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ORIGINAL ARTICLE

Mixed linear model for the prediction of infiltration rates in urban pervious concrete pavements in dense wooded parks

Modelo linear misto para a previsão de taxas de infiltração em pavimentos de concreto permeáveis urbanos em parques densamente arborizados

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Abstract: Clogging of porous concrete pavements is understood as a performance pathology within this peculiar concrete component. Albeit the clogging performance of porous concrete pavements is a sensitive topic in technical literature, most studies refer to laboratory investigations on concrete samples using different kinds of apparatus for the simulation of loss of permeability due to debris insertion on porous interstices. However, infiltration rate measurements are the basis for defining maintenance needs in actual pavements and shall be carried out periodically to measure and endorse infiltration rate adequacy as the kern of a clogging management protocol. This study dealt with a field experiment in a pervious concrete sidewalk surrounded by a wooded garden with tropical native and a variety of exotic trees. Over four years, eleven monitoring measurements were carried out using the ASTM C1701 infiltration ring test. The main contribution of this paper is a proposition of a mixed linear prediction model considering conditioned exponential distribution and a random normal intercept for the infiltration rate. From residual analysis and diagnosis plots, it can be seen that the proposed model presents a goodness of fit, allowing anticipation of infiltration rates reduction due to clogging by dense organic matter. Minimum infiltration rate is taken as 0.1 cm/s and such condition was achieved in a couple of months, awakening consciously to consider three to four intensive cleaning maintenance per year in dense wooded areas like public parks.

Keywords: pervious concrete, pavement, clogging, permeability, maintenance, public parks.

Resumo: Embora o desempenho em termos de colmatação de pavimentos de concreto porosos seja um tópico sensível na literatura técnica, a maioria dos estudos se refere a pesquisas laboratoriais em corpos de prova utilizando diferentes equipamentos para a simulação da perda de permeabilidade devido à inserção de detritos nos poros. Entretanto, medidas de taxa de infiltração são a base para a definição da necessidade de manutenção em pavimentos reais e devem ser realizados periodicamente para medir e endossar que a adequação da taxa de infiltração é o cerne do protocolo de gerenciamento da colmatação. Este estudo trata sobre um experimento em campo em uma calçada de concreto permeável circundada por um jardim arborizado com árvores nativas tropicais exóticas. Ao longo de quatro anos, onze medidas de monitoramento foram realizadas utilizando o teste do anel de infiltração recomendado pela norma ASTM C1701. A principal contribuição deste artigo é a proposição de um modelo linear misto considerando a distribuição exponencial condicionada para a taxa de infiltração e uma interceptação normal aleatória. Pela análise de resíduos e parcelas de diagnóstico, é possível observar que o modelo proposto apresenta uma boa adequação, permitindo prever a queda da taxa de infiltração devido à colmatação por matéria orgânica densa.

Palavras-chave: concreto permeável, pavimento, colmatação, permeabilidade, manutenção, parques públicos.

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1 INTRODUCTION

1.1 Rational aspects for pervious concrete paving in large cities

Tropical storms and rainfall floods for many decades have been a serious concern in large metropolitan areas like São Paulo (21.65 million inhabitants as of 2018, according to UNO [1]). The urban growth since the 1950's increased by ten times, mostly disarranged and disordered, leading to the soil covering (creating impervious surfaces) not only by buildings and roofs, but also due to the large asphalt and concrete paved street canyons; as downtown is surrounded by rivers, typical intense rains cause water floods overcharging the streets drainage systems besides carrying water to valleys in high velocities, thus, increasing erosive processes. The combination of such systemic issues is harmful to the performance of rainwater galleries and pipes drains, resulting in damage in critical points. As a rough example of urbanization making impervious surfaces, São Paulo city has more than 200 streams and brooks, with at least three important ones. The watershed of *Tamanduateí* river comprised originally 662.5 km and, due to urbanization process, 65.5 km were rectified and 176.9 stoppered from 1950 to 2000 [2]. Great avenues have taken the place of rivers' surfaces frantically for decades.

