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RESEARCH ARTICLE OPEN ACCESS

THE USE OF PERMEABLE ASPHALT FOR THE BENEFIT OF DRAINAGE SYSTEMS IN URBAN AREAS - A LITERATURE REVIEW

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ABSTRACT

Due to the high population growth rate in urban areas, the evolution of infrastructure is necessary in order to keep up with the demand. However, this growth brings a series of challenges, such as the increase in impermeable surfaces, resulting in high runoff peaks and an increase in flood occurrences. This situation has negative environmental, social, and economic consequences, requiring the adoption of measures to address them. In light of this, a literature review was conducted with the aim of analyzing the benefits of using permeable asphalt in aiding conventional drainage systems. The methodology adopted for this study was a bibliographic review, in which literature addressing urban drainage, drainage systems, and permeable asphalt were analyzed. After conducting the study, it can be concluded that the use of permeable asphalt is highly effective in mitigating the problems caused by floods. However, factors such as application and purpose in a specific location need to be evaluated, in addition to conducting a thorough study to assess economic feasibility.

I. INTRODUCTION

Due to uncontrolled population growth and the human need to develop infrastructure, the expansion of urban areas into rural regions has become an inevitable option. The increasing occupation and paving of land, coupled with the absence of adequate ecosystem planning and limited sanitary and stormwater sewage systems, have resulted in the increase of impermeable areas such as streets, roads, sidewalks, parking lots, and avenues [1].

According to Pezente (2018) [2], urbanization leads to a significant increase in impermeable areas, which causes rainwater to accumulate on the impermeable surface. This accumulation intensifies surface runoff and increases the velocity of flow in pipes and channels, restricting infiltration capacity in the soil and causing alterations in the hydrological cycle.

During flooding events, cities face difficulties in allowing natural drainage of rainwater and rely on public drainage systems to ensure rapid water runoff. When drainage systems fail, streets and avenues become vulnerable, resulting in the occurrence of floods and causing various problems such as the spread of diseases, financial losses, negative impacts on health, and loss of human, animal, and plant lives [3].

As a consequence of the vulnerability presented by these drainage systems, it has been essential to develop new methods and effective techniques to mitigate the impacts of flooding in urban areas. Therefore, the adoption of measures to reduce the volume of surface runoff is indispensable [4].

Permeable pavements are examples of systems capable of restoring the natural hydrological cycle in urban centers, allowing for increased evapotranspiration and infiltration capacity [5]. Their main function is to infiltrate rainwater through layers that make up the system. The high porosity in the surface layer gives it specific prominence [6].

Based on the aforementioned, a study was conducted with the aim of analyzing the benefits of using permeable asphalt as an aid to drainage systems, as well as examining the characteristics of permeable asphalt compared to conventional asphalt, evaluating its technical and economic viability.

II. METHODOLOGY

For the development of this article, a literature search was conducted, presenting aspects related to drainage systems, characteristics of permeable asphalt, and a comparison with conventional asphalt, as well os its technical and economic viability. The research relied on references from books, scientific articles, journals, and websites, including the CAPES Periodicals Portals and Google Scholar, using keywords such as permeable asphalt, sustainability, and urban drainage.

As inclusion criteria, it was defined that the full articles should be in Portuguese, English, or Spanish, within the time frame from 2014 to 2023, and address permeable asphalt and urban drainage. As exclusion criteria, articles without an objective methodology and studies without open access were excluded.

Through the literature search conducted on the CAPES and Google Scholar databases, a total of 1,370 articles were found according to the search terms and year, as shown in the Flowchart in Figure 1. After this step, titles, abstracts, and descriptors were read and analyzed based on the inclusion and exclusion criteria, resulting in the selection of 48 articles. During the final selection of articles to be used, 18 were chosen according to the central theme of the present article.

