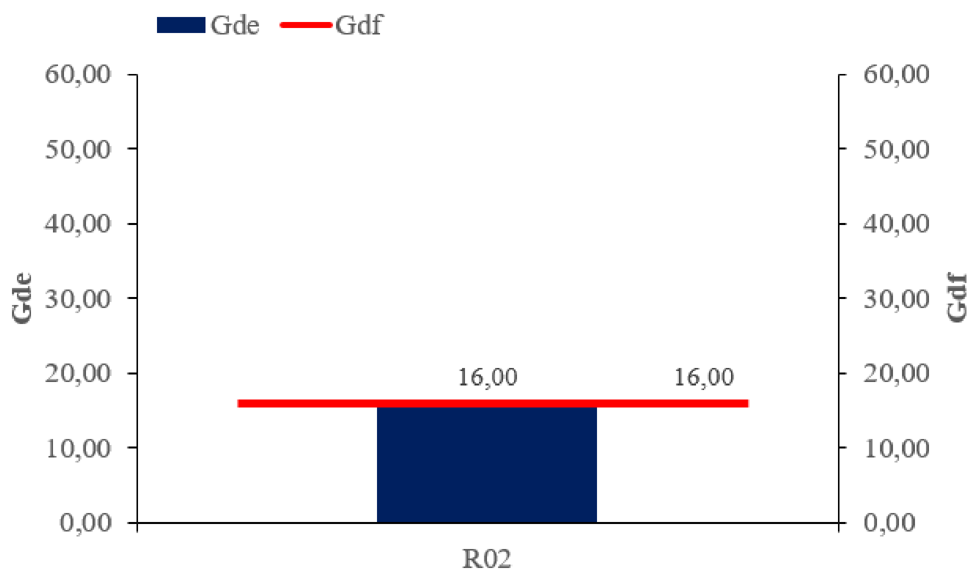

Figure 10. Degree of deterioration of the lower reservoir.

In addition, in the expansion joints, the presence of two elements that present the same degree of deterioration was found, but the degree of deterioration of the family is higher than the value obtained for the elements individually. Thus, by the mathematical formulations, it is possible to observe that the influence of the repetition of elements that have the same degree of deterioration does not represent such a significant increase since it has the maximum value as a reference, this value is multiplied by the result of the root that involves the sum and the maximum value. Figure 11 shows the value of G_{df} and the values of G_{de} for each element.

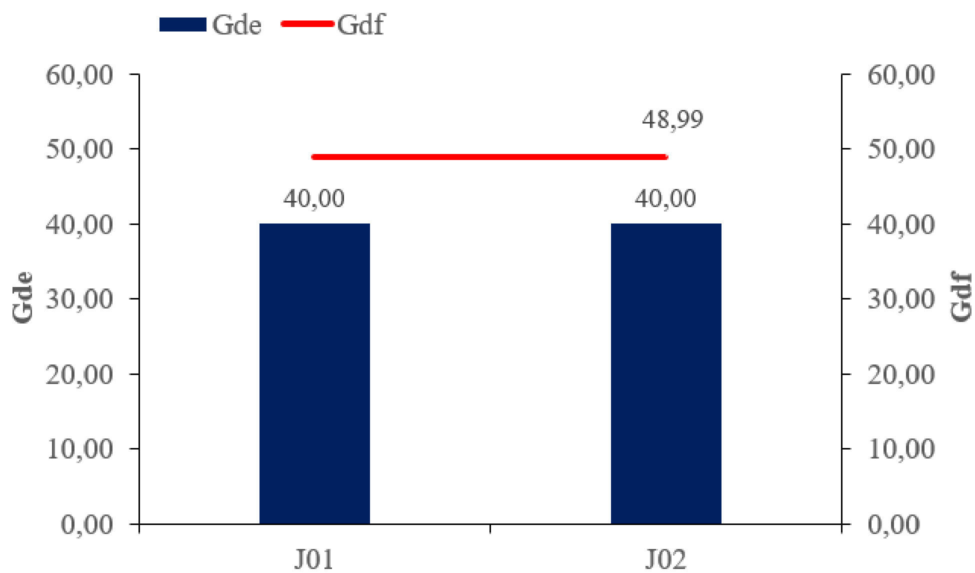

Figure 11. Degree of deterioration of expansion joints.

