XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Identification and Quantification of Failure Modes of New Buildings Façades in Brasília

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ABSTRACT

The occurrence of pathologies in buildings façades has shown up as a problem more and more frequent in Brasilia. The façades are frequently constituted of masonries, which are covered by rendering mortars and ceramic tiles. Several failure mode were observed, from stain, cracks, until the detachment of the façade covering.

The present study approaches the case of four buildings with different architecture, and from which, the analysis of the failure mode was developed. The methodology used consisted of: initial inspection, detailed inspection of the façade elements and, damages mapping, tests and diagnosis. From the observed results the most frequent degradation pattern recognized on the observed façades was: the detachment of ceramic tiles, following by the cracks. It was observed that the areas of larger incidence of pathologies are the sorounding of the openings, following by the continuous façades (large regions without openings).

As a contribution to the theme, the present study talks about the methodologies for identification and quantification of pathologies, as well as, it focuses on the results observed as a feedback for prevention of future pathologies.

KEYWORDS

Quantification of failure, Façade, Rendering mortars, Ceramic tile, Detachment, Cracks.

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1 INTRODUCTION

Brasilia, capital of Brazil, is the first urban center of the twentieth century considered as a World Heritage Site by UNESCO. Inaugurated in 1961, the young capital completed 50 years with its buildings showing several detoriation symptoms. This study has its focus on the approach on building façades. Typically, the façades are made of masonry of ceramic and concrete bricks, covered mostly by ceramic tiles and stone cladding.

The deterioration of the façades is identified by both the incidence degree, and the severity of defects, among which, were could observe: detachment and lost of adhesion of ceramic tiles, cracks, stainings, ceramic tiles deterioration and desintegration.

The survey on the incidence of failures ia a systemic study which involves a sequency of operations aimed at identifying the active failure mode, as well as, at mapping the deteriorations. The end of all analysis sticks to the formulation of a mechanism, capable of clearly describe the formation and development of failure. To find a adequate failure mechanism is obviously necessery to go beyond a simple assessment of incidenced, requiring detailed inspections, as well as, tests of the respective material.

The Laboratório de Ensaio de Materiais – LEM (Laboratory of Material Test), Universidade de Brasília - UnB (University of Brasilia) , has a team of researchers on the subject, and has developed a methodoly already applied for several years, in which one seeks to study the main failure and degradation pattern of building façades in Brasilia . In summary, the methodology LEM-UnB is devided in the following steps, like descripted according Bauer *et al*. [2010] :

- **Preliminary information:** Which attempts to identify the history of interventions, the building´s architectural desposal, the exposure to weather and, to document the main deteriorated areas. It is common, at this stage, a vaste photografic record of the building´s entire façades.

- **Inspection:** This step has already made a detailed evaluation of the critical areas or, of all façades. It seeks both to document the composition and constructive details (materials and components details, thickness) of facing materials (mortars, ceramics, masonry), and also to identify the failure mode and its occurance extension. To implementof the inspection is necessary the use of rapel or the access by cranes. The final result is the mapping of failure modes in different façades of the building.

- **Tests:** The execution of tests on the spot, such as the tensile adhesion (pull-out), is one of the elements necessary for the identification of the mechanical stability of the façade. Tests on the material characteristics, such as the water absorption and surface cracking of ceraminc tiles helps in understanding the mechanism of occurancy of failure. Oftentimes, are developed experiments specific to investigate a certain occurance mechanism. In this sense, Pereira [2007] reports the use of thermal panels for the stydy of the detachment by shrinkage of the facing mortar, held out by inspection in LEM-UnB.

- **Diagnosis**: The diagnosis stage uses all information obtained in previous steps in the formulation of the mechanisms specific for the development of the degradation pattern. Were identified the causes, the intensity of deterioration fhenomena and, also were defined the mechanical stability and the façades security.