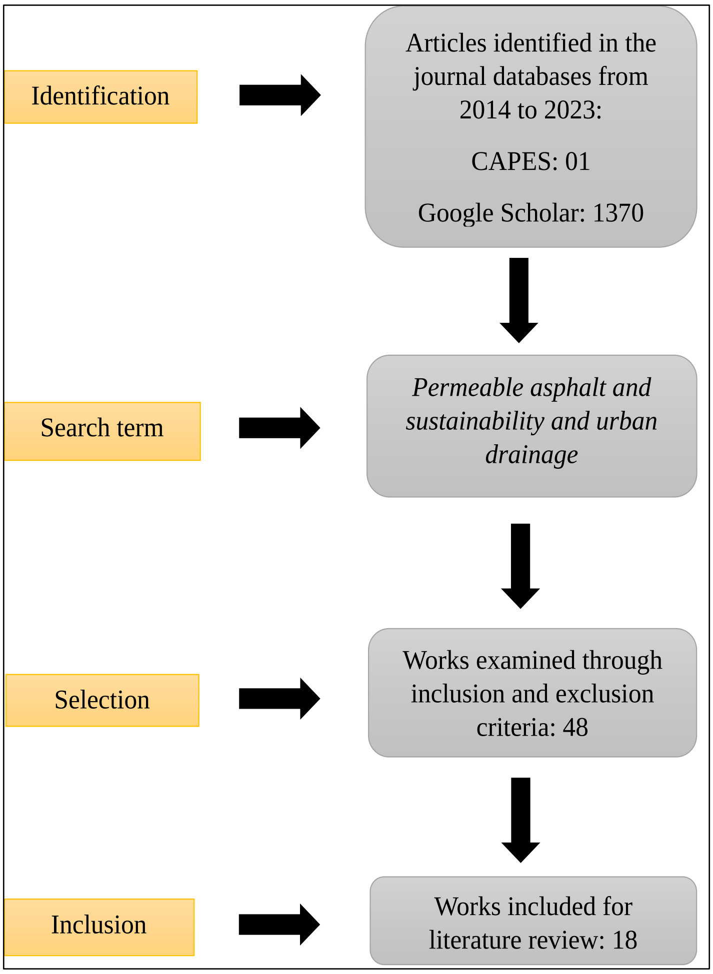

Figure 1: Flowchart for Article Selection in the Literature Review.
Source: Authors, (2023).

The present study is classified as a qualitative theoretical research in the exploratory category. The qualitative research was conducted through a literature review, with the selection of specific bibliography that covers the following themes: urban drainage, sustainability, and permeable pavements.

III. THEORETICAL REFERENCE

III.1 URBAN DRAINAGE

Urban drainage system is understood as a process that aims to prevent floods and inundations, especially in low-lying areas of communities susceptible to such conditions [7]. In recent years, urban development has grown haphazardly, resulting in degrading consequences in many regions due to increased occupied spaces. As a result, during rainy seasons, there is a constant increase in floods in cities, causing a reduction in quality of life due to the risks of epidemics and diseases [8].

Sustainable socioeconomic and human growth is of paramount importance for the development of cities, requiring solutions to problems related to the management and control of stormwater. Through urban planning as a legal norm, the objective is to establish the development of collective urban obligations and ensure the convenience of the population. However, it is concerning to note that most cities still do not give due importance to planning or the drainage master plan, lacking a specific project for this category [9].

The Drainage and Urban Development Master Plan needs to involve actions for planning and distribution of water, incorporating structural measures that affect the flow properties, altering the course and management of water flow, leading to a change in the natural drainage system [9]. Therefore, it is a fundamental and essential instrument of principles for urban evolution and growth, contributing to the recognition, safety, and balanced control of natural resources [7].

Ineffective and obsolete urban systems occur mainly in small municipalities, and this is justified by the difficulty in local management and planning. These municipalities develop in a disorderly manner until they approach the legally defined number of residents, and only after that, the plan is chosen [7]. In the face of the current scenario of population growth, devices and systems have been created to mitigate the effects of deficiencies in drainage systems and urban flooding [4].

