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Application of the Betonbloc system, as an alternative to contain coastal erosion in the municipality of Ipojuca/PE

Aplicação do sistema Betonbloc, como alternativa de contenção da erosão costeira no município de Ipojuca/PE

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Abstract: The disorderly and unplanned growth of large urban centers tends to aggravate the process of coastal erosion, becoming a problem that has been impacting about 40% of the world's population that lives in coastal areas. The present study aimed to present the BetonBloc system, which consists of the construction of walls composed of concrete blocks without the use of reinforcement, as an alternative for maritime containment located in the municipality of Ipojuca -PE. The methodological process began with the analysis of satellite images, with the aim of identifying urban transformations over the years in the study area. Then, through studies of beach profiles, with measurements before the beginning and after completion of the work, an analysis was made of the efficiency of the system. As a result, there was an increase of 257% in the urbanized area and a reduction of 72% and 46% in the areas of water bodies and natural vegetation, respectively. In all measurements taken, the beach profile after the work is higher than the profile before the work. Therefore, the system showed satisfactory efficiency, standing out as a procedure that is quick to perform, durable and does not require short-term maintenance.

Keywords: Coastal erosion; Betonbloc; Maritime containment.

Resumo: O crescimento desordenado e sem planejamento de grandes centros urbanos tende a agravar o processo de erosão costeira, tornando-se um problema que vem impactando cerca de 40% da população mundial que vive em áreas litorâneas. O presente estudo teve como objetivo apresentar o sistema BetonBloc que consiste na construção de muros compostos por blocos de concreto sem a utilização de armaduras, como alternativa para contenção marítima localizado no município de Ipojuca -PE. O processo metodológico teve início através da análise das imagens de satélite, com objetivo de identificar as transformações urbanas ao longo dos anos na área de estudo. Em seguida, por meio de estudos de perfis praial, com medições antes do início e após finalização da obra, foi feita uma análise sobre a eficiência do sistema. Como resultados observou-se um acréscimo de 257% na área urbanizada e uma redução de 72% e 46% nas áreas de corpos hídricos e de vegetação natural, respectivamente. Em todas as medições realizadas, o perfil praial após a obra é mais alto do que o perfil antes da obra. Portanto, o sistema apresentou eficiência satisfatória, destacando-se como um procedimento de rápida execução, durável e sem necessitar de manutenção a curto prazo.

Palavras-chave: Erosão costeira; Betonbloc; Contenção maritima.

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1. Introduction

Coastal areas are considered valuable spaces because they have great socio-environmental potential and contain numerous attractions, which serve the most diverse purposes, such as tourism, recreation and housing. It is estimated that about 24.06% of the Brazilian population lives in coastal municipalities (WWF-Brazil, 2021), being common to perform economic activities corresponding to these areas. For these reasons, in recent decades these spaces have been expanding rapidly, driven by the real estate market. This disorderly and unplanned growth tends to aggravate the process of coastal erosion, becoming a problem that has been impacting about 40% of the world's population (FIRMINO; ALVES, 2021).

Because they are regions where land, water and atmosphere interact with each other, coastal zones are dynamic and diversified by nature (AHMAD, 2019), modeled through hydrodynamics, a phenomenon responsible for generating a continuous flow of sediments, that changes in relation to time and intensity (RAMOS, 2021). This variation between incoming and outgoing sediments is called the sediment balance. (ROSATI, 2005). Thus it is the sedimentary balance that determines whether erosion, accretion or stability is occurring in the region. When the sedimentary balance is positive, the beach receives more sediment than it loses, otherwise it is considered negative, causing coastal erosion (RAMOS, 2021).

In areas of greater population density, coastal erosion becomes a major concern, as these environments by nature are already considered fragile, and the increasing occupation of these spaces by man has accentuated the degradation processes. (VASCONCELOS, 2010)., as intervenções humanas e o aumento do nível do mar, o qual pode mudar significativamente a geografia da região afetada Thus, the transformation of the morphology of coastal systems interacts with a set of processes and factors, such as: wave energy, sediment availability, interactions between terrestrial and marine sediments, the geological configuration of the coastal zone by erosion, in a small space of time (ELIAS et al., 2022). This was confirmed by monitoring carried out between 2013 and 2018 by the Brazilian Ministry of the Environment, which found an increase in the erosion process in coastal zones from 40% to 60% (BULHÕES, 2020).

The main consequences of coastal erosion are damage to defense structures, in addition to the loss of habitable territory for commercial and/or residential properties, and recreational spaces. These consequences have been generating severe impacts on the lives of residents of the Brazilian coast. In this scenario, integrated coastal management emerged, which is a continuous and dynamic process through decisions and actions aimed at the development, sustainable use and protection of coastal areas (ASMUS *et al*., 2006).

Integrated coastal management consists of two protection measures: prevention measures aimed at avoiding the impacts of coastal erosion, establishing a protection strip designed to absorb the coastline retreat, adapting residents to live with the specificities of the environment in which they live; and mitigating measures, which include the construction of rigid structures at the beach area with the objective of stabilizing the coastline in an attempt to minimize the impact of high-energy waves. These measures do not eliminate the causes of erosion, they only attenuate its effects temporarily, and require periodic maintenance to preserve their function., (GUIMARÃES, 2012).

To define the type of containment structure, it is necessary to take into account factors such as: soil characteristics, active loads, execution complexity, cost analysis, among others. The main coastal stabilization works are: bagwalls, rockfill, spiers, jetties, artificial reefs, gabions, breakwaters, retaining walls, among others. (GUIMARÃES, 2012).

Specifying some examples of stabilization works, there is the bagwall which is a technology where geotextile material bags are used to model the concrete. Rockfill consists of stone structures cast or arranged, using mortar or not in grouting. This structure follows the entire coastline. The breakwaters are works parallel to some distance from the shoreline, implanted at depths greater than the spikes that in turn are rigid works transverse the coast towards the sea, made of rocks or precast elements. All of these methods aim to dissipate energy from sea waves by slowing the erosive process (ALFREDINI; ARASAKI, 2009).