Thus, when evaluating the degree of deterioration of the families and the degree of deterioration of the structure, it is noted that the slabs are the ones that represent the greatest influence for the structure to be at an average deterioration level,15 to 50, and therefore it needs intervention within a maximum period of 2 (two) years. Figure 12 shows the values of G_{df} of each family in comparison to the global value of the structure, G_d.

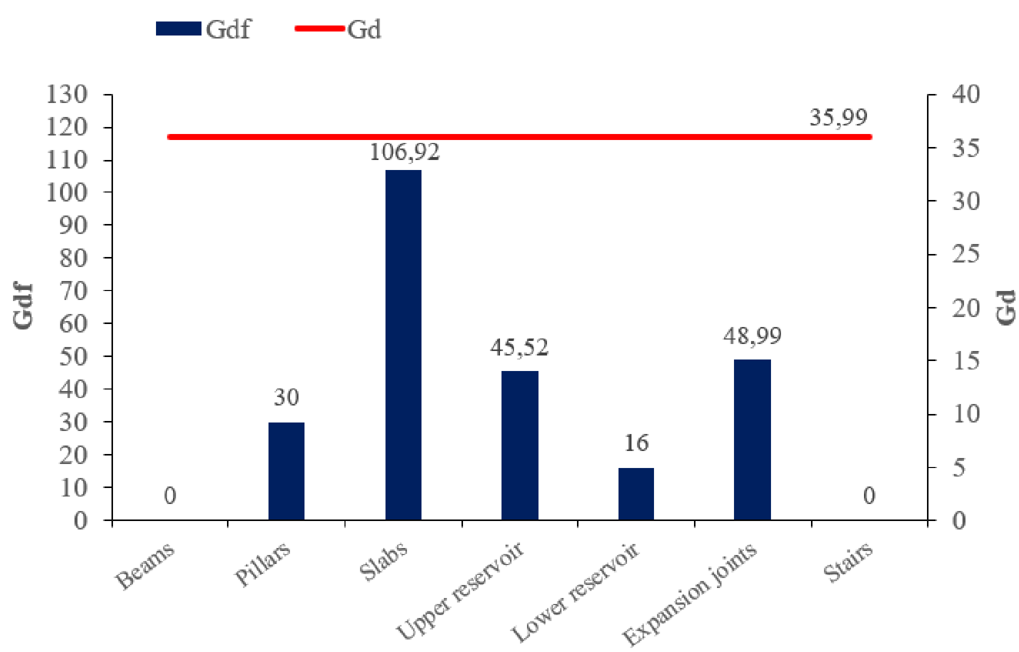

Figure 12. Degree of deterioration of the structure.

The application of the methodologies makes it possible to define which element or pathological manifestation needs priority within the global scenario, which can be decisive for assertive and efficient work. By the GDE methodology (2007) it is defined that the elements L07 and L06 need special attention, given that they present a poor and high level of deterioration, respectively, which implies a need for intervention within a maximum period of 6 (six) months for element L07 and 1 year for element L06. On the other hand, elements E02 and L05 have a low level of deterioration, requiring only preventive maintenance. The other elements are classified at a medium level of deterioration, with interventions being suggested within a maximum period of 2 (two) years. In addition, the structure has a G_d equal to 35.99, classifying it as an average level of deterioration, which requires a maximum intervention period of 2 (two) years. The list of maintenance priorities is presented in table 5(1).

