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Building facade cladding detachment: A case study

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ABSTRACT

The detachment of ceramic tile and natural stone from building facades are a recurring cause of concern to users and construction professionals. This paper describes a facade pathology case study of ceramic and stone coverings on a 30-year-old residential building, identifying occurrences and assessing the situation. The methodology included data collection, percussion and adhesive strength tests, diagnosis, prognosis and solution. The results showed a deficiency in adhesive strength in 57% of the tests and 13% of tiles inspected had a hollow sound. The pathology description and the sequence of diagnostic definition activities are the main contributions of this study, which can help solve several problems with buildings of similar age, materials, and construction techniques.
Keywords: building facade; cladding detachment; ceramic tile; natural stone.

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Descolamento de revestimento de fachada: Estudo de caso

RESUMO

As manifestações patológicas em revestimentos de fachadas no Brasil são recorrentes causas de preocupação. Este artigo objetiva descrever o estudo de caso de descolamento de revestimentos em cerâmica e mármore em fachada de edifício residencial com 30 anos. A metodologia contemplou a coleta de dados, testes de percussão e aderência, diagnóstico, prognóstico da situação e conduta. Os resultados mostraram deficiências na aderência em 57% dos testes e 13% das placas inspecionadas na percussão. A descrição das patologias e a sequência de atividades adotadas para a definição do diagnóstico compreendem as principais contribuições deste trabalho, podendo auxiliar na solução dos problemas das inúmeras edificações construídas com os materiais e as técnicas construtivas característicos da época.

Palavras-chave: fachadas de edifícios; descolamento de revestimentos; placas cerâmicas; mármore.

Desprendimiento del revestimiento de fachada: Estudio de caso

RESUMEN

Las manifestaciones patológicas en revestimientos de fachadas en el Brasil son recurrentes causas de preocupación. Este artículo tiene como objetivo describir el estudio de caso del desprendimiento de revestimientos en cerámica y mármol en la fachada de un edificio residencial de 30 años. La metodología contemplo la recolección de datos, ensayos de percusión y adherencia, diagnóstico, pronóstico de la situación y conducta. Los resultados mostraron deficiencias en la adherencia en un 57% de los ensayos y 13% de las piezas inspeccionadas en la percusión. La descripción de fallas y la secuencia de actividades adoptadas para la definición del diagnóstico comprenden las principales contribuciones de este trabajo, pudiendo cooperar en la solución de los problemas de las innumerables edificaciones construidas con los materiales y las técnicas constructivas características de la época.

Palabras clave: fachadas de edificios; desprendimiento de revestimientos; piezas cerámicas; mármol.

1. INTRODUCTION

The occurrence of pathological manifestations in buildings is caused, in large part, by the adoption of inadequate construction procedures, failure to comply with standardization recommendations, and faulty design specifications and materials used.

Notably, in facade cladding, these factors become even more worrying in the face of the environmental conditions to which the building envelope is subjected to over the years, a situation that can be exacerbated by the natural adversities that hamper maintenance activities. Pathologies associated with facades are certainly one of the problems most feared by builders, especially when they threaten people's lives (Costa e Silva, 2008).

Among all the observed facade pathologies, the one that undoubtedly presents the greatest concern is the detachment or loss of adherence between the ceramic tiles and their support. This is the most dangerous and demanding manifestation due to the potential hazard to users. As warned by (Costa e Silva and Lordsleem Jr., 2010), residential buildings of medium to large size in Brazilian cities, where this type of cladding is most common, have mezzanine levels usually designed for common areas or garage space which remain directly exposed to all kinds of facade problems. The fall of a ceramic piece, from heights of 3 up to 40 or 50 meters, can cause enormous material damages as well as risks to personal safety.

According to (Campante, 2001), the loss of adherence is a phenomenon caused by faults or ruptures in the interface between the ceramic tiles and the adhesive mortar, or between the mortar and substrate, due to tensions arising that exceed the resistant capacity of the connections. When the detachment of the ceramic cladding occurs in the adhesive mortar layer, the origin of the deficiency can be attributed to production, either through faulty application by the worker (due to gaps in very large sheets of mortar, for example), or because of insufficient adherent capacity in the material itself (Esquivel, 2001; Chaves, 2010).