However, the fact is that no coastal protection measure can permanently stop erosion (BRAYSHAW; LEMCKERT, 2012), and it is only possible to minimize its effects through coastal defense works (BULHÕES, 2020). The significant economic losses and the impacts on the environment suffered over time, has been stimulating the formulation of different methodologies for the identification of susceptibility to coastal erosion (FURTADO; WOODROFFE, 2021). For this reason, it is of fundamental importance to verify other structural solutions that act as coastal defense.

This article proposes the application of the BetonBloc system as an alternative to contain coastal erosion, using a stretch of coastline in the municipality of Ipojuca/PE as a study area, evaluating aspects of efficiency of use, cost and durability.

2. The Betonbloc system

The BetonBloc system is a maritime containment technology of Dutch origin, consisting of the construction of a wall composed of concrete blocks, without the use of reinforcement, which fit perfectly forming a semi-rigid structure, being sufficient to contain the energy of the sea through the dissipation of energy in the body of containment itself (Figure 1a and 1b).

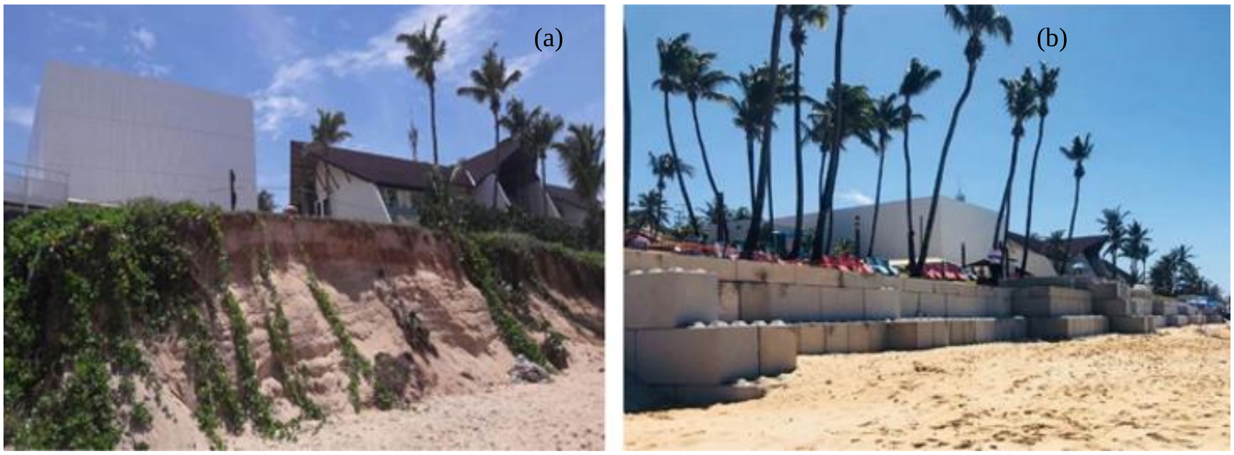

Figure 1 – Application of the BetonBloc System: before (a); after (b) - Natal/RN.
Source: Authors (2023).

This system has a double function, as the upstream acts as a maritime containment, dissipating the impact energy of the waves and the downstream acts as a support, supporting the weight that the terrain creates on the retaining wall. In Figures 2a 2b are the transversal profile and the perspective of the Betonbloc system, respectively.

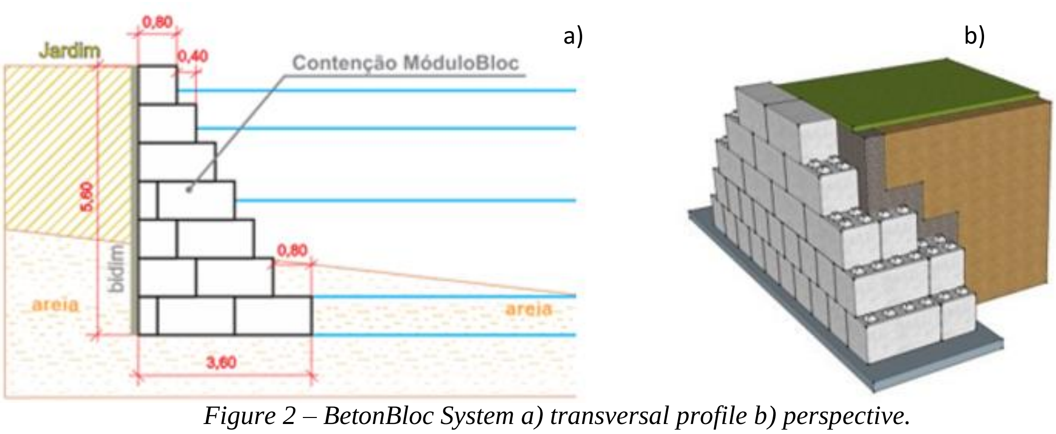

Figure 2 – BetonBloc System a) transversal profile b) perspective.
Source: Authors (2023).

In the BetonBloc system there are favorable characteristics in relation to the other types of coastal defense, because it presents: (a) shorter execution time, because the use of precast and modular parts gives speed to the work. When compared with other technologies, the reduction of time is of the order of 4:1; (b) staggered containment, because it has a ladder-shaped geometry to dissipate the energy of the sea, reduce the force of the return of waves and reduce the spray of water after contact with the wall.

3. Characterization of the área

The coastline of Pernambuco extends for 187 km, corresponding to an area between the border with Paraíba in the North to the border with the state of Alagoas, representing about 3% of the coastline of Brazil. However, only 13 municipalities are located in the coastal strip, sectored by North, Metropolitan Center and South (LINO *et al.*, 2014).

