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The Use of Permeable Pavements to Mitigate Flooding in Large Urban Centers

O uso de pavimentos permeáveis como mitigação de alagamentos em grandes centros urbanos

El uso de pavimentos permeables para mitigar inundaciones en los grandes núcleos urbanos

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RESUMO
A crescente urbanização tem desafiado as cidades a enfrentar problemas ambientais complexos, como enchentes urbanas, degradação dos recursos hídricos, bem como incremento da geração e má gestão de resíduos sólidos urbanos. Nesse contexto, a busca por alternativas sustentáveis na construção civil tornou-se uma prioridade para enfrentar essas questões de forma eficaz. Uma solução inovadora e promissora é o pavimento permeável, que permite a passagem de água através de sua estrutura, minimizando o impacto negativo do desenvolvimento urbano no meio ambiente. Sendo assim, a presente pesquisa teve como objetivo propor a implantação de pavimento permeável com uso dos Resíduos de Construção e Demolição-RCD em praças na Cidade do Recife-PE, com foco na mitigação de alagamentos. Foram cruzados dados de praças, parques e áreas verdes do Recife com os pontos críticos de alagamento, identificando áreas passiveis de utilização desta tecnologia. Este trabalho também indica a substituição do agregado convencional, a brita, por RCD, tornando uma alternativa ainda mais sustentável e técnica/economicamente viável. Essa proposição visa mitigar os efeitos dos alagamentos causados por eventos climáticos extremos. Os resultados apontam uma área passível de utilização como pavimento permeável de 8.897,72m² em 15 praças da Cidade. Desse modo, obteve-se volume útil disponível para reservação de 1.761.748,56 litros de água, auxiliando na mitigação do problema com alagamentos na capital pernambucana.
PALAVRAS-CHAVE: Pavimentos Permeáveis. RCD. Alagamentos.

SUMMARY
Increasing urbanization has challenged cities to face complex environmental problems, such as urban flooding, degradation of water resources, as well as increased generation and poor management of urban solid waste. In this context, the search for sustainable alternatives in civil construction has become a priority to effectively address these issues. An innovative and promising solution is permeable pavement, which allows water to pass through its structure, minimizing the negative impact of urban development on the environment. Therefore, the present research aimed to propose the implementation of permeable pavement using RCD in squares in the City of Recife-PE, with a focus on sustainable urban drainage. Data from squares, parks and green areas in Recife were compared with critical flooding points, identifying areas that could be used for this technology. This work also indicates the replacement of conventional aggregate, gravel, with construction and demolition waste, making an alternative even more sustainable and technically/economically viable. This proposition aims to mitigate the effects of flooding caused by extreme weather events. The results indicate an area capable of being used as permeable pavement of 8,897.72 m² in 15 squares in the city. In this way, a useful volume available for reservation of 1,761,748.56 liters of water was obtained, helping to mitigate the problem with flooding in Pernambucos's capital.
KEYWORDS: Permeable pavement; RCD; Flood.

RESUMEN
La creciente urbanización ha desafiado a las ciudades a enfrentar complejos problemas ambientales, como inundaciones urbanas, degradación de los recursos hídricos, así como una mayor generación y mala gestión de residuos sólidos urbanos. En este contexto, la búsqueda de alternativas sustentables en la construcción civil se ha convertido en una prioridad para abordar de manera efectiva estos temas. Una solución innovadora y prometedora es el pavimento permeable, que permite el paso del agua a través de su estructura, minimizando el impacto negativo del desarrollo urbano en el medio ambiente. Por lo tanto, la presente investigación tuvo como objetivo proponer la implementación de pavimento permeable utilizando Residuos de Construcción y Demolición-RCD en plazas de la ciudad de Recife-PE, con enfoque en la mitigación de inundaciones. Se compararon datos de plazas, parques y áreas verdes de Recife con puntos críticos de inundación, identificando áreas que podrían ser utilizadas para esa tecnología. Este trabajo también indica la sustitución del árido convencional, la grava, por RCD, haciendo una alternativa aún más sostenible y técnica/económicamente viable. Esta propuesta tiene como objetivo mitigar los efectos de las inundaciones provocadas por fenómenos meteorológicos extremos. Los resultados indican un área susceptible de ser utilizada como pavimento permeable de 8.897,72 m² en 15 plazas de la ciudad. De esta forma, se obtuvo un volumen útil disponible para reserva de 1.761.748,56 litros de agua, ayudando a mitigar el problema de las inundaciones en la capital de Pernambuco.
PALABRAS CLAVE: Pavimentos permeables. RCD. Inundación.