During the 1990's, the solution was to keep expanding streets and roads infrastructures by using waterproof materials, while building large pools in lowland areas. Pool installation's primary function should be to pile up large amounts of storm water and release it to the local drainpipes slowly. However, such a solution discloses inherent flaws related to pool cleaning and maintenance, growth of vectors related to human diseases, and, again, creating a large surface concrete slab, in some cases, may result in local heat islands; other built sites considered opened pools, even worst in some perspectives.

On the other hand, whether the big tanks take an approach to solve the excessive stormwater in low areas, it is unable to solve the mobility issues, ensuring safe pavement surfaces for automobiles, motorcycles, bikes, and pedestrians using the urban mobility facilities, including sidewalks and public parks. Besides, pool emptying operations do not address the high-pressure charge within the drainage devices and throw accumulated mud in drainage system, a relevant concern even in short-term.

Official data rescued from the Municipal Works Secretary [3] point out circa 70% of waterproof infrastructure surfaces, with 8 million of vehicles using more than 16,000 km paved streets, and roads and sidewalks making up circa 480 km^2 (by 33% of the city area). Those data are evaluated for auto and bus lanes, parking lanes, footpaths, and sidewalks, as well as for bike lanes; avenues with paved medians are not included in available data. Harvey [4] reported paved areas in American cities ranging between 25% and 40%.

However, any move to the use of pervious and permeable materials for stormwater flow mitigation is confronted by another city peculiarity: intensive afforestation of sidewalks neighborhoods, street medians and public parks with trees (Figure 1). Falling leaves, seeds and fruits, all year long, configure another relevant issue. Compensative systems as pervious pavements are subject to clogging due to deposition of soils (mud carrying over pervious pavements is something to be fully avoided as it will lead to the loosing of surfaces and pavement bases infiltration characteristics) and organic matter over surfaces, blocking the porous structure of the materials. The solution is to manage infiltration performance over time and perform recurrent maintenance procedures to restore the permeable function of pervious pavement layers. Recommendations for programmed maintenance can be found elsewhere [5].

This paper aims to present a contribution to prognosticate clogging in pervious concrete pavements, namely, a predictive model for the estimation of infiltration rate loss at the concrete surfaces. Thus, the results obtained over four years of measurements of infiltration rates in a real scale sidewalk surrounded by dense vegetation area are shared. The data was statistically analyzed and a mixed linear model was proposed. A three-stage clogging mechanism was observed during the studies, in accordance to former laboratory research with pervious concretes. Data were achieved from a short track test of pervious concrete pavement continuously monitored over a couple of years.