According to (Medeiros, 2000), based on 17 case studies, there are three causes considered to be the most important with regard to detachment of ceramic facade cladding: absence of movement joints, inadequate filling of ceramic tiles with adhesive material, and poorly specified adhesive material. For this author, these causes originate in the project design, through application techniques, and the definition of materials and control procedures

According to research by (Campante and Sabbatini, 2002), four cases were analyzed which had deficiencies originating in the design (absence of joints), materials (inadequate specification of ceramic tiles and adhesive mortar), and the production process (lack of proper filling).

In summary, the causes of pathological manifestations associated with ceramic facade cladding can be synthesized in the following manner: materials and components not being used as required by standardization specifications; design deficiencies, such as lack of coordination, poor choice of materials, or neglecting construction details; production problems, involving control of reception of materials, mixture preparation, obedience to deadlines for the release of services, and quality control; as well as the lack of required maintenance to ensure adequate performance of the cladding for years to come.

Detachment of ceramic tile cladding in both new and old buildings is one of the principal problems identified, particularly in the city of Recife, in the northeast of Brazil, especially because of the complexity involved in its production and the observed lack of general knowledge on the part of those executing the work (Costa e Silva, 2001; Tecomat, 2011; Faro, 2013).

2. OBJECTIVE

In the context presented, the present work describes a case study analyzing pathologies in the ceramic tile and natural stone facade of a 30-year-old residential building, identifying the occurrences and evaluating the cladding adherence situation through the use of percussion and adhesive strength tests.

3. CASE STUDY RESEARCH

3.1. Methodology

The present case study was developed based on the pathological problem-solving methodologies proposed by (Lichtenstein, 1985) and the facade ceramic cladding diagnosis and recovery proposed by (Campante, 2001).

Four inspections were carried out at the site in order to observe the existing pathological manifestations, from which were also sought the supporting evidence and case history to understand the causes and evolution of the problems over time.

Additional adherence strength and percussion tests were carried out in order to support the diagnosis. Following this, the diagnosis was made based on all the collected information, as well as the prognosis, which associates each symptom with its causes and possible methods of recuperations.

It should be noted that the results of the tests were obtained from a specialized company who was contracted by the building owners, as a result of the detachment of some tiles from the facade cladding.

3.2. Building inspection: collection of supporting evidence and case history

3.2.1 Description of building, structure, and masonry sealing

The building targeted in this study is located in Recife and was completed in 1985, making it more than 30 years old. It has 12 stories, with eight standard apartments (one per floor), a two-story penthouse, pillars on the ground floor, and a semi-basement garage.

The structure and vertical facade sealing subsystems are made up of a concrete structural lattice reinforced with pillars, beams, and slabs, with masonry of ceramic bricks having 8 (eight) horizontal holes, and dimensions of 9x19x19 cm.

The building has a traditional architectural configuration, where living spaces are located facing towards the east, and service areas to the west.

3.2.2 Description of facade and cladding

The rough mortar utilized for the facade was composed of cement and coarse sand. The plaster mortar was composed of cement, gravel and coarse sand, with the presence of clay demonstrated by the reddish color of the mortar, a common practice at the time of construction.

The ceramic tiles used were of the semi-stoneware type (water absorption between 3% and 6%, medium) and medium thickness of 6 mm, with dimensions of 5x25 cm. The striped white marble tiles (water absorption between 0.1 and 0.4%, medium to high) had a height of 95 cm and width ranging from 20 to 30 cm. The grouting between the ceramic tiles was done with mortar composed of cement and fine sand, with a width of 15 mm, and that for the marble with white cement approximately 2 to 3 mm wide.

As shown in Figure 1, the facade was divided into eight sample areas (section T1: east facade; sections T2, T3, and T4: south facade; sections T5, T6, and T7: north facade; and section T8: west facade).