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1 INTRODUCTION

The increase in urbanization, surface impermeability, urban solid waste, and the recurrence of extreme events result in more floods and higher risks to riverside areas, hills, and slopes. In addition, the disorderly population growth, the lack of integrated urban management, and the insufficiency of sewage and stormwater systems bring severe problems to cities, most of which still do not have Urban Development Master Plans. Given this scenario, it is noted that urban areas are becoming increasingly impermeable, contributing to the increase in surface runoff volumes and speed (COUTINHO, 2011).

Another issue associated with intense urbanization is the generation of Urban Solid Waste (USW). It is worth noting that some of this waste is not correctly separated and disposed of, which causes obstructions in urban drainage systems (BRASIL, 2022a). In the national context, in the city of Recife, Pernambuco state, data from the National Sanitation Information System (SNIS) indicate that the amount of rubble, limestone, or shrapnel collected in the reference year (2019) by the City Hall or a company hired by it was 144,391.00 t/year.

Almost all this waste is sent to landfills, and another part is improperly discarded on public roads, parks, squares, riverbanks, and canals, burdening the public urban cleaning system. Considering the context presented, one of the possible ways to reuse this waste is to design permeable pavement, partially replacing gravel with aggregate from construction and demolition waste. This project aims to reuse and recycle Construction and Demolition Waste (CDW) to reduce the impacts generated by the Civil Construction (CC) industry and other sectors involved in the process. It is a procedure that reduces the extraction areas of natural aggregates and preserves natural resources (MATAR; BARHOUN, 2020).

According to the Intergovernmental Panel on Climate Change (IPCC), Recife (PE) ranks 16th among the cities most vulnerable to climate change worldwide. Climate change can significantly impact urban centers' drainage systems. This situation becomes even more severe in coastal urban plains like Recife, which has disorderly urbanization, high rainfall rates, and a drainage infrastructure vulnerable to daily tidal variability (SILVA JUNIOR et al., 2020).

Based on this scenario, why not use urban public spaces like squares for drainage since they can be found in all large urban centers? Squares play a vital role as public spaces for socializing and leisure. Although the connection between squares and drainage is rarely discussed, they can play a fundamental role in efficiently managing city rainwater. Permeable pavement is still discredited and infrequently used in infrastructure works throughout the country. Therefore, this study focuses on searching for solutions and alternatives for permeable pavement as a mitigating technique in urban drainage, adding to the sustainability theme by incorporating recycled material from Construction and Demolition Waste (CDW).

2 OBJECTIVE

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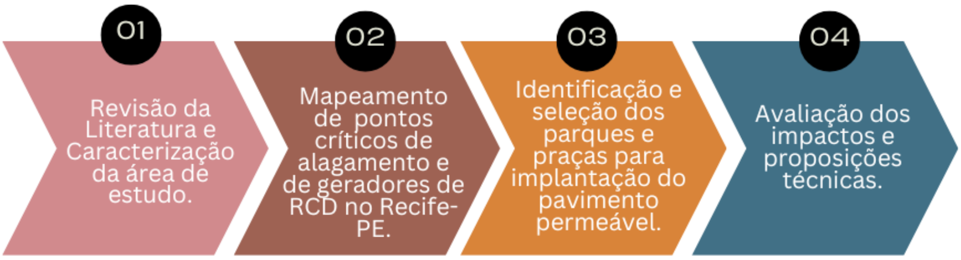
To evaluate the implementation of permeable pavements in squares, alongside CDW reuse, to help mitigate flooding effects in Recife (PE).