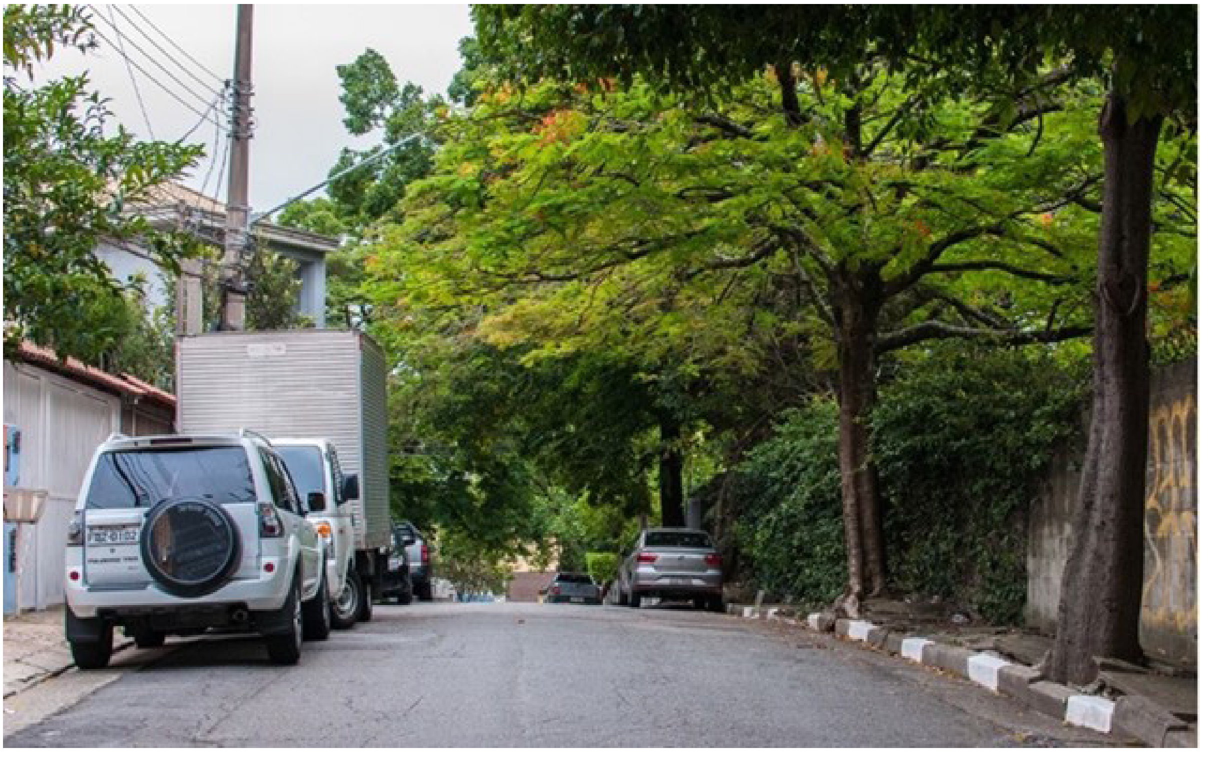

Figure 1. Typical arborized sidewalks in *Saúde* District in São Paulo City (Photo by Wilfredo Rodríguez; Google Commons).

2 CONDITIONING PARAMETERS FOR PERVIOUS CONCRETE

Mechanical and hydraulic parameters need to be considered during pervious concrete mix formulation to ensure the targeted performance for pavements or sidewalks used for parking areas, pedestrian ways, and bikeways. One can observe that, even in public parks, access is granted to police cars, ambulances, fireman trucks and so on, requiring minimum pavement mechanical performance considerations for design. However, one main concern for the effective performance of pervious concrete pavements is its long-term capabilities of draining storm waters causing surface runoff in urban public areas, say, its future clogging potential of its porous interstices. Non-drained stormwater's surface runoffs are harmful for pedestrian and bicyclists' safety as well. One special issue concerning the definition for maintenance requirements of pervious concrete pavements is the case of floor facilities within gardens and parks, urban or forestalled ones, when falling leaves, flowers, fruits, and seeds of surrounding trees lead to the decay of organic matter which can be the main agent for porous concrete surface clogging. Common characteristics for pervious concrete porosity and permeability are recovered in Table 1, summarizing some classical results (including some physical indexes and material strength) presented and discussed elsewhere [6]–[8], [10]–[19].

It is remarkable that, based on such a reduced number of representative chosen references, the parameters variation is large: porosity from 5% to 35% (nowadays it is usual to refer to the band between 15% and 35%); specific density from 16 to 24 kN/m^3 (approaching to the higher values of conventional concretes at the cost of increasing cement content or reducing drastically the voids); compressive strength as low as 4 MPa at 28 days and, oppositely, as high as 56 MPa. It is worth recalling the complexity of relations between the parameters on the dependence of type and nature of aggregate, cement type and consumption, water/cement ratio, cement/aggregate ratio, fine aggregate content, among others; likewise, it is possible to assert inverse relations between porosity and resistance or porosity and modulus of elasticity, porosity, and fatigue behavior, whereas direct relations between porosity and hydraulic conductivity.

Table 1. Some key characteristics of pervious concrete.