The municipality of Ipojuca is located on the southern coast of Pernambuco, which belongs to the Metropolitan Mesoregion of Recife and Microregion of Suape and stands out mainly for its beautiful beaches. The Muro Alto beach is about 3 km long, formed by long reefs that create natural pools and calm sea, offering great potential for increasing urbanization (IBGE, 2022). Figure 3 shows the location map of the study area.

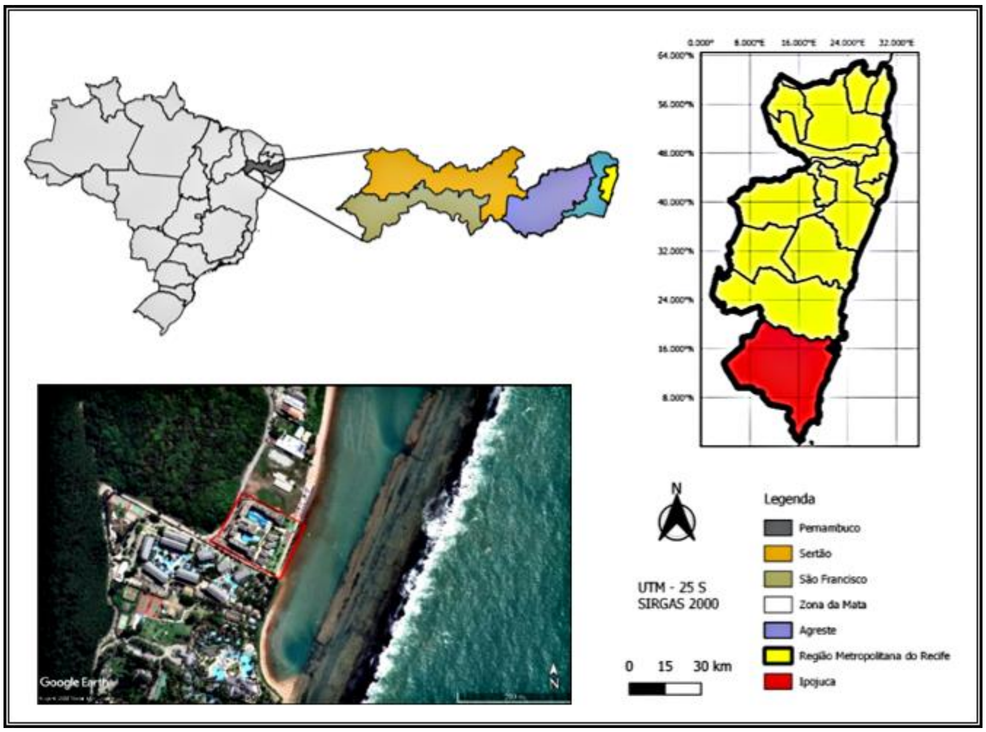

Figure 3 – Location map of the study area
Source: Authors (2023)

The municipality of Ipojuca has a tropical climate that contributes to high temperatures almost all year round, with hot summers and highs that can reach 30º C. In winter presents more rainfall, being rainy and mild can reach 15 ºC It is located in an area with high rainfall, with an annual average of 1239 mm. In June the relative humidity of the air reaches 83.46%. The predominant vegetation is of the sub-evergreen forest type (Atlantic Tropical Forest), which is gradually taken over by sugarcane cultivation in the coastal humid zone. The coastal vegetation of Pernambuco is mainly represented by undergrowth vegetation, cerrado, Atlantic forest and mangroves that meet due to the influence of the tides (IBGE, 2023). The hydrography of Pernambuco is formed by the rivers, São Francisco, Capibaribe, Ipojuca, Una, Pajeú and Jaboatão. The Ipojuca River is characterized by being the most extensive in Pernambuco, with water springs in the area of the agreste running east-west, crossing a course of 320 km. Its body water has been greatly modified during the last years, as a result of the installation of the Suape Port Complex (CITY HALL OF IPOJUCA, 2023).

The municipality of Ipojuca is considered one of the largest industrial centers in Pernambuco, having one of the main ports in the northeast and a well-developed sector of the transformation industry. The predominant economic activity in the municipality is sugarcane monoculture, historically focused on filling the international market, although it also supplies the regional market. The growing demand for the product has been causing the expansion of the cultivation area previously limited to the floodplains of the rivers that cross the entire region (CITY HALL OF IPOJUCA, 2023)

Each year conquering more tourists, the Muro Alto beach sector is characterized by its native vegetation, coconut groves and natural pools, in addition to attractive tours. In the area you will find a residential dynamic of high standard condominiums, luxury hotels and inns.

The study area has a plot of approximately 6,160.93m², where is located a high-standard residential condominium, built since 2005 by the sea of Muro Alto, and with an extension of 120m facing the coastline. The study area had a self-sinking sea wall, where the existing infrastructure was in a very poor state of conservation, offering high risk of collapse and danger to the population.. The existing wall has been degraded due to the advance of the sea and the erosion caused by the vortex of the waves, as shown in Figure 4. The outflow of sand from the abrasion platform has contributed to the collapse of this infrastructure.