Other tools were developed for the study of the deterioration in façades, as described by Gaspar and Brito [2005], where was defined the sensibility of the occurrence of pathologies in certain façades from a probabilistic analysis. In order to better establish the diagnosis, Silvestre and Brito [2009] proposes the use of matrices of correlation between anomalies and probable causes. Antunes [2010] applied this concept and obtained matrices of correlation for the study of buildings in Brasilia.

2. METHODOLOGY

The present study preliminarily sought for identifying and quantifying which façade pathologies occurs in the studied buildings.In this metter, were evaluated the different buildings through the defects index, in which, it quantifies the number of defects per square meter of the façade. Antunes [2010] held a vast survey study of the defect index, in order to characterize the extension of the pathologic manifestations in Brasilia´s buildings. This study also sought to quantify the relative percentages of failures in relation to the total observed failures. The defect index is descrited in equation (1).

(1)

$$FI = \frac{NF}{FA}$$

Where:
FI– defects index
NF – number of defects (quantity)
FA – façade area (m^2)

The index of defects was determinated for each façade and for the total of every building. Subsequently, were identified which are the most vunerable regions of the façades, using the mapping of failure incidences. For that, was held a graphic sistematization in which, are expressed the façades areas and the level of occurance incidence obtained.

The study sample consisted of 4 buildings, with total façade area of aproximatly 12.000m^2. All buildings have reinforced concrete structure and masonry walls, which are coated with ceramic tiles. The number of floors are defined by Brasilia´s building code, according to the region and destination of the building. Table 1 presents details of the studied buildings. Buildings A, B and C located in Brasilia´s central area has 6 floors. Building D has 12 floors. The entire sample is formed by residential buildings.

Table 1. General Characteristics of studied buildings.

Buildings	*Number of floors*	*Age (years)*	*Façade area (m^2)*
A	6	11	3350
B	6	40	1200
C	6	40	3400
D	12	10	3840

During the determination of the preliminary evaluations the folowing main failure modes were identified:
- loss of adhesion : the ceramic tile has lost the continuity with the supporting wall given by the mortar but did not detach from the facade;
- detachment of ceramic tile: the detached ceramic tile has fallen out of the facade;
- grout failure: the grout between ceramic pieces cracked and/or fell off, allowing the access of rainwater ;
- cracking: there was cracking in the facade surface;
- efflorescence: white spots formed by the deposition of salts from the masonry or the façade materials;
- seal failure (joints between walls and windows): joints damage, especially in the neighborhood of windows and openings, from which occures the penetration on rainwater.

Due to different façade regions they were distinguished in order to give each one its own defects. So were analyzed and quantified the defects in the following areas:
- top: involves the last floor façade area, surrounding to coverage or roof;
- joints: corresponds to the region near the movement and dilatation joints;

- balconies: facade areas in where the facade elements are externally projected;
- corners and edges: neighboring area of the façades;
- transition between floors: area that includes the interferences of both floors;
- continuos walls: areas where the façade is a continous plane, without gaps (windows or balcony) ;
- openings: area surrounding windows and doors; - ground level: junction of the façade and the building base.

3. RESULTS AND DISCUSSIONS

Figure 1 presents the results observed by façade and by building for the defect index. We can observe that building B presents the higher global values, followed by building C. In these 2 cases we have buildings with higher age (40 years), what leads to a conclusion of a higher deterioration of the elements that compounds the façades. It´s important to emphazise that these buildings do not have a maintanance plan, and the pontual interventions are always done when the deterioration level is extremely high. Buildings A and D, eventhough with lower ages (11 and 10 years) presented a significant value of defect index. Building D presented the lower index observed.

In relation to the façade defect index, concerning the cardeal orientation, was observed that the same is higher when: in Building A is the northeast façade, in building B is the northeast façade, in building C is the north façade and, in building D is the northeast façade. Data shows that northeast, north and northwest façades are the ones that presented higher deterioration. One of the aspects that may influence the deterioration machanisms is the solar incidence. Excectly during the months of higher solar exposure (winter, from May to September) there is a diary solar movimentation that incides for longer period in North façade and its neighborhood (from east to west). This climatic incidence may be one of the main factors of façades deterioration.