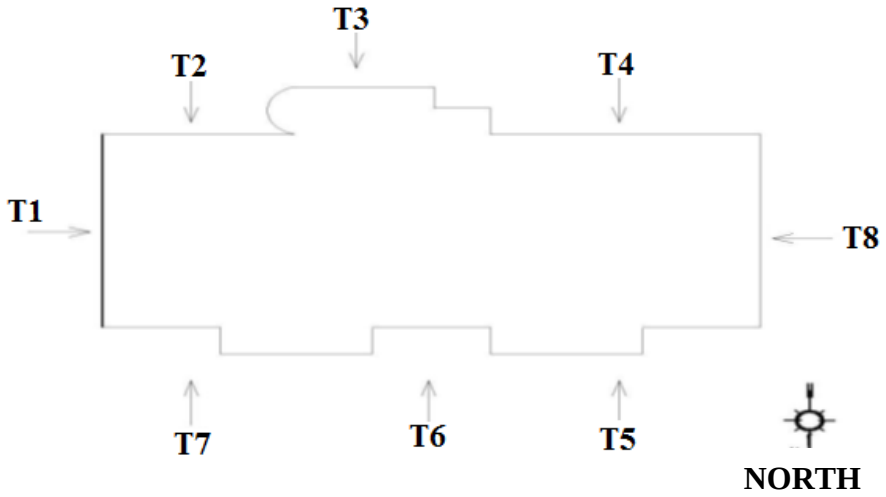

Figure 1. Sketch of building section identifying the facade and its division into sample areas.

It should be noted that the city of Recife has a humid tropical climate of monsoons with high relative humidity and high rainfall. On the hottest summer days, the temperature can reach 35ºC, while on colder days the minimum temperature is 16ºC. The average annual temperature is 26ºC, probably more common during the installation of the facade cladding. Recife has approximately 2,550 hours of sunshine per year, with an ultraviolet index (UI) of solar radiation at the Earth's surface of 10 on a scale of 14, considered to be very high.

Figures 2, 3, 4, and 5 illustrate the cladding and architectural details of the facades.

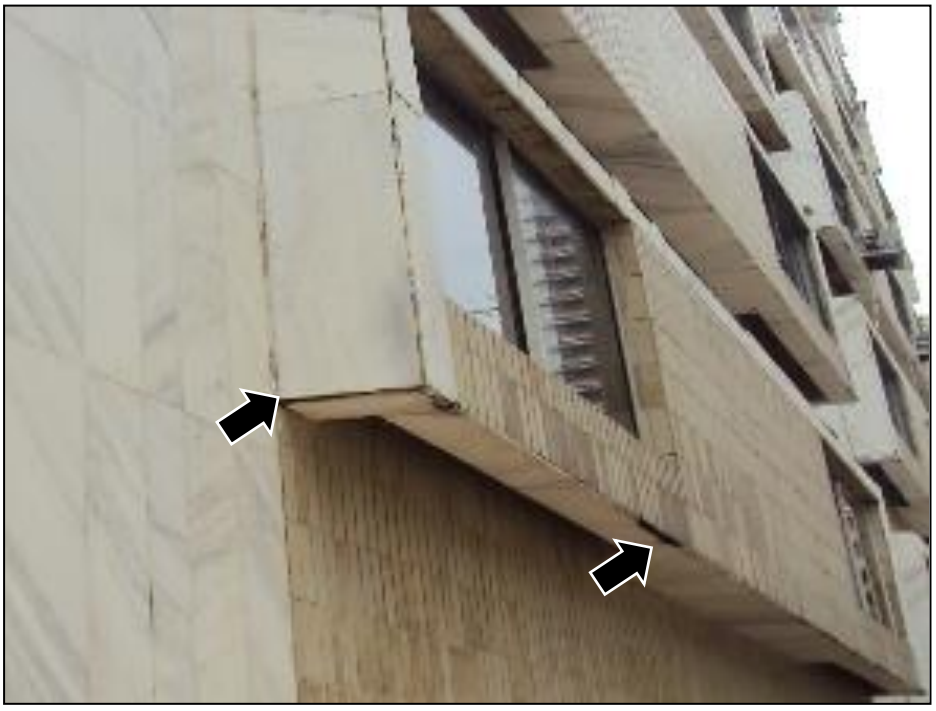

Figure 2. Northern facade (sections T5, T6, and T7).

Figure 3. Eastern facade (section T1).