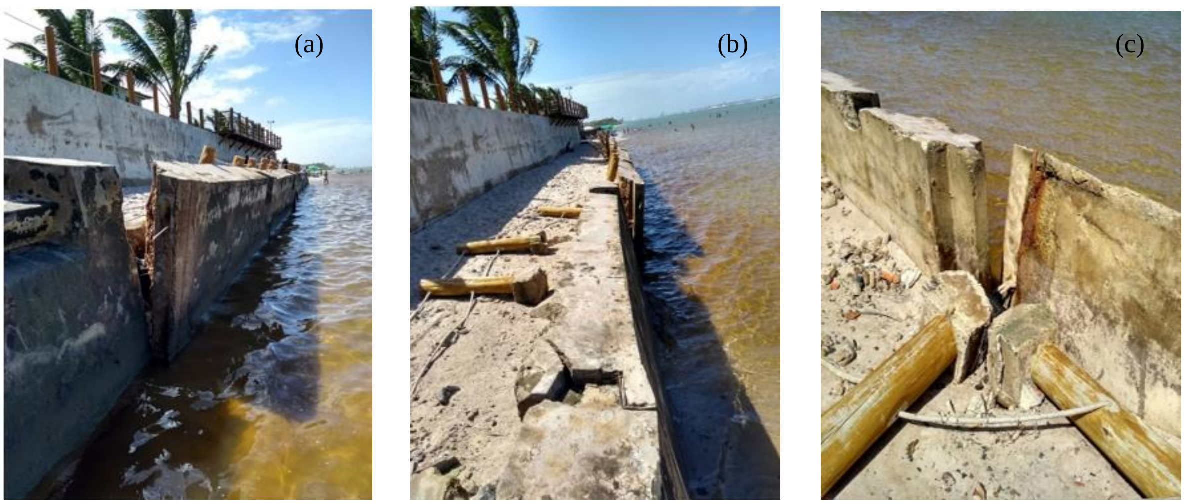

Figure 4 – (a,b,c) situation of the existing maritime retaining wall, Ipojuca/PE.
Source: Authors (2023).

4. Methodology

The research is applied with practical and immediate purpose, using a quantitative-qualitative approach to present a new system of protection to the coastal erosion process. The analysis was performed between the years 2018 and 2021, including the situation of the study area before, during and after the intervention in betonbloc system.

4.1 Identification of the Urban Transformations

Identifying urban transformations consists in observing the progress of coastal erosion over time. For this, it was necessary to analyze the historical series of urban changes, to understand which factors contributed to this process. Images of the years 1985, 2006 and 2019, with scale of 1:100, obtained through the software Google Earth Pro Version 7.3.3.7786 (64-bit), which is based on the Geodesic Reference System WGS 84.

Using the add polygon and/or add path tool (located on the Google Earth Pro toolbar), the vectorization of land use and occupation features was carried out. With the quantification of the areas, it was possible to verify the percentage of layer contribution in relation to the total area of the studied region, according to Equation 1 (MOURA, 2021):

$$A_c (\%) = \frac{Ac}{At} \times 100$$

Where:

A_c (%): Percentage of area contribution from the land use and land cover feature;

$A_{c:}$ Land use and occupation feature area (ha);

$A_{t:}$ Total area of the studied region (ha).

Table 1 shows the features of urbanized area, natural vegetation area, exposed soil area, emerse beach area and bodies water area. In addition, the changes in the coastline were located.

Table 1 – Classification of types of features

FEATURES	DESCRIPTION
Urbanized Area	Surface waterproofed by anthropic action (buildings and/ or paved areas).
Area of Natural Vegetation	Area with presence of large and/or small vegetation cover (trees, undergrowth).
Area of Exposed Soil	Area with presence of large and/or small vegetation cover (trees, undergrowth).
Emersed Beach Area	Area covered and discovered periodically by the waters, plus the subsequent strip of detrital material (sand, gravel, pebbles and boulders).
Area of Water Bodies	Area with significant accumulations of surface water.

Source: Moura (2021).

4.2 Elaboration of the executive project

As an alternative to contain erosion was verified the possibility of creating a physical barrier (walls of containment) able to support the energy that the sea exerts on the containment, dissipate with greater amplitude the waves, thus weakening its vortex and decreasing as much as possible the suppression of the abrasion platform. The maritime containment project proposal included the construction and replacement of the entire existing retaining wall for the BetonBloc system, which has a deeper foundation.

4.3 Construction process and post-construction monitoring

In the phase that happened the construction of the wall the process of manufacturing the blocks, logistics of execution, among others, was evaluated. The monitoring of the erosive process was carried out through the planialtimetric topographic survey, being essential to determine the level 0.00m of the sea and the design that the water makes on the beach in the low sea of syzygy*. Thus, to certify the efficiency of the system, there was a monitoring of the beach profile before and after construction and four more measurements every three months. The control of the beach profile aimed to characterize the dynamics of sedimentation of the beach over time, identifying the main indicators of coastal erosion, and define the risk classification before, during and after the execution of the work.

To monitor the beach profile before the work, two georeferenced planialtimetric topographic surveys were carried out, one at the beginning of the project named “Primitive – May/2019” and the other “Pre Work – October/2019”, with an interval of five months from one to the other. Based on the topography marks on the wall, for greater accuracy in monitoring the topographic sections were always made in the same places. At the end of the work, measurements called "Post Work - February/2020" were carried out. Then, the system efficiency results of the following measurements were highlighted and compared:

- “Primitive – may/2019” and “Pré work – october2019”
- “Pré work – october/2019” e “Post work – february /2020”

5. Results and discussion

The construction of thematic maps based on the vectorization of orthophotocharts, images of aerial photographs allowed the analysis of the evolution of each of the typologies of land use and occupation. In Figures 5 to 7, it is possible to observe the urban fabric of the year 1985, 2006 and 2019, respectively, highlighting the areas of exposed soil, water body, emerged beach, urban area and vegetation.