Porosity (%)	Specific gravity (kN/m^3)	Hydraulic conductivity (cm/h)	Cement content (kg/m^3)	Compressive strength @ 28 days (MPa)	Flexural strength @ 28 days (MPa)	Reference
15 - 25	16 - 20	720 to 1,908	270 to 415	5.5 to 20.6	1.0 to 3.8	Tennis et al. [6]
15 - 35	-	-	-	-	2.5 to 3.9	Olek et al. [7]
19	-	-	-	26.0	4.4	Beeldens [8]
20 - 30	18.9 - 20.8	-	-	17.6 to 32.1	3.9 to 5.7	Beeldens [9]
11 - 15	-	108 to 648	-	-	4.2 a 7.5	Kajio et al. [10]
-	-	-	-	19.0	-	Tamai and Yoshida [11]
18 - 31	-	-	-	11.0 to 25.0	-	Park and Tia [12]
-	-	-	-	31.0 to 54.0	-	Zaharieva et al. [13]
-	-	-	275 to 350	14.0 to 27.0	-	Pindado et al. [14]
3 - 29	18.6 - 22.3	10.8 to 792	344	7.5 to 18.8	-	Lee et al. [15]
5 - 35	-	36 to 3600	-	4.1 to 55.8	-	Delatte et al. [16]
-	-	2,520 to 5,760	295 a 352	4.5 a 14,5	-	Huang et al. [17]
-	18.4 - 23.9	36 to 3,312	-	10.5 to 32.8	-	Henderson et al. [18]
20 - 29	17.4 - 19.6	396 to 540	374	6..02 to 10.17	1.77 to 2.52	Batezini and Balbo [19]

3 CLOGGING OF PERVIOUS CONCRETE AS A MAINTENANCE ISSUE

The action of transporting foliage, soil, debris, and sludge through runoff waters produces what is called clogging, i.e., the obstruction of the capillary net of porous within the pervious concrete structure. Moreover, under certain conditions, such as an exceptional carrying of debris or soils, the clogging of the permeable bases may occur, leading to loss of its permeable function. Clogging of pervious concrete porous structure is mainly related to the type and the size of the clogging debris, the porous geometry or tortuosity [20] and the channel net in the concrete, as well as to the water flow through the surface, among other secondary ones. Therefore, studying clogging potential related to pavement permeability and local requires prediction of the obstructing phenomena since it causes the loose of their primordial function due to the drying and adhesion of mud or organic matter between its voids.

Among neighborhoods' land using aspects, fall or growth of vegetation on their surfaces must be a serious performance concern for architects, engineers and urbanists, as well as to public city managers. It is estimated that, with proper maintenance, permeable pavements can fulfill their main tasks during long periods of service, maybe two decades [21]. The clogging of permeable pavements gradually causes the loss of infiltration capacity in the surface or in the structure, being an essential aspect in the process of management of such a paving system.

The process of clogging permeable pavements can thus be inexorable, albeit slow, and it is desirable to predict the loss of permeability for scheduling maintenance services, based on knowledge of past behavior (empirically). Comfortably, however, a previous study showed that clogged floors are still offering infiltration rates over 7×10^{-4} cm/s [21]. In such a study, for clogging with fine sand, the infiltration capacity of permeable concretes remained high in laboratory tests, restricted to the upper 20 mm of the surface permeable layer.

The clogging is dependent on the climate regime and the vegetation cover around these pavement structures; it is also influenced by sediments carried by rainwaters from peripheral areas [22]. It is observed that the clogging by clay particles is more severe and faster than that caused by particles of sandy soils. Available data suggest a rapid loss of infiltration capacity in two years [5].

Laboratory investigations accessed clogging performance of pervious concrete mixtures through several arrangements of tests. For instance, Lim et al. [23] employed constant head test and water contaminated with clogging materials as residual soils and dust found over road surfaces; Sandoval et al. [24] studied the phenomena based on constant head tests as well as infiltration tests results offered by former field investigations, achieving reduction of permeability up to 95%. Studies concerned to particular climate regimes were also carried out in recent years; Amirjani [25] focused on wind-suspended particles clogging due to wind erosion in desert areas.