III.2 DRAINAGE SYSTEMS

The hydrological cycle is a natural process that involves the continuous movement of water between the atmosphere and the Earth's surface, playing a vital role in the functioning of the environment. Water flows freely along the longitudinal extent of the surface until it encounters a water body or infiltrates into underground reservoirs. However, when an area becomes urbanized, water no longer follows its natural path but is instead directed by mechanisms that change its trajectory and redirect it to another location. These mechanisms capable of directing or diverting stormwater in specific areas are expressed as drainage systems [7].

Urban drainage systems are divided into microdrainage and macrodrainage. The microdrainage system consists of devices that channel surface runoff into galleries or open channels. It includes features such as curbstones, gutters, catch basins, connecting pipes, galleries, and manholes [10], as shown in Figures 2 and 3.

- Curbstone: a long strip that separates the sidewalk from the road.
- Gutter: a channel installed between the curbstone and the road, designed to receive and convey water to catch basins or manholes.

- Catch basin: a device that captures surface water runoff from the gutter.
- Connecting pipes: conduits responsible for conveying the captured runoff from catch basins to manholes or galleries.
- Gallery: public conduits that receive runoff water from connecting pipes, directing it towards the city's streams.
- Manhole: a device that provides access to underground networks, allowing for control of changes in the hydraulic system and cleaning of conduits.

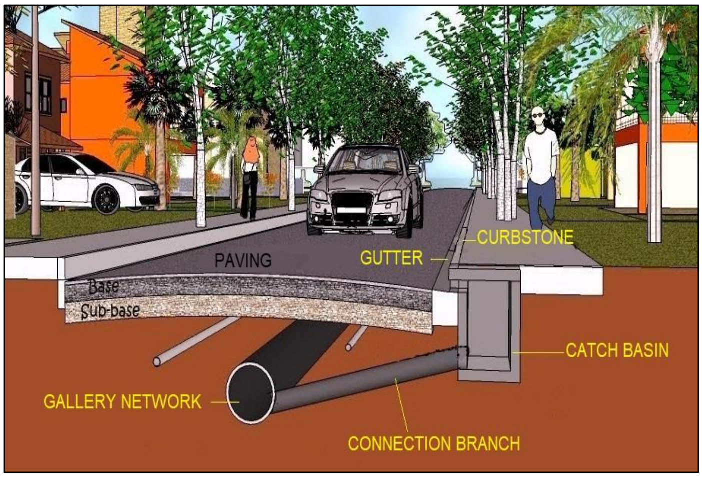

Figure 2: Illustration of various microdrainage mechanisms in a paved road.
Source: Authors, (2023).

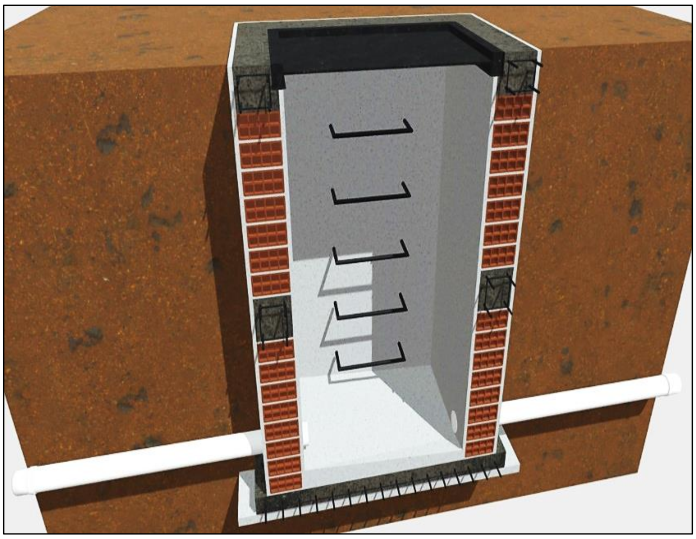

Figure 3: 3D Manhole.
Source: Authors, (2022).