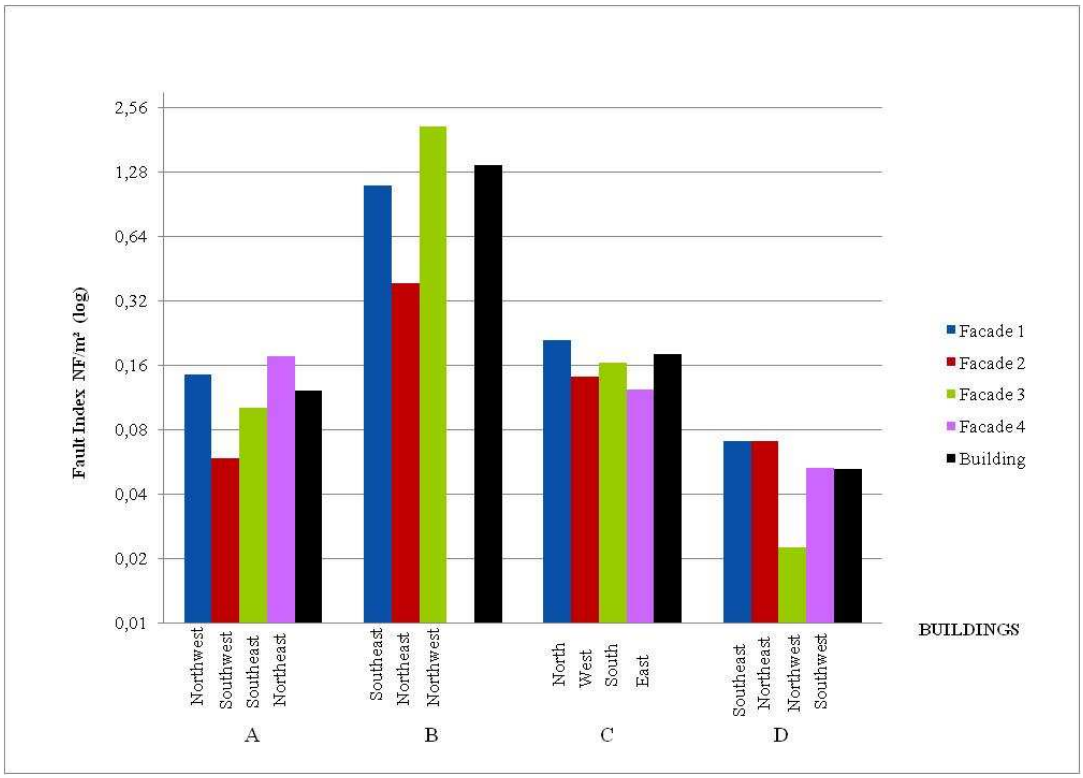

Figure 1. Defects index (FI) for façade and building (log scale).

Regarding the percentage of defects observed, Table 2 shows the values for the four buildings. It is observed that the defect with the highest incidence (over 55% in all cases) is the loss of adhesion of the ceramic tiles. Interestingly, the highest incidences occur for buildings A and D, just those of minor

age and with lower failure rates (Figure 1). One deduces from this fact that the predominant failure of newer buildings (A and D) is the loss of adhesion of the ceramic tiles.

The second defect with the highest occurrence is the failure of grout which occures mainly for buildings A and B. Interestingly, this type of defect is usually associated either with façades with large thermal effect (great efforts in the facades submited to sun action) or in situations of deteriorating of old grout. That last situation seems to be the case of building B, in which the grout has deteriorated compared to degradation over time.

Cracking appears in building B at higher percentage, mostly related to efforts in the neighborhood (corners) of the windows. Another region of crack incidences is the continuos walls ont the top of the building.

Sealing failure (defects) were significantly observed in buildings B and C. Typically, this defect is associated with lack of maintenance, since its effects, such as infiltration of rainwater, are strongly detected by the building user and require immediate repair. Buildings B and C, the oldest, presented higher degree of general deterioration (Figure 1) what can explain the greatest number of sealing defects.

