

Impact of Amazon environmental conditions on the deterioration of soil-cement block coatings

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Abstract: The housing deficit in Brazil, particularly in the Amazon and the metropolitan region of Belém, highlights housing as one of the major urban challenges, especially in less developed areas such as the Amazon and the Northeast, which have the worst human development indicators. To address this situation, it is urgent to implement low-cost construction technologies that enable affordable housing with quality and compliance with technical standards. This study evaluates the degradation of a multifamily residential complex in the metropolitan region of Belém, consisting of 94 units built with soil-cement blocks, five years after their occupation. The main pathologies identified were infiltrations, efflorescence, wear, paint stains, and ceramic detachment. These issues were exacerbated by local climatic conditions, characterized by high temperatures, high humidity, and strong solar radiation throughout the year, which directly impact the durability of the materials. The lack of adequate maintenance also accelerated the degradation process, compromising the quality and durability of the buildings. It is concluded that, in addition to choosing appropriate construction techniques, it is essential to consider the adaptation of materials to the local climate and continuous maintenance to ensure the sustainability of the constructions.

Key words: soil-cement block; pathological manifestations; evaluation; performance; climatic conditions

1 Introduction

Compacted earth blocks represent a modern and current construction technique, yet one based on ancestral methods derived from adobe and rammed earth construction procedures, since the dawn of humanity, soil has been used to build shelters that are effective against the hostilities of the environment. However, in recent years, earth blocks—also known as soil-cement blocks or ecological blocks—have attracted attention due to their sustainability, ease of construction, and low production cost (CUNHA et al., 2022) [1].

The soil-cement block is a material resulting from the mixture of soil, cement, and water that undergoes a physicochemical stabilization process, in which the consequences arise from a structuring resulting from the reorientation of the soil's solid particles with the deposition of cementitious substances (cement/lime) in the intergranular contacts, therefore, the relative amount of each of the three phases (solid, water, and air) that constitute the soil (ABNT NBR 10834, 2012) [2]. The percentage of cement in these blocks ranges from 5% to 10% of the mass of the soil used, and with these percentages, the raw material does not need to be fired, which is an environmentally beneficial aspect. In addition, soil-cement blocks have holes that allow pipes to pass through, reducing the amount of waste generated during cutting (Teixeira et al., 2021) [3].

Furthermore, several authors have conducted studies on Portland cement-stabilized clay blocks, emphasizing their effectiveness and environmental benefits (OTI and KINUTHIA, 2012, and MORELL et al., 2017) [4,5]. It should be noted that some research has been conducted to evaluate the thermal properties of earth-based construction materials, focusing on the impact of density on hygrothermal properties related to thermal insulation/renovation and the improvement of the hygrothermal balance of buildings, thereby helping to prevent pathological issues in building systems to ensure the integrity and service life of buildings (NIANG et al., 2018 and COLINART et al., 2020) [6,7].

In this regard, Lopes and Farias (2020) [8] emphasize that when pathological manifestations occur in dwellings, investigations must be conducted to identify their causes so that appropriate strategies can be adopted for their resolution, and that it is common to attribute the introduction of new materials as a possible cause of these anomalies; however, only through thorough and technical analyses is it possible to verify whether these materials are actually involved in the degradation mechanisms.

In this context, the present study aims to conduct a quantitative assessment of the physical characteristics of soil-cement blocks used in a case study at a residential complex in the metropolitan region of Belém, PA. Furthermore, the study seeks to evaluate possible correlations between the characteristics of the blocks and some of the early pathological manifestations observed in the buildings. Another factor taken into account regarding the observed damage was the environmental conditions of the Amazon region, since stains, mold, efflorescence, and biofilm formation were recurring anomalies that are possibly linked to the local climate.

2 Method

The subject of study comprises a residential complex consisting of 94 two-story homes, distributed across 6 blocks, with a construction system featuring reinforced concrete structural elements, soil-cement block infill masonry, and an exterior finish of mortar and paint. Thorough inspections were conducted in various apartments, covering both interior and exterior areas of the condominium, to evaluate the performance of the soil-cement blocks as part of the cladding system and to detect any pathological manifestations present, correlating them with their possible causes.

Initially, soil-cement blocks used in the masonry construction process were identified and sampled, as shown in Figure 1. Next, these were cleaned and dried (in an oven at 100°C) to be tested for the following characteristics, namely: Geometric Dimensions (ABNT NBR 10836, 2013) [9], water absorption (ABNT NBR 10836, 2012) [9], and compressive strength (ABNT NBR 10836, 2013) [9]. The following figure shows the configuration of one of the blocks collected on-site, before and after cleaning and drying.



Figure 1: Image of soil-cement block samples taken from the construction site. Source: the author

Subsequently, information was gathered on the dwellings, such as: structural and construction systems, architectural characteristics, orientation of the facades, and whether or not repair maintenance had been performed. The visual inspections and mapping consisted of identifying existing pathological manifestations using auxiliary inspection tools (binoculars, digital camera, laser tape measure, and compass) to serve as a technical record for assessing damage caused by local climatic conditions.