The service life (from the hydraulic point of view) of the permeable pavement system depends not only on the clogging of the pervious concrete covering, but also on the transport of solid particles to the permeable bases, although it may take a reasonable time to fill its voids of the uniform grain size in permeable granular bases (usually 40% of the pavement volume). Clogging within the pavement bases will, over the years, cause the clogging of corrugated subsurface drains (in their external environment) gradually decreasing or even eliminating their functionality. One of the most critical situations that can occur is the percolation of water filled with diluted fines, or mud coming from the contribution area surrounding the pavement, which, after drying with the drought, will cause a drastic decrease in the number of voids, greatly reducing the porosity of the base. There are studies dealing with the modeling of filling of open granular bases [26]. A recent lab study demonstrated that clogging of the porous structure in pervious concrete happens in three distinct phases: the first as a rapid one; then some period of mitigation; at last, the non-stop progressive phase [27].

According to National Ready Mixed Concrete Association [28] and Razzaghmanesh and Beecham [5], sweeping can be effective to control clogging if taken as a routine maintenance, as well as blowing. Powerful suction is recommended semiannually to remove incrusted solids and organic matter. However, only water blasting of high pressure can release clogged porous structures when infiltration rates fall down to one-quarter of its initial value.

In the present study, the clogging performance of pervious concrete was studied in field. A sidewalk test section was purposely built over an area surrounded by dense tree vegetation, both tropical and exotic, representative of forestation patterns in Sao Paulo City. Analysis and comparison of actual field loss of infiltration rate are then related to some former available laboratory simulations. The quick clogging results obtained for this sidewalk during the summertime is contextualized. Also, purposely, no maintenance services were carried out until April 2020, to simulate the scenario of lack of conservation of public infrastructure, as well as to really achieve the worst infiltration rate after 48 months. This attitude has been discussed and justified as the city has huge needs for implantation of mobility infrastructure in the peripherical and suburban areas where public service assistance is still deficient.

4 EXPERIMENTAL URBAN SIDEWALKS – DESIGN CONCEPTION AND SITE CONDITIONS

4.1 Site location for sidewalk test – Flora around the facility

The university campus at the São Paulo State Capital is a large green area (3,700,000 m^2) inside the city, in the extension of Atlantic Forest, with predominant tropical vegetation besides relevant number of exotic trees. Mendonça [29] categorized 152 vegetation species at the university campus, comprising 107 biological genera under 43 families. The most common species are *Leguminosae* (24%), *Myrtaceae* (10%), *Palmae* (9%), *Bignoniaceae* (7%), *Moraceae* (6%), *Bombacaeae* (2.5%), and *Sterculiaceae* (2.5%). Native tropical species make up 59%, while exotic ones represent 41% of the whole flora within the campus. However, flora species are randomly spread in the area; most of the area has urban characteristics alike parks crossed by over 20 km of streets and avenues.

The vegetation surrounding the area of the sidewalk test site (Figure 2) was of paramount aspect for achieving rapid natural clogging in pervious concrete, associated to climate conditions. The falling of organic debris from the surrounding vegetation would contribute, adding to the rainfall period, for the decay of the organic material and its penetration inside the pervious concrete porous structure. Therefore, site choice was selected in a dense vegetation area within the gardens of the Civil Engineering building (Lat. 23°33'44" S). Several tree species located in the neighborhood of the sidewalk were identified. In Table 2, a list of identified ones is presented, based on Mendonça [29], and Figure 3 represents the location of the sidewalk and surrounding trees.