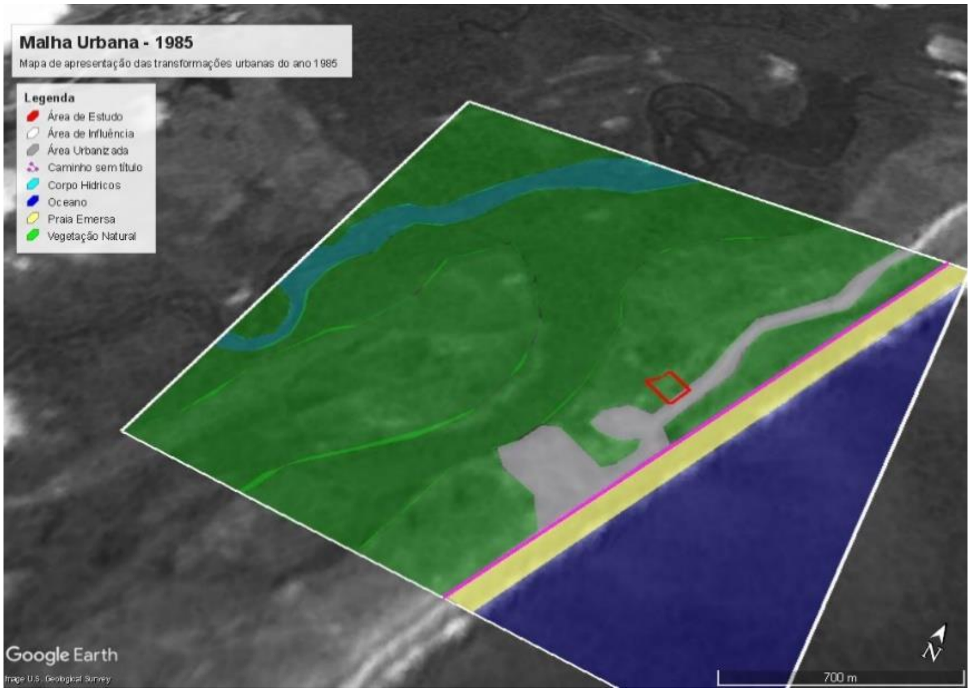

Figure 5 – Urban transformations 1985
Source: Authors (2023)

* Astronomy term that generically identifies the alignment of three bodies belonging to a gravitational system. They occur during new and full moons and are characterized by high tides and very low low tides.

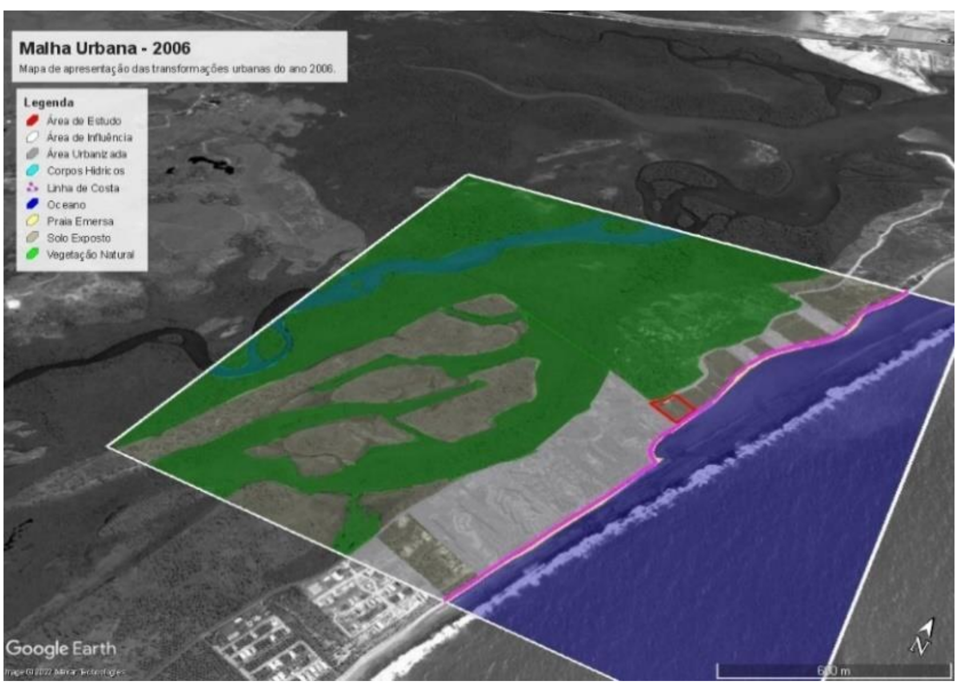

Figure 6 – Urban transformations in 2006
Source: Authors (2023).

Figure 7 – Urban transformations of the year 2019
Source: Authors (2023).

Na Tabela 2 são apresentadas a área, em hectares (ha), e a porcentagem (%) de ocupação de cada FEATURE do solo com o decorrer dos anos. Na Tabela 3 é demonstrada a taxa de variação de cada FEATURE, em percentagem (%), comparação de cada um dos três anos de medição com o seu ano anterior.

It is important to highlight the causes of coastal erosion in the area of influence, as there was a great advance of the sea, increased urbanized areas on the coast and funneling of water bodies, with the presence of silting points. The level of urbanization increased 257% between 1985-2019, a fact caused by the decrease in the area of natural vegetation and strangulation of the emerse beach. These factors were essential to impact the remodeling of the coastline in the area of influence.

Table 2 – Area and percentage of occupation of each feature of land use and occupation over the years.

FEATURE	**OCCUPIED AREA**					
	1985		**2006**		**2019**	
	hectares	**%**	**hectares**	**%**	**hectares**	**%**
Urbanized Area	22,2	4	38,3	7	57,1	11
Water Bodies	30,6	6	25,53	5	21,9	4
Natural Vegetation	439,6	85	223,34	43	202	39
Emersed Beach	22,6	4	3,66	1	5,48	1
Exposed Soil	0,1	0	86,18	17	60,67	12
Area of Influence	515		515		515	

Source: Authors (2023).

Table 3 – Variation rate of each feature of land use and occupation with the years.

FEATURE	VARIATION RATE (%)		
	1985 a 2006	**2006 a 2019**	**1985 a 2019**
Urbanized Area	173	149	257
Water Bodies	83	86	72
Natural Vegetation	51	90	46
Emersed Beach	16	150	24
Exposed Soil	8618	70	6067

Source: Authors (2023).

5.1 Evaluation of the executive project

The retaining wall in BetonBloc was designed with a foundation built below sea level 0.00 m. This characteristic has the function of preventing transversal sediment transport under the wall foundation, thus avoiding the destabilization of the retaining wall (Figure 8).