2.1 Study of climatic conditions

The city of Belém, capital of the state of Pará, has a land area of 1,065 km² comprising 39 islands and is under the direct influence of the tidal regime, since it is bordered to the west by Guajará Bay, to the south by the Guamá River, to the north by Santo Antônio Bay, and to the east by the municipality of Ananindeua. The city has an average elevation of 10 meters above mean sea level; however, as its terrain is predominantly flat, approximately 60% of its area lies above 4 meters relative to that level. The climate in Belém, according to the Köppen classification (1900–1936), is of the Am type, that is, a tropical monsoon climate. The annual climatological average air temperature is $26.0 \pm 0.4^{\circ}\text{C}$, with maximums and minimums ranging from 31.5 ± 0.7 to $22.0 \pm 0.3^{\circ}\text{C}$, respectively. The average annual rainfall, one of the highest in Brazil, is $2,858.7 \pm 76.6$ mm/year, with the highest volume occurring during the rainy season (December to May: Amazonian winter), accounting for 71.2% of the annual total, while the remaining 28.8% is distributed across the months of June through November, during the Amazonian summer (SILVA JUNIOR et al., 2022) [10].

Due to the characteristics mentioned above, the Amazon region is distinguished by its high and consistent daily temperatures, with high humidity, regular rainfall, light winds, and strong, direct sunlight year-round. Furthermore, the combination of rain and wind, which generates what is known as wind-driven rain, becomes an intense source of moisture that triggers degradation agents in buildings, as it directly affects water transport processes in porous materials and the loss of waterproofing in facade components (COSTA, 2011; PACHÊCO, 2021) [11,12].

Thus, when analyzing the durability of a building's exterior cladding system, factors such as temperature, humidity, and the amount of precipitation occurring at the site must be considered for maintenance purposes and to assess the longevity of the materials used. In this regard, various studies, such as those by Castello (2022) and Chen et al. (2021) [13,14], highlight the relationship between environmental conditions and the performance of exposed exterior cladding, with an emphasis on the analysis of temperature, humidity, and direct rainfall.

3 Results

One of the hypotheses put forward for the early emergence of anomalies in buildings was the use of soil-cement blocks, which were made directly on-site during construction, perhaps because they did not meet the physical-mechanical characteristics required by standards, thereby exacerbating many of the pathological manifestations, particularly those related to the waterproofing of buildings, such as stains, mold, and efflorescence, which are commonly observed in assessments of pathological manifestations in the Amazon region (CAMPOS et al.; 2018 and Do VALE et al.; 2022)[15,16].

However, the values presented in Table 1 show that this would not be the decisive factor for degradation processes to be occurring intensely, especially regarding water absorption and axial compressive strength, which are directly related to one another. It is worth noting that, to verify the homogeneity of the samples, statistical analysis was performed using the One-Way ANOVA test, in conjunction with Levene's test. The arithmetic mean \pm standard deviation was used as a parameter, considering significant differences at $P < 0.05$, which demonstrated the homoscedasticity of the blocks.

Table 1: Results of the tests performed on the soil-cement blocks used in the buildings and limit values specified by NBR 10834. Source: the author

Tests	Minimum	Maximum	Obtained	Standard Deviation	Result
Water absorption, average of samples – NBR 10834 (ABNT, 2012)	-	20%	15%	2.16%	Accepted
Water absorption, individual minimum – NBR 10834 (ABNT, 2012)	-	22%	19%		Accepted
Compressive strength, average of samples – NBR 10834 (ABNT, 2012)	2.0 MPa	-	3.35 MPa	0.93 MPa	Accepted
Compressive strength, individual minimum – NBR 10834 (ABNT, 2012)	1.7 MPa	-	2.59 MPa		Accepted

According to the study by GIORGI et al. (2018) [17], a vertical sealing system using soil-cement blocks is fully capable of meeting the relevant regulatory limits regarding rainwater tightness, thermal action, and thermal shock. Thus, it is emphasized that the alternative use of masonry with this type of block can perform acceptably in terms of the standard values regarding the aforementioned agents.

In parallel with the determination of regulatory characteristics through sampling of the soil-cement blocks, technical site visits were conducted, which enabled detailed mapping and the identification of various pathological manifestations, such as: fungal growth and blistering in finishes, leaks, efflorescence, stains, and paint wear (exterior) and ceramic tile detachment (interior: kitchen and bathroom), as illustrated in Figure 3. The on-site analysis reinforces the importance of continuous monitoring and planned maintenance strategies to prevent the progression of these issues, as well as the revision of construction practices to better adapt to the local climate and conditions of use.



Figure 3: Set of pathological manifestations found in the residential building. Source: the author

It was observed that the deterioration stemmed from various factors, some of which have been widely discussed in the literature but which the technical community continues to repeat, such as design flaws, incorrect material specifications, and construction errors; and that, in this case, the consequences were visibly exacerbated by local climatic conditions; that is, the interaction of facade cladding with climatic phenomena must be considered to ensure the system's durability. In this regard, research is currently being conducted to identify the factors that trigger and accelerate deterioration phenomena, particularly with regard to the unique conditions of the Amazon region (CARDENAL, 2017; SANTOS et al., 2019; BORGES et al., 2023; NETTO et al., 2023)[18,19,20,21].