Table 3 synthetizes the blooming and fructifying (along with rainfall) periods for the trees (when pertinent) in the experimental area. In the last three lines of the table the superposition of such events and the rainfall monthly average in the campus area are highlighted, from where it can be inferred that the critical time for falling leaves and fruits in conjunction to the rainier (and windy) season, December to March (typical of tropical environments in South America). The experimental sidewalk was built on December 3, 2015, exposing the pervious concrete to the immediate action of the combination of organic matter fall and hot-humid period, leading to the worst combination for the decay of organic matter over the concrete surface and its top-down percolation through the porous concrete. Therefore, the site location gathered all conditions for a rapid in situ clogging of the pervious concrete. The above-mentioned events disregard average distance to the sidewalk and number of same trees in the neighborhood.

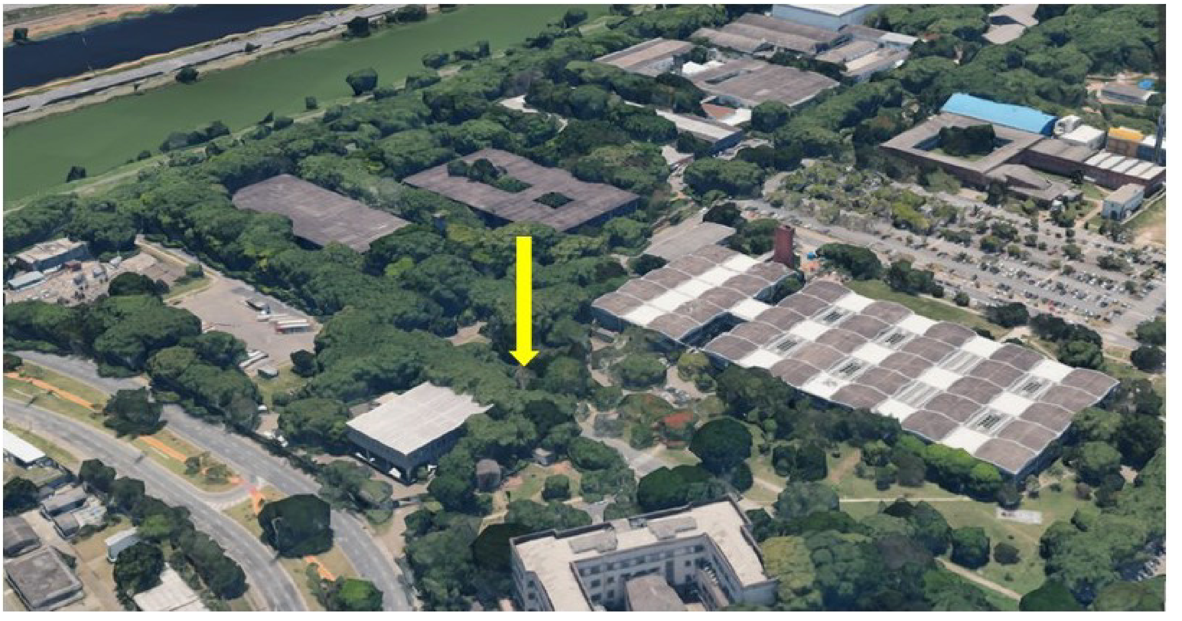

Figure 2. Aerial view of the sidewalk surroundings (sidewalk location indicated by a yellow arrow) – Source: Google Maps. USP Campus at São Paulo, 2020.

Table 2. Tree specimens surrounding the test section (survey based on Mendonça [29])