Table 5. Table of maintenance priorities according to the GDE and GUT methodology

(1) GDE

Element	G_{de}	Level of deterioration	Maximum intervention period
L07	81,57	Suffering	6 months
L06	80,00	High	1 year
R01	45,52	Medium	2 years
L04	40,00	Medium	2 years
J01	40,00	Medium	2 years
J02	40,00	Medium	2 years
P01	30,00	Medium	2 years
L01	24,00	Medium	2 years
L02	24,00	Medium	2 years
L08	24,00	Medium	2 years
L03	16,00	Medium	2 years
R02	16,00	Medium	2 years
E01	4,80	Low	Preventive maintenance
L05	3,20	Low	Preventive maintenance

(2) GUT

Element	Pathological Manifestation	Grade	Degree
P01	Corrosion	384	Medium
L06	Cracks	384	Medium
L07	Cracks	384	Medium
P01	Concrete detachment	288	Low
L04	Efflorescence	288	Low
R01	Efflorescence	216	Low
L02	Moisture	108	Low
L07	Moisture	108	Low
L08	Stains	108	Low
R02	Efflorescence	108	Low
L01	Dark spots	54	None
L03	Moisture	54	None
J01	Moisture	54	None
J02	Moisture	54	None
L05	Moisture	27	None
R01	Poor waterproofing	27	None
E01	Detachment	27	None

By the GUT methodology (2014), it is possible to evaluate only the pathological manifestations separately. Thus, based on the scale of values defined by the methodology, in tables 2, 3, and 4, where from 81% to 100% is defined as a total degree, it was considered that the attribution of grades 10 for the three parameters, or that is, grade 1000 represents 100% and consequently, the percentage of the other values can be easily obtained and thus assign a classification to the pathological manifestations. Having defined this, in table 5 (2) the pathological manifestations were listed in order of priority, that is, from the highest to the lowest score.

It is noted that by the GUT methodology (2014) there is a certain repetition of values, which makes it difficult to determine priority. In addition, most of the pathological manifestations are of a low or no degree, in terms of severity, urgency, and tendency, diverging from the GDE methodology (2007). However, for both methodologies, it is possible to define that elements L07 and L06 need maintenance priority.

4. CONCLUSIONS

From the analysis of the results, it was observed that most of the pathological manifestations that occur in the structure of the building are associated with humidity to a certain degree, either causing efflorescence, stains, or infiltrations. So, it is a recurring factor that must be solved because it can compromise the health and safety conditions of the owners.

Due to the age of the building, the projects do not meet with the administration of the condominium, so it was not possible to have access to the structural project, which made it difficult to identify some of the structural elements, such as the beams and pillars. Due to this fact, the analysis became limited only to what was inspected. The building underwent occasional maintenance as problems arose over time, which mitigates, to a certain extent, the effect of time on the building, with the upper part of the building being the one with the most degradation due to its exposure to the weather. Regarding the application of the methodologies, it was observed that the use of the two methodologies is complementary. However, as also performed by Santana et al. (2019), it was found that the use of the GUT methodology alone (2014) would be unfeasible due to repeated results, which makes it difficult to analyze the aspect of determining the maintenance priority. In addition, subjectivity is still present in the GUT methodology (2014), to a certain extent, when compared to the GDE methodology (2007), as the attribution of grades takes into account the evaluator's perception of concepts such as discomfort, annoyances, and others.

Using the GDE methodology (2007) it was possible to determine the degree of deterioration of each element and define the maintenance priority and its respective intervention period. In addition, it was determined that the degree of deterioration of the structure is equal to 35.99, which corresponds to an average level of deterioration and requires intervention within a maximum period of 2 (two) years. Comparing the values of the degree of deterioration of the family with the global value, it is noted that the family of slabs is decisive for defining the value obtained for the structure as a whole, from which it can be identified that the family of slabs needs priority.

By the GUT methodology (2014) it was possible to define the Severity, Urgency, and Tendency of each pathological manifestation present in the elements and not of each element itself, being possible only to define a maintenance priority, without defining a deadline for it to be carried out.

In this way, the application of the methodologies, despite the difficulties pointed out, proves to be efficient and important for decision-making, as it allows an overview of the points that need more attention and facilitates the subsequent process of maintenance and recovery of these buildings.

So, in summary, the building's maintenance priorities are the L07 and L06 slabs, which need an in-depth investigation, to identify if there is a need for reinforcement to resist the additional loading and in addition to the recovery of their cracks in order not to the situation worsens.

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