It was used 1,671 precast concrete blocks with horizontally locked male and female fitting, seated with vertical joints, without use of grouting, frame and tie rods, as shown in Figure 9 and Figure 10. The maritime retaining wall had a total extension of 121.60m, with frontal extension (east) of 00.80 m, lateral extension (south) of 6.40 m and lateral extension (north) of 14.40 m, as Figure 10.

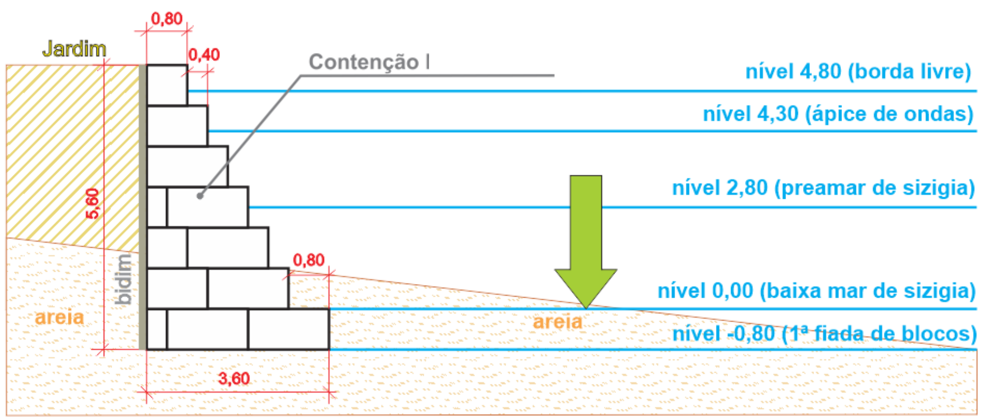

Figure 8 –Transverse profile of the maritime retaining wall in BetonBloc, Ipojuca/PE.
Source: Authors (2023).

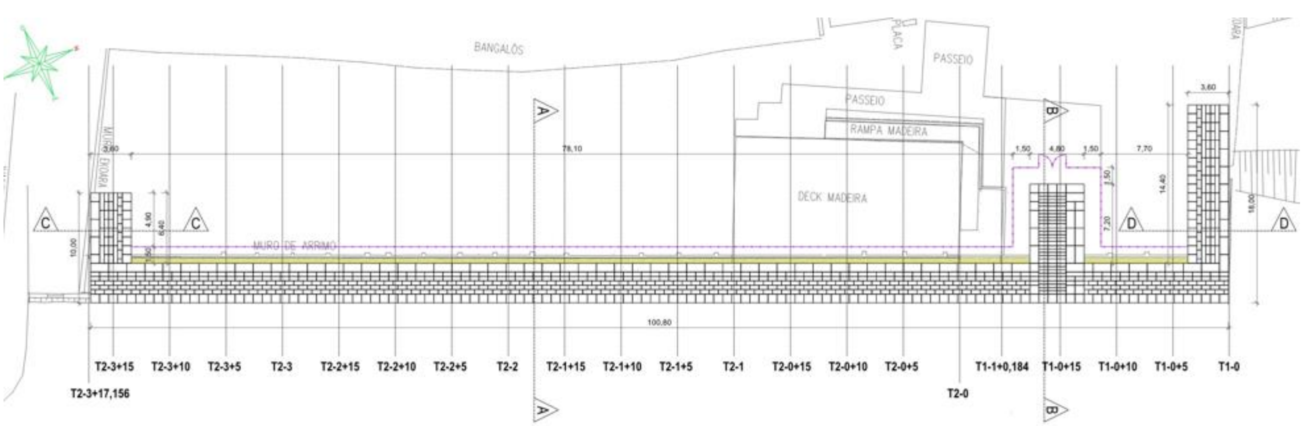

Figure 9 – Floor plan - maritime containment executive project in BetonBloc, Ipojuca/PE
Source: Authors (2019).

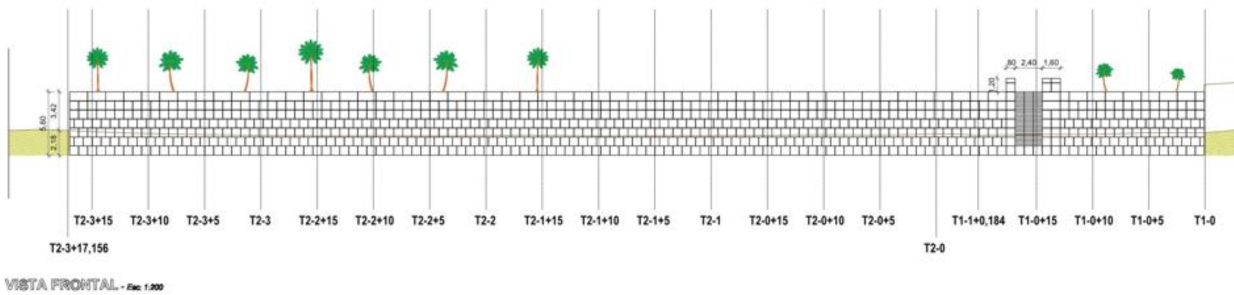

Figure 10 – Front view - maritime containment executive project in BetonBloc, Ipojuca/PE.
Source: Authors (2019).

Table 4 – Design characteristics, Ipojuca/PE.

DESCRIPTION	AMOUNT OF BLOCKS (unit)	CONCRETE VOLUME (m³)	CONTAINMENT LENGTH (m)
Manufacture, supply and assembly of **articulated concrete blocks**, precast, BetonBloc type, with average dimensions 0.80m x 0.80m x 1.60m, with 35MPa concrete.	1.650,00	1.478,71	119,20
Manufacture, supply and assembly of articulated concrete blocks, precast, **staircase** BetonBloc type, with dual function: pedestrian access (standard NBR 9050/2015) and maritime containment	21,00	18,82	2.4
Total	**1.671,00**	**1497,53**	**121,60**

Source: Authors (2019).