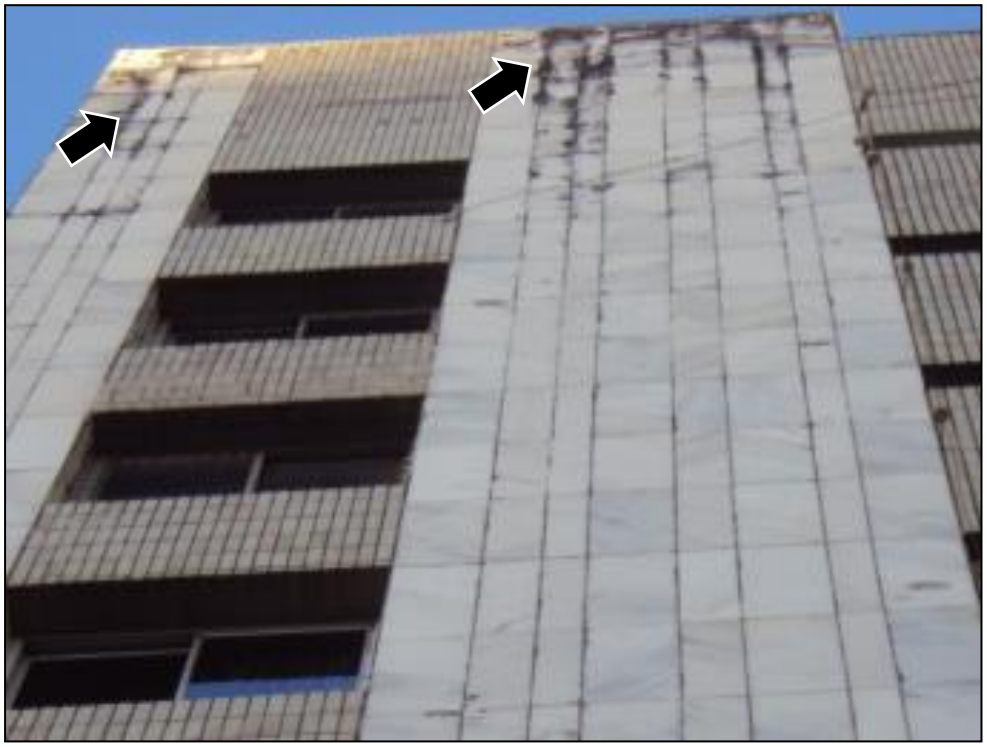

Figure 4. Southern facade (sections T2, T3, and T4).

Figure 5. Western facade (section T8).

The north facade (Figure 2) contains details designed to contribute to interior ventilation, where airflow enters indirectly below the aluminum frames, controlled by a "guillotine" mechanism attached to the marble windowsill (Figure 6).
This detail is important in the analysis of facade pathologies, since most of the occurrences of detachment of the marble slabs were found in this area at the bottom of the beam.