3 METHODOLOGY

Regarding the methodological approach, this research is characterized as mixed, qualitative-quantitative, and descriptive-exploratory, adopting the city of Recife (PE) as a case study. According to Yin (2001), case studies are an exploratory strategy and a distinctive form of empirical research. The methodological steps are presented in Figure 1.

Figure 1 - Methodological Steps



[Literature Review and Study Area Characterization |
Mapping of Critical Flooding Points and CDW Generators in Recife-PE |
Identification and Selection of Parks and Squares for Permeable Pavement Implementation
| Assessment of Impacts and Technical Proposals]
Source: The authors (2024)

3.1 Study Area Characterization

To characterize the study area, the Recife City Maintenance and Urban Cleaning Authority (EMLURB) was consulted to identify the location of squares, parks, and open spaces. Identifying these public facilities was crucial for achieving the objectives proposed in this paper, given that they are generally areas with significant potential for permeable pavement implementation.

A consultation was also conducted with the Brazilian Institute of Geography and Statistics (IBGE) to collect data regarding the population, area, demographic density, and number of households. Recife has an area of 218.843 km² and a population of 1,488,920 (IBGE, 2022).

3.2 Mapping of Critical Points and Selection of Squares

After characterizing the city of Recife, 525 public facilities were found, distributed among squares, plazas, and parks. Sixteen were selected to verify the possible implementation of a compensatory measure for urban drainage. From the 525 squares, parks, and open spaces

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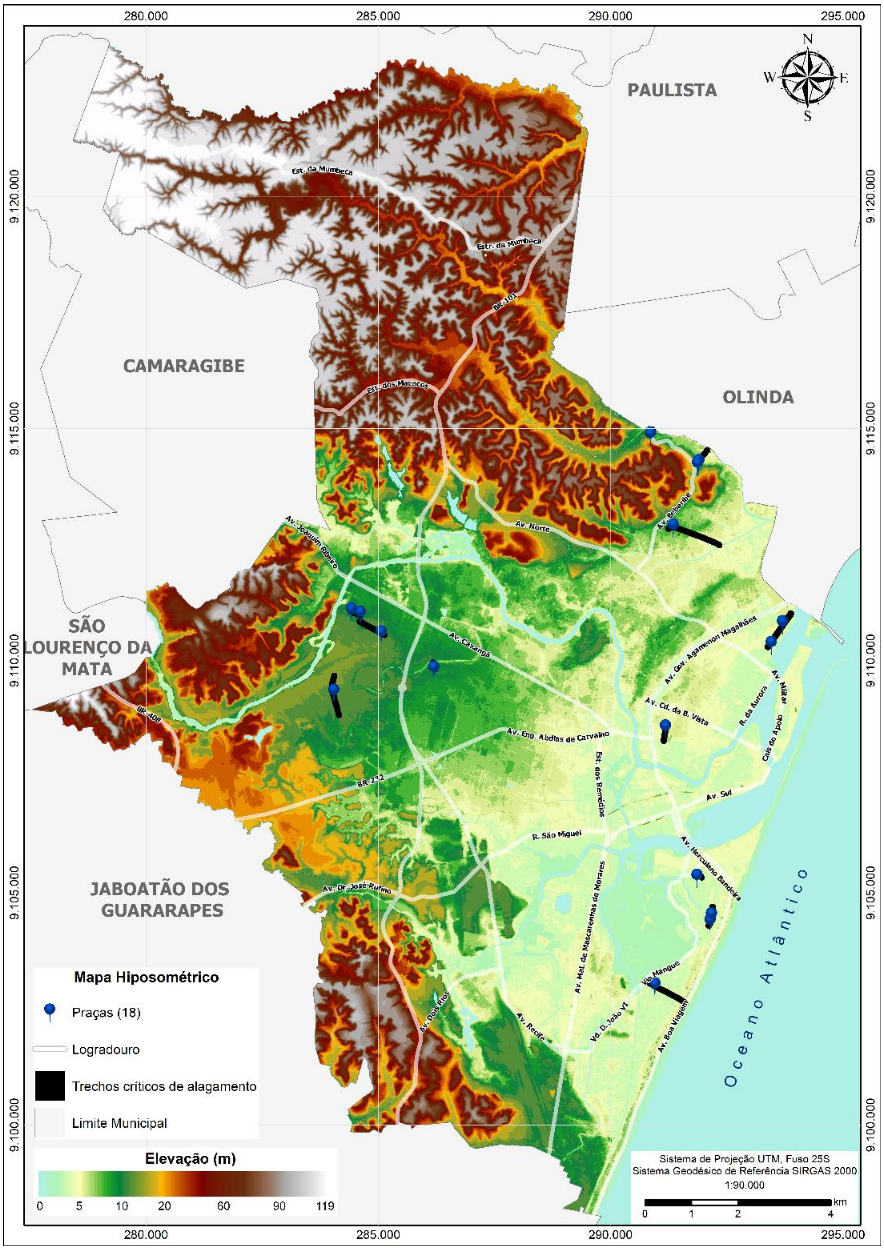
identified, we defined the radii of influence of the critical flooding points of 10 to 100 meters. Based on the results, we used a 20 m radius covering 15 squares, as presented in Figure 2.