The macrodrainage system is responsible for the final drainage of water resulting from the microdrainage system. It optimizes the flow and minimizes disruptions caused by sedimentation and floods in the main channels, consisting of streams or rivers that cross the city [10].

As shown earlier, drainage systems have specific characteristics that, depending on the situation faced by the city, may or may not solve the problems [10], as depicted in Figure 4.

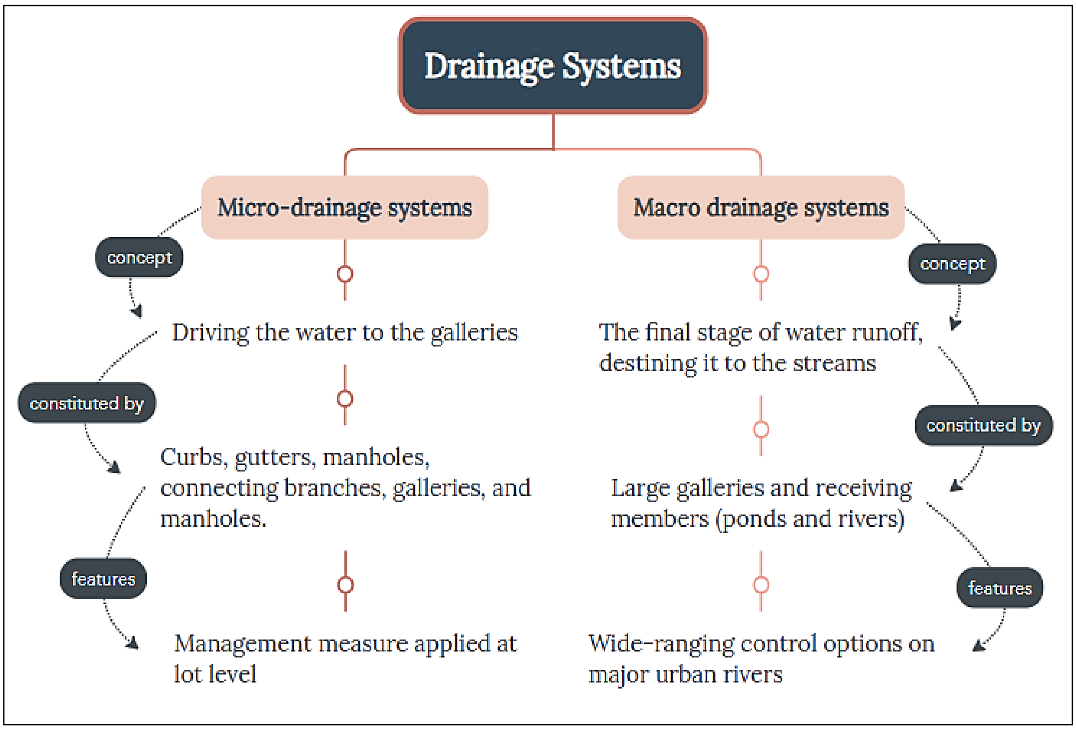

Figure 4: Drainage Systems Organogram.
Source: Authors, (2023).

However, it is evident that drainage systems are becoming obsolete and incapable of efficiently fulfilling their function due to uncontrolled urban growth [9]. Therefore, there is a need to create methods that promote sustainable development of urban drainage, expanding the infrastructure and making the urban environment conducive to a better quality of life [8].

IV. PERMEABLE ASPHALT (PA)

Permeable asphalt is a device designed to allow the passage of fluids, such as rainwater, while also providing resistance to vehicle traffic, pedestrians, and objects. Its main function is to temporarily retain water, using materials with porous characteristics that promote drainage through infiltration into the subsoil. These infiltration zones receive water from impermeable areas, restoring the potential for replenishing groundwater reserves. [11].

Permeable asphalt is composed of layers of aggregates, differentiated by their particle size distribution, which allows for an increased void volume with water storage capacity, distinguishing it from conventional asphalt [15].