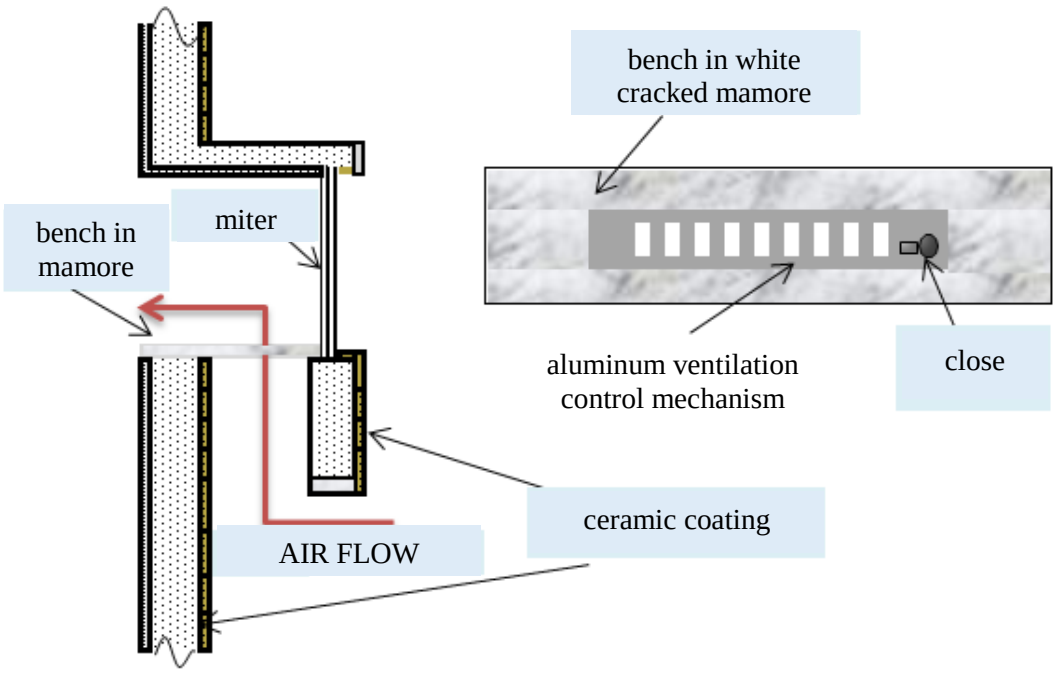

Figure 6. Schematic detail of indirect ventilation in window frames.

3.2.3 Problems identified

During the inspections, a high incidence of detachment of marble slabs was noted on the north facade, where the structure suffered greater exposure to aggressive environmental agents (Figure 2).

In general, the marble slabs and building facade joints showed signs of moisture condensation, highlighted by the presence of molds. The front facade of the building faces towards the sea (east), thus having its cladding exposed to continuous direct sea breezes. This cladding is entirely composed of striped white marble and has spots of black coloration at variousl points, characterized by the formation of mold caused by the constant moisture in the grout and the marble slabs due to the water absorption and porosity (grout), as well as the favorable environment for the proliferation of fungi (Figure 3).

The southern facade is composed of semi-stoneware ceramic tiles of beige color and rectangular plates of white striped marble, with dimensions of 95x20 cm and 95x30 cm (Figure 4). On the south facade, grout and plates with black spots were observed at roof level, characteristic of mold. There is also a history of detachments occurring in the cladding applied horizontally from below the bottom of the edge beam of the roof balcony.

The west facade is covered mostly by the same ceramic as the other facades, in a closed sheet, having only at the edges a single finishing row of white striped marble. On this facade, the detachment of two slabs can be seen in the finishing marble, while the ceramic remains intact without showing signs of adherence failures (Figure 5).

Another occurrence reported with respect to the west facade was the recurring appearance of infiltrations on the 8th floor, according to a resident. In addition, the condominium contracted for 15 years a company to perform maintenance services on the facade, recovering the grouting of each facade and replacing some tiles that showed signs of adherence failure.

The technique used to lay ceramic and marble tiles was characterized by the fact that it was applied simultaneously with the application of plaster, commonly known as Brazil as the *bolão* method (Figure 7).

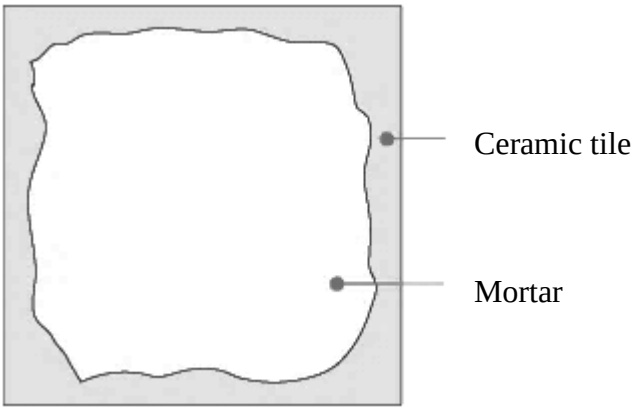

Figure 7. Example of plaster mortar spreading and fixing on the back of the tile – *bolão* method

The cement paste was spread on the back of the tile. In this type of application, the previous wetting of the cladding material (ceramic tile and natural rock - marble) is an important condition to avoid the loss of part of the water needed to cure the mortar.
No joints were observed that would act as movement joints. Most of the occurrences of detachment happened with tiles set in the horizontal, but there was also detachment of some marble slabs set in the vertical panels, confirming the existence of failures in marble slab adherence of the facade cladding. After the removal of a piece of concrete from the bottom of the periphery beam, the corrosion of the reinforcement and the separation of the covering from the reinforcement became evident.
On the south facade, specifically on the first floor balcony, after the removal of some cladding stone, it was observed that the reinforcements and supports of the beam are in the process of corroding. These issues will not be the subject of discussion of this study.