5.2 Analysis of the construction process

In the manufacturing process of the blocks, metallic molds were used, reinforced on top of metallic plates. The concrete was poured directly into the mold, where there were no traces of wood, bags, sand and any other input in the manufacturing process, ensuring the homogeneity of the concrete, figure 11. After 3 days of concreting the blocks were unformed and stored in the shed. Only the blocks that would be used on the day of assembly were transported to the construction site. In the manufacturing process of the blocks, metallic molds were used, which were assembled on top of metallic plates.

The construction of the concrete blocks was carried out in internal areas of sheds, already existing near the site of the work, not being necessary therefore, the construction of new buildings to manufacture them. A period of 60 days is required for total block manufacturing.

Although it was a system that had a total cost close to others available on the market, BetonBloc stood out in some factors such as: short execution time; there was no need for new facilities for the manufacture of concrete blocks; used only a truck to transport the blocks; electric excavator for material excavation; truck with telescopic handler for transporting and launching the blocks; involves only 6 employees for execution, in addition to not generating short-term maintenance.

Figure 11 – Modeling and concreting of blocks a) concreting b) the concrete block
Source: Authors (2019).

Figure 12 shows the implementation of maritime containment already at the completion stage of the work.

Figure 12 – Maritime containment execution / Ipojuca -PE
Source: Authors (2019).

5.3 Post-work evaluation

It was found that the concrete block system - BetonBloc, used as sea containment, fulfilled the function of dissipating wave impact energy upstream, and downstream to support the weight that the terrain creates on the retaining wall. For the planialtimetric topographic surveys "Primitive - May/2019" and the "Pre-Work - October/2019", it was verified that in the period before the execution of the work, the profile of section 0+0.00 presented a loss of 28 cm of sand height (Figure 12-a). In this measurement, the profile that stood out the most with loss of sand height was 0+10.00 with 71cm less height (Figure 12-b).

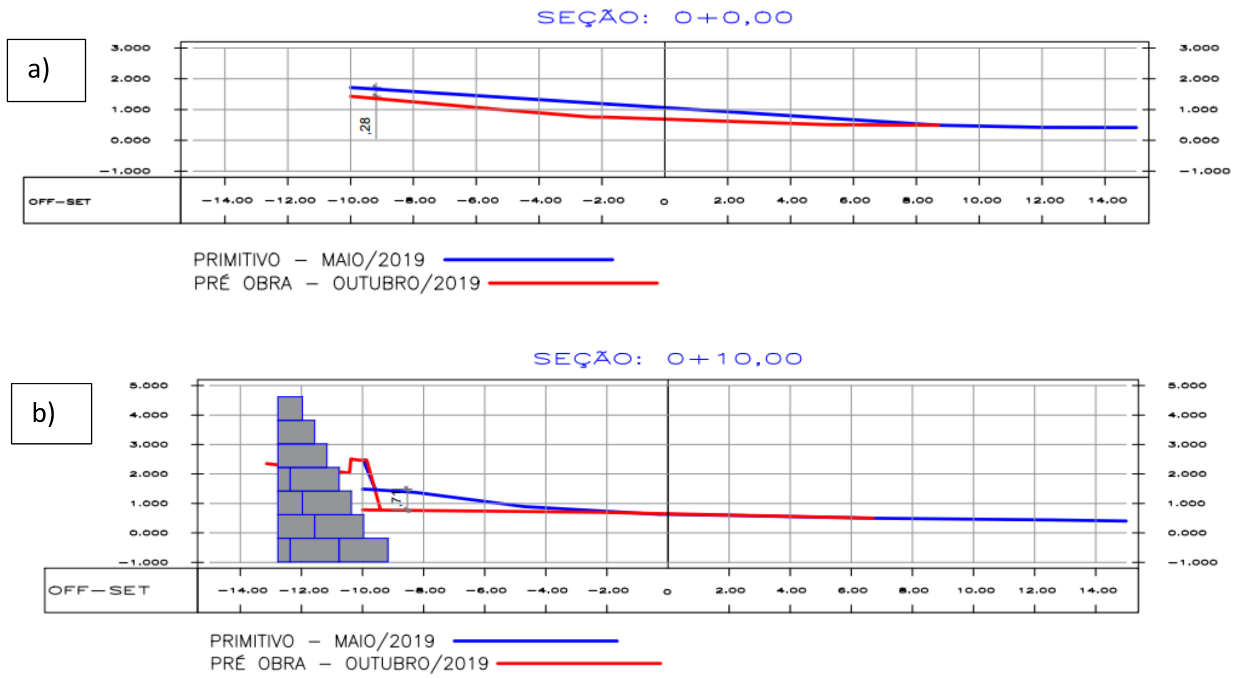

Figure 12 – Comparison of maritime containment topographic levels: a) primitive-May/2019; b) pre-construction - October/2019
Source: Authors (2019).

Table 5 shows all sections and their respective results of loss of sand height, showing the accelerated erosion process that existed before the work.

Table 5 – Overlaps of primitive x pre-work profiles and pre-work and post-work profiles.

SECTION (m)	PRIMITIVE (05/2019) x PRE WORK (10/2019)	PRE WORK (10/2019) x POST WORK (02/2020)
0+0,00	-0,28	0,80
0+10,00	-0,71	0,95
1+0,00	-0,67	1,08
1+10,00	-0,61	1,15
2+0,00	-0,50	1,24
2+10,00	-0,34	1,25
3+0,00	-0,34	1,20
3+10,00	-0,34	1,25
4+0,00	-0,38	1,35
4+10,00	-0,40	1,34
5+0,00	-0,55	1,18
5+10,00	-0,35	0,70

Source: Authors (2019).