The surface covering of permeable pavement exhibits porosity and excessive permeability, positively influencing the hydrological cycle, particularly in terms of surface runoff. This allows water to infiltrate the surface and move into the reservoir of stones, where it is stored before further infiltration into the soil [3].

According to Santos (2017) [10], permeable pavement is composed of different layers that perform specific functions. The top layer, known as the surface layer, consists of small stones mixed with asphalt. This composition allows for the permeability of rainwater, enabling its infiltration into the soil. The deeper layers are composed of larger stones, creating a void space of approximately 25% of the total volume. This composition ensures that water can infiltrate through the smaller stones and be stored. Thus, rainwater is captured by the drainage system and directed towards the stormwater galleries, as depicted in figure 5.

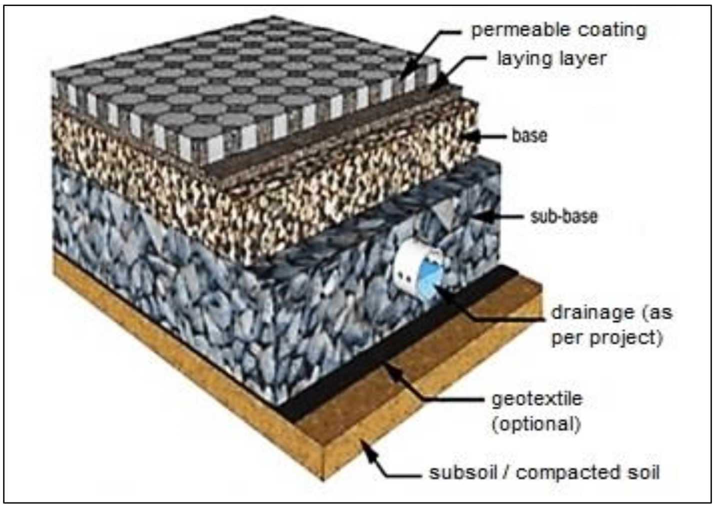

Figure 5: Representation of the main layers of the permeable pavement system.
Source: Adapted from [18].

Porous pavements contain porous asphalt, porous concrete, blocks, and other construction systems that can be used in urban areas. They are made from practically the same materials, even though they have different connotations, as shown in table 1 [15].

Table 1: Components and elements used in permeable sidewalks.

Terminology Applied to Porous Pavements	
Terminology	**Definition**
Base Layer	A layer placed below the surface pavement to increase the thickness of the pavement. It can simply be referred to as Base.
Layer	Space occupied between two types of materials in the pavement structure.
Filter Layer	Any layer between other layers or between the pavement and subgrade that prevents the migration of particles into the voids od the underlying layer.
Geomembrane	Impermeable fabric, usually plastic or High-Density Polyethlene (HDPE), used in waterproofing systems.
Geotextile	Non-woven fabric made of polypropylene filaments that allows the free passage of infiltration water to the drainage medium.
Pavement	Any treatment or covering on the surface that supports any type of traffic.
Overlay	Layer applied over any existing pavement.
Pavement Structure	Combination of material layers placed over the subgrade that provide mechanical support of the pavement.
Reservoir	Any part of the pavement with water storage capacity and conductivity. The reservoir can be overlaid or combined with other pavement layers. Also known as Base Reservoir, Drainage Layer, or Drainage Bed.
Subbase	Layer placed below the Base layer to increase the thickness os the pavement.
Subgrade	Natural or reinforced soil below the pavement structure, responsible for ultimately absorbing the loadings.
Surface Layer	The layer of the pavement that directly receives the traffic load.

Source: Adapted from [15].

Porous pavement presents itself as a new alternative for roads. With a simple application, the materials used are practically the same as conventional asphalts, even though they have different connotations, and as an advantage, it can contribute to drainage issues in large urban centers [15].

Porous pavements have two functions that characterize their structure [15]:

- Mechanical Function: It is possible to determine the load imposed by vehicle traffic through the analysis of the type of structure used.
- Hydraulic Function: Regarding storage, there is a temporary deposition of water through the porosity of the materials, allowing drainage and infiltration into the soil when feasible.