3.3. Complementary tests of adherence strength resistance and percussion

Six direct adhesive strength tests were carried out in each sample area of the facade, for a total of 42, distributed across different floors. For confirmation of each point to be tested, it was important to have the percussion test performed by a professional with more than 20 years of experience at the specialized contracted company – a laboratory accredited by the National Institute of Metrology, Quality and Technology (INMETRO), homologated by the Ministry of Cities as a Technical Evaluation Institution (ITA), and capable of verifying the performance of innovative construction systems or those not yet disseminated widely in the Brazilian market.
A criterion adopted for carrying out the strength tests was to replace the sample when the hollow sound was detected, so as not to invalidate the experiment, because the low result could compromise the data obtained.
The tests were performed according to Brazilian standard NBR 13755 (ABNT, 1996), with the cut in the cladding to prepare the sample done by marble saw, which cut through the cladding layers, making it possible to identify the most fragile interface of the rupture. The percussion test was carried out in order to identify areas lacking adequate adhesion between the mortar and the tile.

3.4. Presentation and analysis of results

The test results can be verified in Figures 8 and 9. According to Brazilian norm NBR 13755 (ABNT, 1996), for every six points verified in the same section, at least four of them must have a rupture tension (traction adherence) value points greater than 0.30MPa.

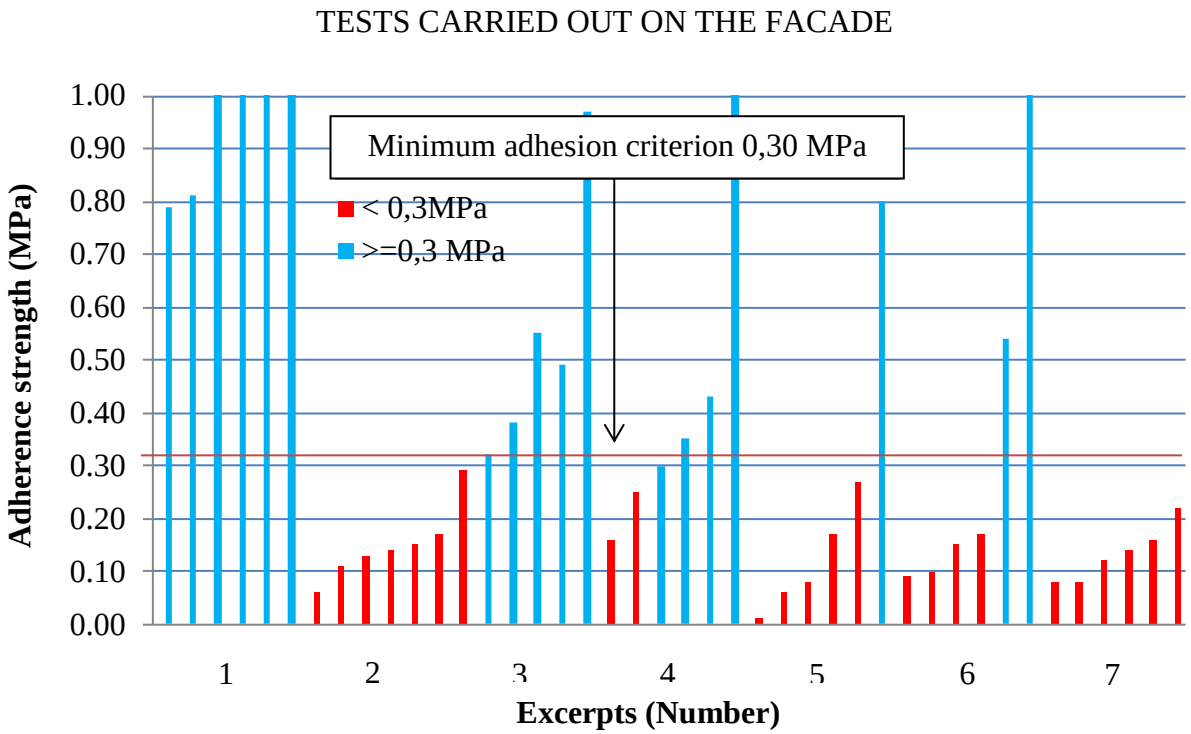

Figure 8. Results of the tensile adherence strength tests (Tecomat, 2011).