In this regard, there are studies (BARBOSA et al., 2015 and NETTO, 2019) [22,23] that show that the temperature range in the city of Belém is not high; however, the direct impact of heat on the facades—exacerbated in this case by the lack of architectural details to protect them from intense solar radiation—may have caused dimensional variations in the

cladding that led to the emergence of a large number of cracks. These cracks, on their own, would not be so harmful were it not for the deterioration mechanisms that may have originated from them, since water penetrates the porous microstructure of the materials through them and also causes other problems for the buildings and their components, such as the white stains characteristic of efflorescence and dark stains resulting from the proliferation of microorganisms.

In this regard, another climatic factor that may also have contributed to the high number of cracks in the rendering mortars is the occurrence of wetting and drying cycles resulting from exposure to rain and sunlight, as the mortar expands and contracts; this, combined with the restriction of this hygroscopic movement, leads to cracking. Therefore, knowledge of the mechanisms of heat and moisture transport in porous materials is essential, as the problems related to these phenomena are diverse.

Construction details, which should be included in the designs and are responsible for harmonizing materials for the construction process, facilitating the compatibility of the elements that form the facades, must not allow for construction omissions in finishes such as drip edges, eave gutters, flashing, and downspouts, which are essential for increasing the durability of components by directing the flow of water in contact with the building. However, inspections have shown that in some cases, the lack of these components—such as eaves suitable for the thermal protection of buildings exposed to intense sunlight—as well as the absence of drip edges designed to "break" the waterline, preventing it from flowing directly down the facades. Thus, rainwater can flow freely over the surface of the cladding panels, running the entire height of the buildings and depositing dirt and stains on the facades.

In addition to rain, it was observed that wind and airborne particulate matter resulting from urbanization processes exposed the facades of the residences to adverse conditions, as, in addition to dirt and the formation of microorganisms, there was significant deterioration of the decorative white paint finish. The paint specification was visibly of low quality and had a matte finish, meaning it was not resistant to intense contact with rainwater.

Given the above, it is clear how important it is to improve the waterproofing characteristics of buildings to prevent water penetration. However, the waterproofing system is often neglected during construction, particularly in low-income housing, as observed in this case study. There were no plans or technical notes that shed light on which areas had actually been waterproofed or which product(s) and technique(s) were used. In this context, several studies have been conducted using water-repellent products added to fresh mortar or applied as a protective surface barrier over the blocks that make up the masonry or directly over the mortar coatings (PAES et al., 2020; ALMEIDA et al., 2023; SOUZA et al., 2023) [24,25,26].

Regarding the detachment of ceramic tiles applied in the wet interior areas of the apartments, the incorrect specification and low quality of the adhesive mortar used to bond the ceramic tiles were unequivocal, as were the workmanship flaws in their installation. The adhesive mortar exhibited a degree of crumbling characteristic of products with an excess of fine aggregate in their composition, and furthermore, the mortar beads had not been "flattened," a fact characteristic of installation with the open time of the "expired" adhesive mortar.

In light of the above, it was observed that despite the undeniable advances in the construction industry, another scenario is also emerging, particularly in the field of projects involving low-income populations whose housing is funded by government programs aimed at reducing the housing deficit among this population. Companies exhibit technical shortcomings and a certain "insensitivity" to the need to develop and implement specific projects tailored to the reality of architectural typologies, particularly in the Amazon region and its climatic conditions, particularly regarding façade designs. There is a tendency to view the exterior cladding system as a decorative product rather than an engineering solution; consequently, construction is carried out without planning or quality control commensurate with the complexity

of the problem, and without a maintenance plan involving the "actors" in this chain.

4 Conclusion

It is important to understand the need to study pathological manifestations in order to prevent their occurrence and avoid future problems. However, what is commonly observed is that professionals responsible for the built environment and urban planning in the city of Belém do not take into account the sun's behavior and climatic conditions, which causes the performance of buildings—particularly regarding waterproofing and thermal comfort—to be negatively compromised, thereby also affecting the quality of life of local residents.

Based on the results presented and the detailed analysis conducted, it is concluded that the soil-cement blocks used in the residences of the housing complex in question meet regulatory requirements in terms of both water absorption and compressive strength, thereby allowing the hypothesis that the blocks influence the emergence of these anomalies to be rejected. On-site inspections revealed various pathological manifestations, including cracking, efflorescence, wear, and stains on the paint, as well as ceramic tile displacement. These manifestations are primarily associated with problems related to the absence or deficiency of construction details that minimize the effects of moisture and thermal radiation, incorrect material specifications, and construction defects.

An integrative and preventive approach is vital for the longevity of buildings and user satisfaction, underscoring the importance of careful planning and appropriate technical interventions to maintain the building's performance and service life.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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