The classification of pavement types that have functions related to urban and stormwater drainage is as follows:

- Pavements with permeable surfaces: They allow rainwater to reach the lower layers of the pavement and cause a rapid decrease in surface runoff.
- Porous pavements for retention: They serve the function of temporarily storing rainwater, without infiltration, and are divided into:
  - Porous storage pavements with direct infiltration, with permeable surfaces.
  - Porous pavements for retention with indirect infiltration, with impermeable surfaces.
- Porous infiltration pavements: They perform two different functions of temporary storage and penetration of rainwater, divided into:
  - Porous infiltration pavements with distributed infiltration, with permeable surfaces.
  - Porous infiltration pavements with localized infiltration, with impermeable surfaces.

In terms of their use, each of these different types of pavements has a specific structure [15].

In densely populated urban areas, the area allocated for road networks and parking lots occupies a considerable space, sometimes reaching up to 30% of the area of a drainage basin [12]. The use of permeable pavement plays a crucial role in addressing the difficulties caused by urban flooding, as it contributes to the reduction of surface runoff. This type of pavement possesses distinct properties, such as high porosity and good drainage capacity, determined by its appropriate gradation [13].

The use of this pavement is recommended for areas in industrial, commercial, and residential sectors, warehouses, yards, lightly trafficked streets, in condominiums and housing complexes, parks, sidewalks, and parking lots [14]. In light of this, it offers considerable advantages for its functionality. However, despite being an innovative technology that promotes environmental preservation, the applicability of permeable pavement is still limited. In Figure 6, we can observe a table with its main advantages and disadvantages (or precautions) [11].

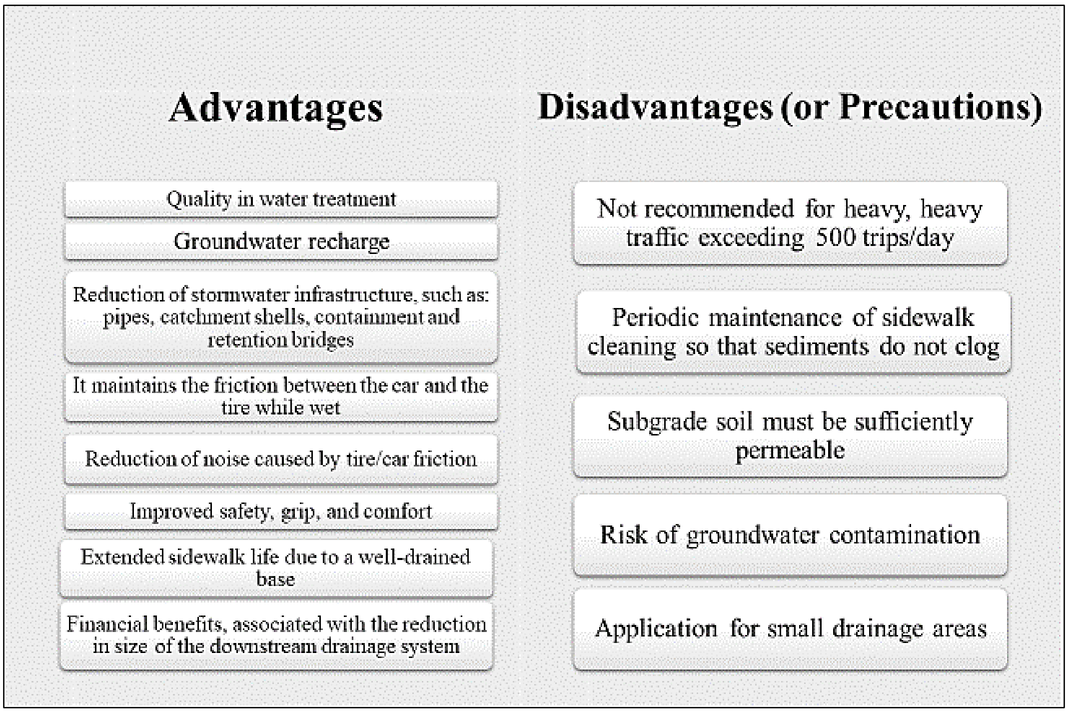

Figure 6: Table of Advantages and Disadvantages (or Precautions).
Source: Authors, (2023).