In the monitoring of the post-construction beach profile, the first measurement was carried out in February/2020, after 30 days of completion of the work, where it was called "Post Work - February/2020" which was the beginning of monitoring the beach profile of the following 12 months. In the measurement "Pre Work - October/2019" and "Post Work - February/2020", there was a gain of 80 cm of sand height in section 0+0.00 (Figure 13-a). The section 4+0.00 was the one that stood out with an increase of 1.35 cm of sand height, indicated in Figure 13-b.

Analyzing the overlapping of the Pre Work – October/2019 and Post Work – February/2020 profiles, it was found that the beach profile immediately after the work is higher than the profile before the work in all measurement sections (Table 5).

It was found that even with accumulated erosion occurring in some periods, the sand level is still above the level it was before the implementation of the maritime defense structure, showing that after the completion of the work, the containment system presented satisfactory efficiency

Every concrete structure, in any environment, is subject to deterioration by agents present in the environment, but the stronger and more aggressive the environment, the faster the process of deterioration of the structure. In nature, one of the most aggressive factors to concrete is contact with tidal waters. The betonbloc precast concrete block system was installed at the study site, considering its durability and strength

The containment perimeter totaled 121.60 linear m and the total cost of the work reached 1,402,226.57 (one million, four hundred and two thousand, two hundred and twenty-six reais and fifty-seven cents). The execution of the betonbloc modular concrete block system applied as a maritime retaining wall cost 11,907.00 R$ (eleven thousand, nine hundred and seven reais) per linear meter of retaining.

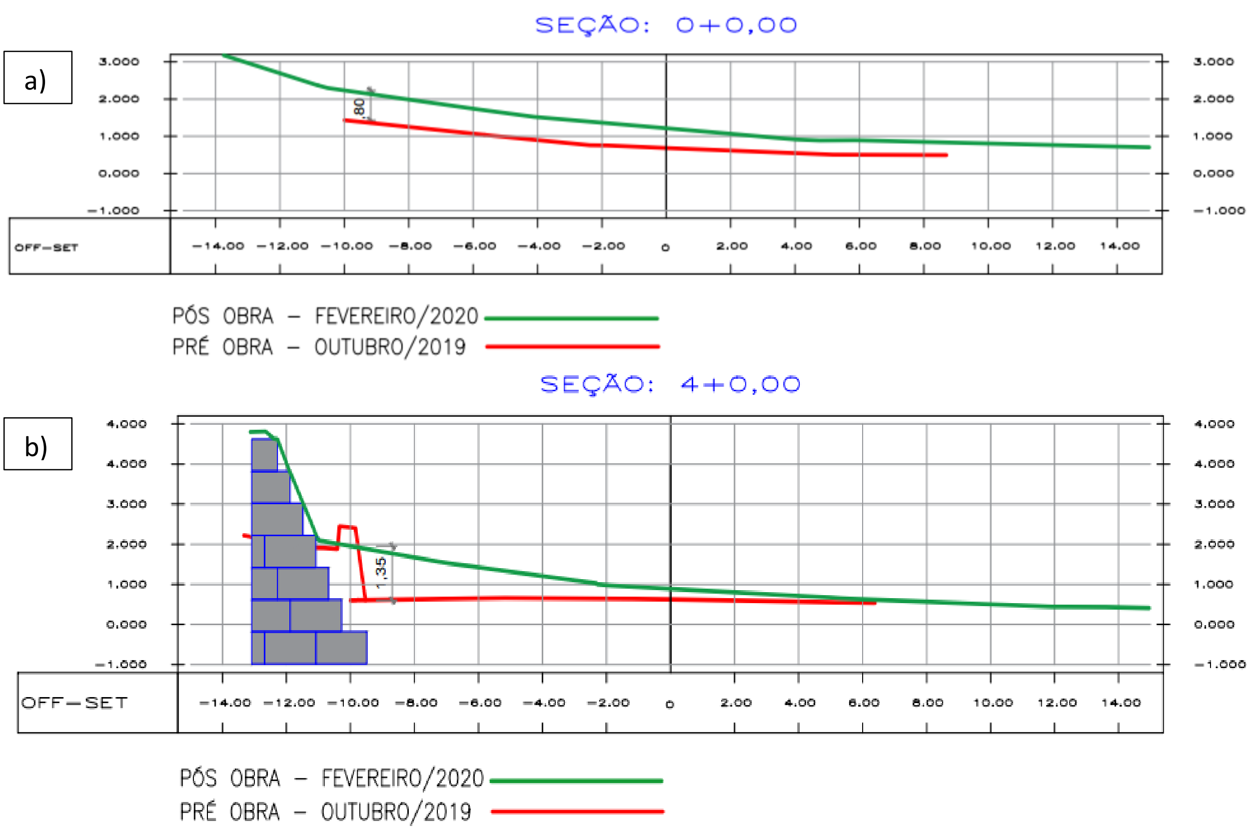

Figure 13 – Comparison of topographic levels of maritime containment: a) pre-work – October/2019; b) after work - February/2020

Source: Authors (2020).

6. Conclusion

Among the results found it was possible to observe that in the last 60 years there was an intense modification of the coastline, caused by the advance of the sea and the increase of urbanization, intensifying the coastal erosion in the study area, it is necessary to modify the existing maritime containment. The intervention proposal chosen was the use of a system of articulated, precast concrete blocks, with the aim of stabilizing the retaining wall, thus avoiding the movement of sedimentary material for the foundation of the wall..

Through studies of the morphodynamic behavior of the beach profile, the variation of the cross-section of the beach was observed, on days of high tides, the system was efficient in stabilizing the coastline and minimizing the impact of wave force. With the application of this method there was a fast production of the blocks and execution time for the containment, reaching three months for the conclusion of the work.

Finally, the Betonbloc system showed results that prove the effectiveness of its functionality, and can be used as a decision support in the use of precast concrete blocks for containment purposes.

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