Table 2. Incidence of defects observed in buildings.

Buildings	*A*	*B*	*C*	*D*
Ceramic- loss of adhesion	169 (82%)	926 (55%)	514 (83%)	183 (91%)
Ceramic detachment	6 (3%)	113 (7%)	0 (0%)	18 (9%)
Grout failure	23 (11%)	410 (24%)	39 (6%)	0 (0%)
Cracking	6 (3%)	201 (12%)	54 (9%)	0 (0%)
Efflorescence	2 (1%)	0 (0%)	0 (0%)	0 (0%)
Sealing failure (joints)	0 (0%)	25 (1%)	11 (2%)	0 (0%)
Total cases	206	1675	618	201

The mapping of defects is shown in Figure 2 for the buildings under study. Was held for such an adaptation of the methodology of Gaspar and Brito [2005] and of the aplications of Flores-Collen [2009]. The percentage of defects measured was associated to each façade area, trying to identify areas most susceptible to degradation.

The defects observed in the building top area ranged from 2 to 7%. Basically, they are ceramic detachment and grout defects.

In the joints surrounding area were observed 73% for building A and 10% for building B. Obviously the situation for building A is associated with a lack of maintenance of the moving joints, or to defects in materials and workmanship. Basically, these defects observed at the joints area consisted of detachments of the ceramic tiles, as with the failures of the joints associated with infiltration of water into the facade system, leading to a loss of adhesion in the surrounding region.

The balconies areas showed a low level of defects incidence. In situations as these (building A), problems observed were of detachment, grout faults and efflorescence. Because these regions suffer from high incidence of rainfall, the failure due to water are the most frequent.

Corners and edges presented rates of occurrence of 10 to 17%, consisting primarily of ceramic detachment and efflorescence. In these regions, because of the changing directions of the facade plans, often constructive failers are in greater number, what exacerbates the flaws in general.

The transition area between floors is critical in buildings B and D. In building B were loss of adhesion, grout failure and cracking. In Building D was the higher extension of loss of adhesion.

The region of continuous walls appears to be the most critical for the occurrence of faults, together with the openings. It was observed in buildings B, C and D high failure rates, reaching 44% for building D. It was observed that the loss of adhesion has the highest incidence, followed by grout failure and cracking.

Regarding the openings, it was observed that the older buildings (B and C) have much higher rates, compared to newer buildings (A and D). As the occurrence of defects is observed that cracking, detachment and sealing defects are the first.