Permeable pavement stands out as one of the most efficient alternatives to solve these problems due to its ability to adapt to the urban environment, promoting ecological balance and ensuring economic viability. In light of the aforementioned, the implementation of permeable pavement encourages society to embrace activities that ensure the preservation of urban areas, employing effective methods that contribute to the management of surface drainage and minimize the damages caused by improper land occupation, which leads to impermeability [12].

V. RESULTS AND DISCUSSIONS

V.1 TECHNICAL FEASIBILITY

Perrone and Souza (2019) indicate that the composition of asphalt varies according to its purpose, and as the strength increases, the permeability capacity decreases. Permeable asphalt has void ratios of up to 25%, while conventional asphalt has a void ratio of 4%. Conventional asphalt is primarily used for traffic pavement, whereas permeable asphalt has some limitations in terms of performance, such as slope. If a permeable asphalt road has a steep slope, the rate of water infiltration will be reduced [13].

To efficiently drain surface water, permeable asphalt is designed with a specific particle size distribution that results in a high void ratio, which is the main difference between permeable and conventional asphalt [13]. In conventional asphalt, the surface layers are made impermeable to provide greater mechanical strength [7].

The formation of permeable pavement is similar in certain aspects to conventional pavements, such as the top layer being constructed in the same way, but with a difference in retaining the sand fraction combined with aggregates that compose the pavement, resulting in an open grading. As a result, this grading provides an asphalt mixture with 18% to 25% voids, allowing for rapid water percolation [16].

The urban functions of permeable pavement are similar to those of conventional pavement, with the difference lying in its ability to reduce surface runoff from stormwater. Technical standards assist professionals in developing calculations for the hydraulic aspects, traffic, and pavement layers concerning permeable asphalt [17].

Therefore, Mello and Rigo (2023) [18] point out the Brazilian standard ABNT NBR 16.416/2015, which requires permeable asphalt to simultaneously meet mechanical stresses and rolling conditions while facilitating water percolation or temporary accumulation within its structure.

Permeable pavements can be classified into different types, such as porous asphalt, porous or pervious concrete, and permeable pavers, as shown in Table 2.

Table 2: General properties of permeable pavements.

	Porous Asphalt	Porous or cast concrete	Parallelepipeds
Slope	2%	2%	4%
Constituition	Fine sand fraction (open gradation) of the sidewalk aggregate mix	Granular material, such as sand, and filled with undergrowtch, such as grass	Granite is an igneous rock, which presents in its composition quartz, feldspar, mica, amphibole, pyroxene, and olivine
Resistance	Medium	Average to good	Medium
Emptiness	18% to 25% voids, fast water percolation	15% to 25% average water percolation	15% to 25% average water percolation
Capability	Good	Good	Medium

Source: Adapted from [10].

It can be observed that porous asphalt and porous concrete demonstrate a good absorption capacity, which is essential for efficient drainage. In this regard, porous asphalt has an even greater advantage as it provides faster water percolation, contributing to the reduction of surface accumulation and minimizing problems related to floods and inundations. This characteristic makes porous asphalt a highly recommended option in urban areas subject to high precipitation volumes. [10]. In Table 3, the accumulated values of runoff and water infiltration are presented, highlighting the efficiency of permeable pavements.

Table 3: Cumulative values of runoff and water infiltration in different sections.

Treatment	Cumulative precipitation (mm)	Surface runoff (mm)	Infiltration (mm)
Asphalt	236,62	168,00	68,62
Parallelepiped	236,62	51,64	185,28
Gramado	236,62	5,00	231,62
Permeable sidewalk: porous asphalt and porous concrete	236,62	0,00	236,62

Source: Adapted from [10].