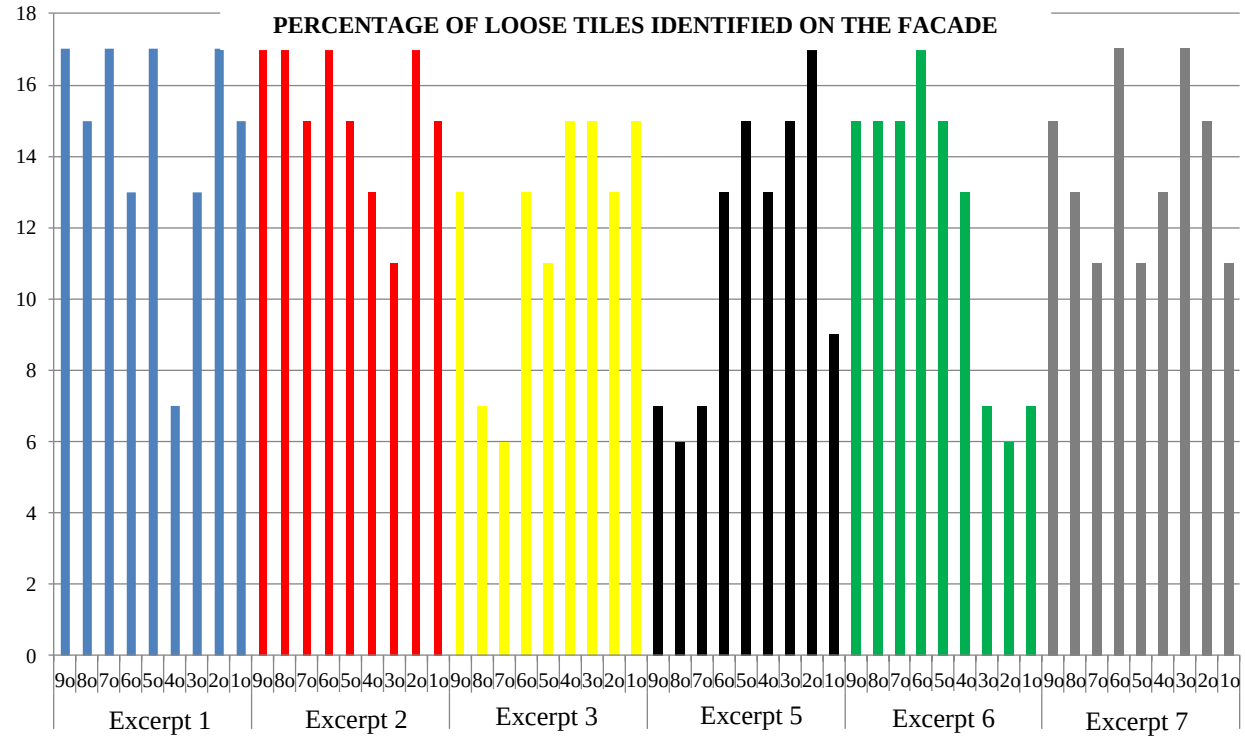

Figure 9. Results of the percussion tests (Tecomat, 2011).

It should be noted, initially, that the sections tested (T) were clad with marble slabs, except for section 3, which used ceramic tiles and whose results were satisfactory. Judging by the standardized criteria, the values obtained show clear defects in adherence resistance in sections 2, 5, 6, and 7.

In the case of section 1, contrary to expectations, results were found to be far better than the criteria mentioned above. It is reasonable to suppose that what could justify such a large difference in performance may have been either the use of different procedures for this section, or greater ability on the part of the professional who executed the east facade.
Percussion tests were also performed, where a hollow sound obtained by means of striking the cladding with a rubber hammer indicates a flaw and suggests the possibility of detachment of the tile. It should be clarified that there is no normative criterion that indicates acceptable levels for this test and it should not be adopted in isolation (Table 1).