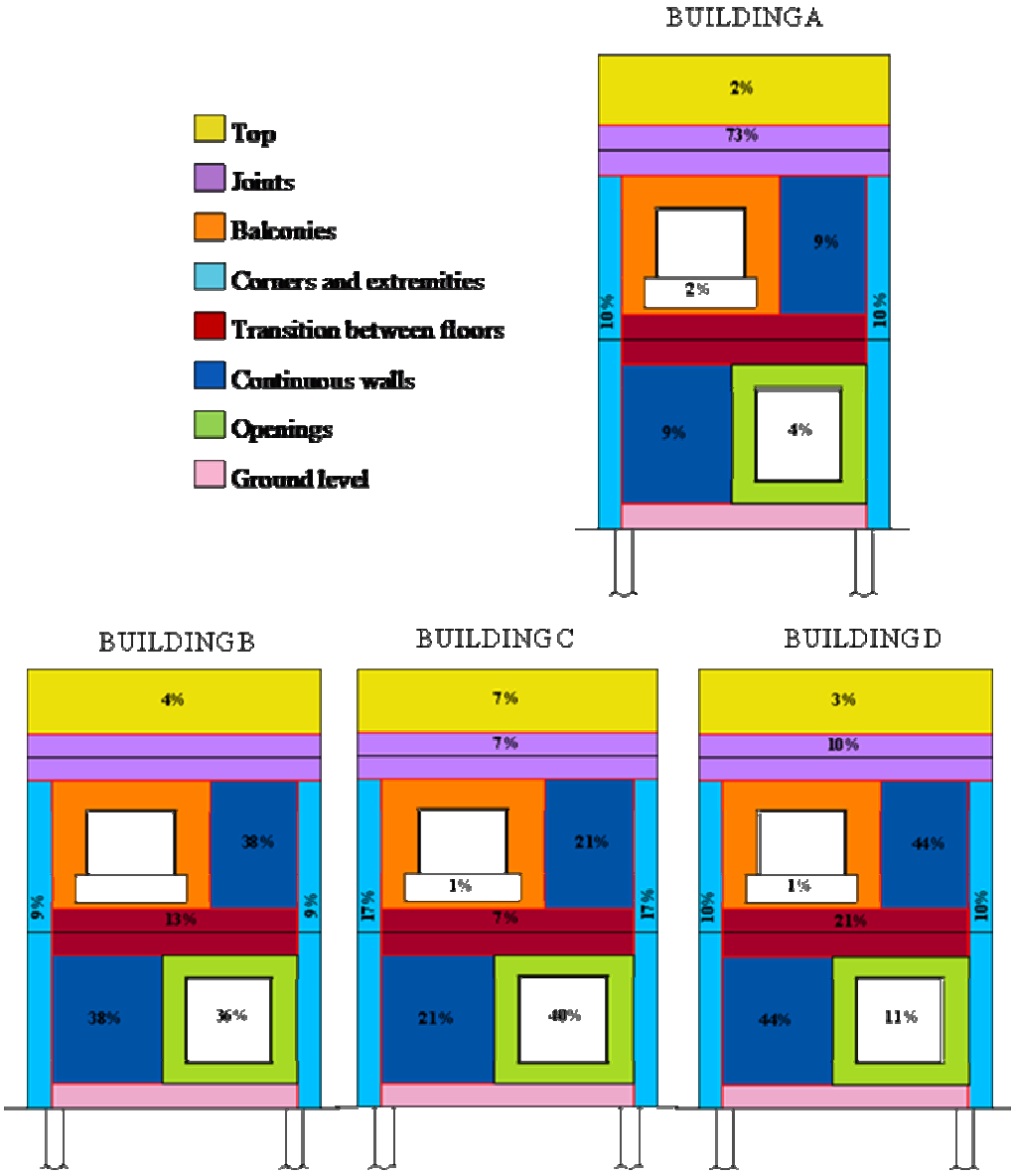

Figure 2. Mapping of the failure percentage allocated to each façade area.

4. CONCLUSIONS

From the presented study we can enumerate the following main conclusions:
- The defect index is a parameter that can be used to identify areas of further deterioration in buildings. The same was seen in the analysis of more older buildings, as well as in the identification of more aggressive façades regarding sun incidence. Another application is the simple comparison of

buildings with different typology (height, façade details), being compared to deterioration levels in different buildings.
- the great incidence of defects in ceramic loss of adhesion and detachment shows that this is one of the main problems in buildings. It is observed that both new buildings and older ones have a high incidence of detachment in almost all façade areas . It can be inferred that for buildings B and C (40 years) the detachment faults may have occurred by the very gradual deterioration of materials, infiltration and other actions. For new buildings (A and D), however, the high degree of detachment incidence may have as likely causes the constructive and material failings.
- the mappingof failures incidence in façades showed differences for each studied case. It was observed that for older buildings (B and D) the region of greatest problems is the region of solid walls and the region surrounding the windows. This leads us to interpret these failures as a result of the building structure aging, which present deformations in the structure causing cracks and ceramkic detachment.
- the absence of planned and appropriate maintenance procedures, seems to be a critical factor in the severity and incidence of observed defects. Even in newer buildings, one can infer that earlier intervention could increase the durability of the façade components.

ACKNOLEDGMENTS

The authors wish to acknowledge the support of the Laboratório de Ensaio de Materiais (LEM) and of the Centro de Apoio ao Desenvolvimento Tecnológico (CDT) of the University of Brasília (UnB).

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