According to Santos (2017) [10], the table demonstrates the effectiveness of permeable pavements compared to the most commonly used pavement type in Brazilian cities. Conventional asphalt shows a limited capacity for rainwater infiltration, with results below 29%, resulting in approximately 71% of surface runoff.

V.2 ECONOMIC VIABILITY

From an economic standpoint, the use of permeable pavement proves to be a highly viable solution. Although there are additional maintenance and construction costs compared to conventional pavements, these costs are often offset by the reduction in expenses related to drainage systems, as peak flows are reduced. This results in long-term savings. [7].

Based on the information presented in Table 4, obtained from the study conducted by [15], it is possible to establish a comparison between some aspects of permeable pavement in relation to conventional concrete and asphalt.

Table 4: Comparison between types of pavement.

Material/Criterial	Permeable Asphalt	Concrete	Convencional Asphalt
Maintenance Frequency	Veried depending on usage (6 monthrs to 2 years	6 months to 2 years	Depends on location
Implementation cost	Medium	Medium	Medium
Maintenance cost	Medium to high	Medium to high	Low
Type of use	All, as long as reinforced	All, as long as reinforced	Structure is used, All
Absorption capacity	Good	Good	None
Acoustics	Good	Good	Average

Source: Adapted from [15].

According to Mello and Rigo (2023) [18], permeable pavement is a widely studied and standardized alternative regulated by ABNT NBR 16.416/2015. This standard establishes the minimum conditions required for the design, specifications, and execution of permeable pavements, and it is regulated by municipal laws. However, it is important to note that there are still limitations regarding the available information for cost estimation, requiring a more comprehensive analysis for its application.

VI. CONCLUSION

The use of permeable asphalt is a highly effective measure to combat floods and urban inundations, providing a range of environmental benefits. Among these benefits, the restoration of groundwater levels, increased moisture in urban green areas, and improved quality of infiltrated water are noteworthy, as permeable pavement is capable of filtering impurities.

Although economic feasibility is favorable, it is essential to conduct a comprehensive field study to accurately assess construction and maintenance costs related to implementation and labor, especially in public infrastructure projects. This need became evident during the literature review, emphasizing the importance of a more in-depth analysis for informed decision-making.

From a technical standpoint, permeable asphalt demonstrates highly satisfactory performance compared to conventional asphalt. However, it is important to highlight that there are significant differences in terms of mechanical strength, which requires careful analysis when considering its application in areas with heavy traffic. In-depth studies are necessary to fully understand the load-bearing capacity of permeable asphalt under such conditions, ensuring its durability and safety in high-traffic environments.

Based on the authors cited in this research, it was possible to highlight that the use of this type of pavement is an efficient and relevant solution to mitigate the problems faced during periods of rain in urban areas, bringing significant improvements to drainage systems. Therefore, it can be concluded that the objectives of this research were achieved, emphasizing the importance of conducting additional studies focused on the economic viability of this solution.

VII. AUTHORS' CONTRIBUTION

Conceptualization: Knopy Lima Lustosa.
Methodology: Knopy Lima Lustosa and Francisco Luís da Silva dos Santos Júnior.
Investigation: Knopy Lima Lustosa.
Discussion of results: Knopy Lima Lustosa and Francisco Luís da Silva dos Santos Júnior.
Writing –Original Draft: Knopy Lima Lustosa and Francisco Luís da Silva dos Santos Júnior.
Writing –Review and Editing: Knopy Lima Lustosa.
Resources: Knopy Lima Lustosa and Francisco Luís da Silva dos Santos Júnior.
Supervision: Knopy Lima Lustosa and Heyder de Souza Castro Oliveira.
Approval of the final text: Knopy Lima Lustosa, Francisco Luís da Silva dos Santos Júnior, and Heyder de Souza Castro Oliveira.

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