Figure 2 - Squares x Critical Flooding Points x 20m Influence Radius



[Hypsometric Map | Squares | Street | Critical Flooding Sections | Municipal Boundary | Elevation | UTM Projection System, Zone 25S | Geodetic Reference System SIRGAS 2000]

Source: The authors (2024)

A planialtimetric survey on the Pernambuco Tridimensional—PE3D portal was used to select public facilities. It is also worth noting that the squares located upstream in the basins or sub-basins play a relevant role in the amortization of surface runoff to downstream points.

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At this stage, a consultation was also carried out on the registry of irregular solid waste disposal points mapped by Emlurb's inspections. In addition, the need for registration and monitoring of construction waste transportation companies, as recommended in the Urban Cleaning and Urban Solid Waste Management Code of the Municipality of Recife, was considered, mapping large generators of construction and demolition waste.

For small generators, up to 1.00m³, ecostations are available for the correct disposal of CDW, with these locations having adequate space and facilities to receive the waste.

3.3 Assessment of Impacts and Technical Proposals

At this stage, an on-site survey was carried out in the 15 squares within a 20-meter radius of the critical flooding points. This survey aimed to define an area for installing permeable pavement samples (in m²) in each square, measure the water level, and take photographs.

Finally, the volume of water absorbed in the public facilities was quantified based on a pre-defined cross-section. It should also be noted that the areas chosen for installation are exclusive for pedestrian traffic, allowing construction without significant concerns.

As recommended by ABNT NBR 16416 (2015), in this system, the precipitated water is temporarily stored in the pavement structure and does not infiltrate the subgrade; the water is later drained. Equation 1 was applied to quantify the volume of water to be absorbed/retained.

$$V = A \times h \times n \qquad \text{(Eq. 1)}$$

Where:
V = useful volume of absorbed/retained water (m³);
A = area of permeable pavement (m²);
h = height of the drainage layer of the pavement with crushed stone 25 (commercial) from CDW (m);
n = porosity of crushed stone 25 (commercial) (%).

4 RESULTS

Figure 3 shows a map with the registry of critical points of irregular solid waste disposal composed mainly of CDW. The figure shows that irregular solid waste disposal points are spread throughout the city according to their Political Administrative Regions (RPA). Neighborhoods such as Santo Amaro, Ilha do Leite, Ilha do Retiro-RPA 01; Vasco da Gama, Nova Descoberta, Brejo de Beberibe; RPA 02 and Boa Viagem, RPA 06 are the most prominent on the heat map. However, this does not mean that the population of these neighborhoods discards more waste irregularly. This act is usually committed by generators who hire operators to transport their waste and ignore its correct disposal.