Table 1. Synthesis of test results (Tecomat, 2011)

Summary of test results						
Section	Percussion test			Adherence resistance test		
	Tiles surveyed	Tiles with hollow sound	%	Samples below 0.30MPa	Samples above 0.30MPa	Complies
1	486	70	14%	0	6	Yes
2	486	73	15%	6	0	No
3	-	-	-	1	5	Yes
4	486	58	12%	2	4	Yes
5	486	55	11%	5	1	No
6	486	59	12%	4	2	No
7	486	66	14%	6	0	No

On the side of the first-floor balcony on the south facade, discrete rupture points at the base/slab interface can be seen, which is likely to be caused by inadequate cleaning of the base before the cladding was installed.
The reddish color of the plaster mortar indicates the presence of gravel in the mortar, a material widely used at the time (to substitute hydrated lime and ensure plasticity with lower cost), which today is avoided due to the difficulty in controlling the quality of the material and thus presenting a high degree of variation in its composition. The presence of the clay in the mortar may be responsible for the detachment or poor adhesion, due to very fine grains of clay penetrating the pores of the substrate in place of the cement hydration products that would form at the interface and produce the mechanical locking of the paste in the pores.
Analyzing the execution process used at the time, where quality depended very much on the skill of the professional, in the case of the adherence of stone cladding, the risk of failure occurring was quite high. At the time, there were no premixed or additive products, and regularization mortar (plaster) was used, to help fix the cladding elements, especially in the case of large tiles or slabs.
In order to start the fixing process, it was necessary to set up wooden shoring to support the first layer of tiles, which would later serve as support for the subsequent layer and so on. Due to their weight, the tiles were supported by the lower layer, while application of the mortar occurred simultaneously with the percussion of the plates using a rubber hammer, until the correct position was obtained. To facilitate this activity, the mortar was not spread across the entirety of the back of the tile, allowing it to be spread and ensure complete filling during the percussion, often unsuccessfully.
It is also necessary to consider the possibility of a gradual reduction in adherence between the back of the tiles and the mortar, due to eventual natural settling of the building (wind action, temperature and, in particular, concrete inflow and slow deformation of the structure through time), which may also contribute to this problem.

In general, the results of the direct tensile strength and percussion tests indicate that most of the marble cladding area is found to have compromised adhesion in some stretches with imminent risk of detachment. The perspective is that with movement, whether due to rain, wind, or the various stresses to which they are subjected, other cladding tiles will eventually detach, producing a hazardous situation with the potential for material and personal damages.
The black stains on the marble cladding in the wetter areas have the appearance of fungi (mold and mildew) that develop in the pores of the cladding and grout, creating a crust on the surface. Regarding the procedures to be adopted to recuperate these pathologies, different solutions must be adopted for each case diagnosed. However, it is important to remember that they are interconnected, as there is no way to treat the facade cladding without performing structural recovery of the compromised pieces.
Specifically, stains caused by atmospheric contamination (pollution) and humidity should be treated after recovery of the structure, cladding, and grout, by cleaning with pressurized water.
The elaboration of a cladding project is recommended to replace the mostly compromised facade marble by other material to be specified in order to reconstruct facade and provide greater efficiency in its functions.
For preventive maintenance purposes, an annual inspection is recommended in order to monitor any new occurrences.

4. FINAL CONSIDERATIONS

Detachment of facade material is undoubtedly a situation that exposes the users of a building to the risk of accidents, with potential for both personal and material damages. Based on the research carried out, it was possible to show that the use of gravel to replace lime in mortars without a rational dosage study, used in numerous buildings across the region, has resulted in the appearance of undesirable pathologies. The tension adherence strength test produced results considerably below the minimum acceptable values, close to the risk of collapse.
The current progress in the rationalization of the component fixation technique stands in contrast to an earlier era where the construction process was based more on empiricism and the intuition of the person in charge of the work, with performance often left to chance, causing serious problems in the relationship between builders and owners.
Another observed and relegated aspect to consider is the culture of preventive maintenance, still very poorly disseminated in our society. In addition to the main causes of facade detachment, it is necessary to take into account other details found in the building that cause deficiency in the facade cladding as a whole, for example, the lack of movement joints and the lack of drip pans behind the beams that would prevent the retention of moisture.

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