Periódico Técnico e Científico Cidades Verdes
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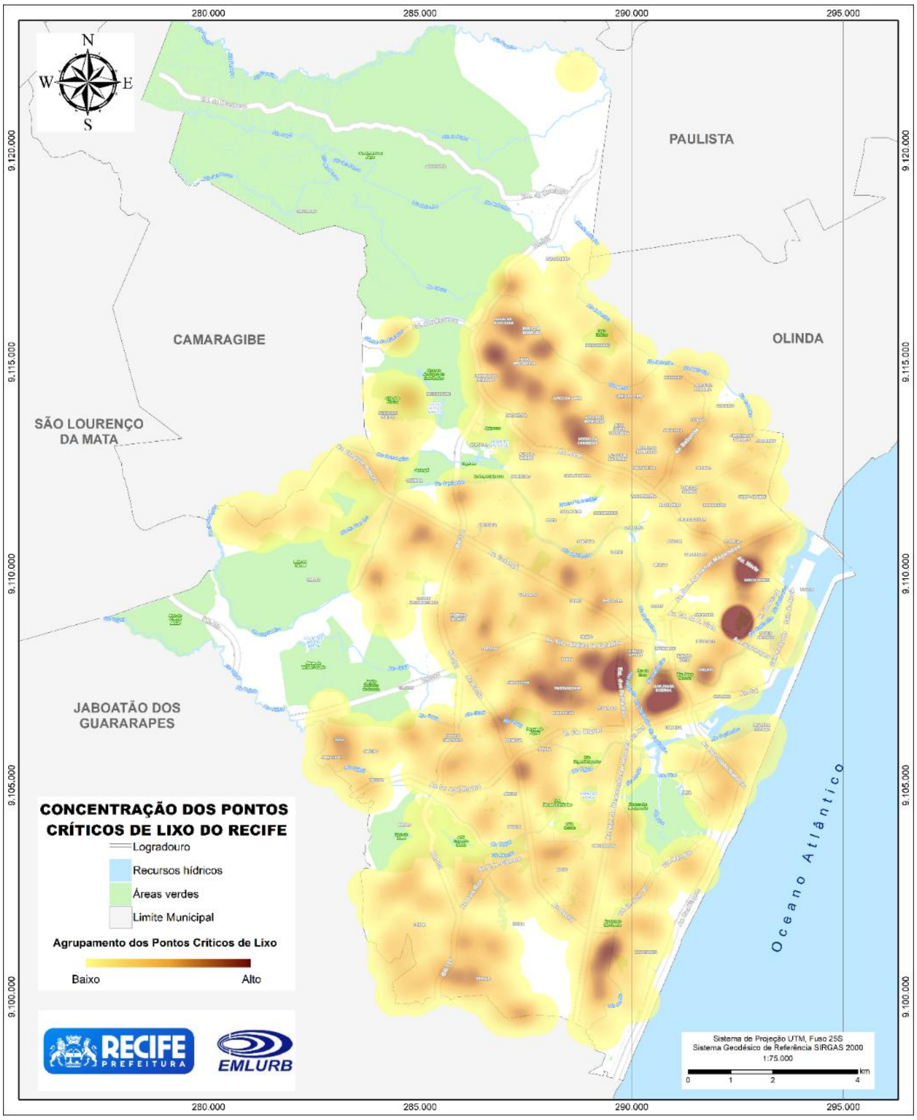
Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 12, N. 38, 2024

Figure 3 - Registration of Critical Points of Irregular Solid Waste Disposal



[Concentration of Critical Waste Points in Recife | Public Road / Street | Water Resources | Green Areas | Municipal Boundary | Grouping of Critical Waste Points]
Source: Emlurb (2023)

Given the presented methodology, it was possible to use public areas to mitigate flood effects. Using permeable pavements with CDW in parks, squares, and open spaces constitutes an efficient and sustainable drainage solution. In recent years, Recife has faced challenges related to climate change and increased extreme rainfall. Heavy rainfall events and flooding have become more frequent worldwide, highlighting the need for adaptation and mitigation measures to deal with its impacts. Figure 4 shows the proposed cross-section for implementation. It is essential to highlight that the proposed granular materials are all recycled from construction waste.

Periódico Técnico e Científico Cidades Verdes
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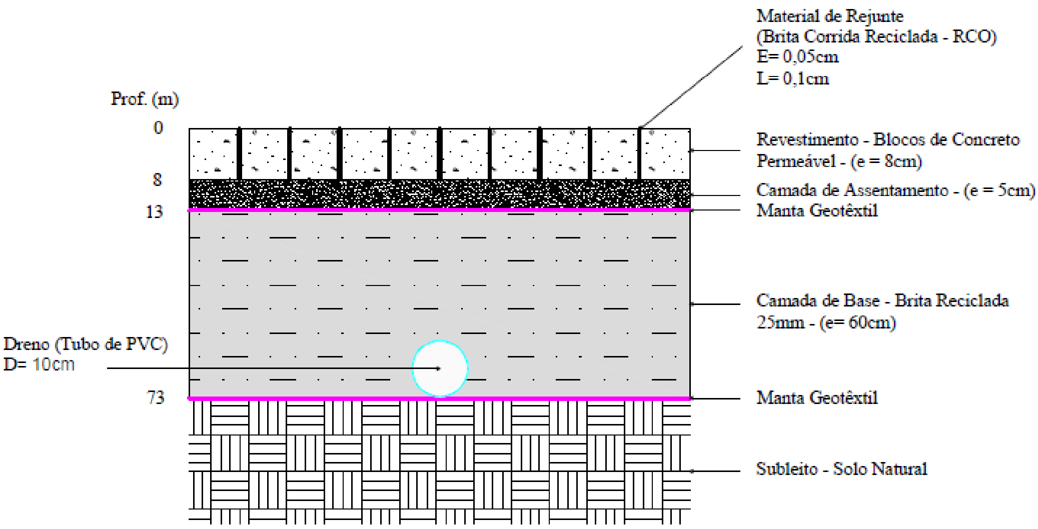
Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 12, N. 38, 2024

Figure 4 - Proposed Typical Cross-Section for Implementation in Selected Public Spaces



[Depth | Drain (PVC pipe) | Grout material (Recycled gravel – RCO) | Coating – Permeable concrete blocks | Settling layer | Geotextile blanket | Base layer – Recycled gravel | Geotextile blanket | Subgrade – Natural soil]

Source: The Authors (2024), adapted from Menezes (2023)

The results of the studies on gravel 25 indicated a void index of 52.8%, with the test performed as a material in a loose state and an index of 49.8% for the material in a compacted state. Therefore, the porosity of the chosen gravel in the compacted state was 33%, and in the loose state, 35%. Table 1 shows the comparison between the quantitative void index and the porosity of the material.

Table 1 - Void Index vs. Porosity

Crushed Stone 25	Compacted	Loose
Drainage Base	%	%
Void Index	49%	53%
Porosity	33%	35%

Source: The Authors (2024)

The study's objective was not to design a permeable structure; otherwise, several other geotechnical tests, IDF curve calculations, and maximum rainfall and recurrence times determination, among others, would be necessary. The study aimed to show the possibility of

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using specific public spaces as drainage structures to absorb and retain water that usually runs off the impermeable surfaces of large urban centers.

Figure 5 shows an example of a photographic report made in the squares chosen for this study. It illustrates the equipment chosen, the existing drainage network, the critical flooding point within the radius of influence, and the found water level.

Figure 5 - Arão Botler Square – Location and Photographic Report

[Nível d’água | Não encontrado | Profundidade do furo | Microdrenagem do Recife | Nível d’água | Caixa coletora com gaveta | Rede | Trechos críticos de alagamento | Delimitação Praça]

Source: The Authors (2024)

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Table 2 presents the proposed areas that could be used as permeable pavement in the 15 studied squares. Of the 15 selected squares, two were excluded. In the Travessa José Leite square, the water level was found to be 0.62 m deep, making it impossible to use since the bottom of the drainage layer in the permeable pavement was 0.73 m deep. Therefore, the drainage layer would already be partially compromised. The Professora Antônia Galvão square was also excluded because the auger could only drill 30 cm deep, making it impossible to check the water level.

Table 2 - Permeable Area by Square

Name	Square area (m²)	Permeable area (m²)	RPA	Neighborhood	Auger depth (m)	Water level (m)
Arão Botler Square	229,72	91,89	RPA 02	Porto da Madeira	1,50	*NE
Bom Pastor Square	5.969,55	1.193,91	RPA 04	Iputinga	1,52	*NE
Brasilit Square	1.259,28	251,86	RPA 04	Várzea	1,18	0,86
Chora Menino Square	2.372,24	474,45	RPA 01	Paissandu	1,52	*NE
Coliseu B Square	418,26	209,13	RPA 04	Várzea	1,42	1,34
Da Convenção Square	2.822,59	564,52	RPA 02	Beberibe	1,52	1,47
Rua Nelson Hungria Square	297,88	89,36	RPA 06	Boa Viagem	1,32	1,14
Travessa José Leite Square	94,73	-	RPA 06	Pina	0,67	0,62
Dr Alberto Wanderley Square	232,30	69,69	RPA 02	Porto Da Madeira	1,50	*NE
General Carlos Pinto Square/Largo dos Casados	3.250,89	975,27	RPA 01	Santo Amaro	1,32	1,26
João Francisco Lisboa Square	250,34	50,07	RPA 04	Várzea	1,50	*NE
Jornalista Otávio Sarmento Cardoso Square/Coliseu A	246,08	123,04	RPA 04	Várzea	1,15	1,05
Onze de Junho – A Square	9.271,83	2.781,55	RPA 01	Santo Amaro	0,95	0,86
Professora Antônia Galvão Square	269,06	-	RPA 02	Água Fria	0,30	*NE
Profeta Joseph Smith Square/da Santa	6.743,25	2.022,98	RPA 06	Pina	1,50	*NE

Source: The Authors (2024)

Paving composed of interlocking drainage blocks measuring 20.0 cm x 10.0 cm in length and width, respectively, and 8.0 cm in thickness, was proposed to complete the chosen cross-section. The interlocking paving is laid on a 5.0 cm layer of coarse sand, and its average compressive strength is 41.5 MPa.

Finally, the useful volume available for storage was calculated, assuming that the chosen system was the one without infiltration. Equation 1 presented in the methodology was applied for this calculation, using the porosity of gravel 25 in the compacted state of 33%. Table

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3 summarizes the total area capable of installing the permeable pavement x useful volume available for storage.

Table 3 - Summary of Total Area x Useful Volume Available for Retention

	Total area (m^2)	**Thickness of drainage layer (m)**	**Porosity (n)**	**Useful volume (m^3)**	**Useful volume (L)**
Installation of permeable pavements	8.897,72	0,60	33%	1.761,75	1.761.748,56

Source: The Authors (2024)

5 CONCLUSION

Permeable pavements represent a sustainable and efficient alternative for addressing the urban challenges faced by contemporary cities. Adopting this technology makes it possible to mitigate the negative impacts of urbanization on the environment, promote responsible management of stormwater and urban solid waste, and preserve the quality of life in urban communities.

Considering the above, it is evident that implementing permeable pavements in the 15 studied squares, with a total area of 8,897.72 m², can retain 1,761,748.56 liters of water, alleviating flood volumes in Recife. It is important to emphasize that the permeable pavement section used in this study was the same for all squares. It aims to illustrate the volume such spaces can retain instead of allowing it to flow over impermeable surfaces.

This research aims to disseminate and encourage further investigations, interventions, and proposals regarding implementing permeable pavements and using construction and demolition waste (CDW) in parks, squares, and open spaces in Recife (PE). The goal is to reduce surface runoff and promote sustainable urban drainage techniques.

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