Tree Specie	Common Name	*Particularities*	Nature	Origin
Archontophoenix cunninghamiana	King Palm	*Green stem and plentiful of red fruits, blooming all the year.*	Exotic	Australia
Ceiba speciosa	Paineira	*Blooming from Mars to July and fruits and seeds consumed by parakeets.*	Tropical local	South America
Delonix regia	Flamboyant	*Blooming from October to December and fruits available by June. Red flower with flame shape.*	Tropical exotic	Madagascar
Dictyosperma album	Princess Palm	*Blooming in October and fruits available in April. Edible palm.*	Tropical exotic	Mascarenhas Islands/Indian Ocean
Eugenia uniflora	Pitanga	*Red edible fruits. Blooming from August to December and fruits available from September to April. Edible palm.*	Tropical local	Brazil
Ficus microcarpa	Chinese banyan	*Shade tree extensively used in parks in São Paulo, Brazil. Blooming all year long.*	Tropical and sub-tropical exotic	Tropical Asia, China to Australia
Jacaranda mimosifolia	Blue Jacaranda	*Blooming from September to December, producing a long span fruit.*	Tropical local	Central South America
Mangifera indica	Mango tree	*Blooming from July to October and fruits available in November and December.*	Tropical exotic	India
Morus nigra	Black mulberry	*Produces edible fruits. Fruits available from August to December.*	Sub-tropical exotic	Asia (West)
Persea americana	Avocato	*Produces edible fruits. Blooming from September to October and fruits available in January.*	Tropical exotic	Central America
Psidium guajava	Guava	*Edible as fruit and used for juices and sweets. Blooming from September to October and fruits available from November to Mars.*	Tropical and sub-tropical local	South America
Psidium guajava	Guava	*Edible as fruit and used for juices and sweets. Blooming from September to October and fruits available from November to Mars.*	Tropical and sub-tropical local	South America
Schefflera actinophylla	Dwarf umbrella	*Ornamental plant. Blooming and fructifying from December to April.*	Exotic	Australia
Syagrus romanzoffiana	Cocos palm	*Edible fiber fruit. Blooming from the Spring to Summer and fruits available from Summer to Fall.*	Tropical and sub-tropical local	South America

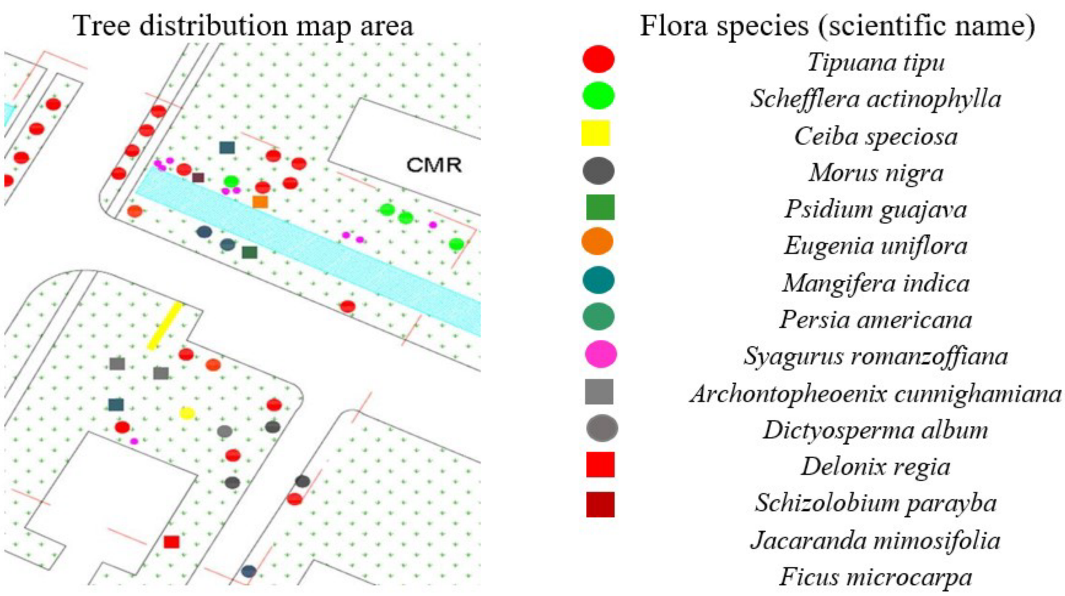

Figure 3. Distribution of trees at the sidewalk (yellow line) surroundings (courtesy: Guilherme Nunes Kalleder)

Table 3. Crossing critical periods concerning clogging due to leaves blooming and fructification periods of trees at experimental area.

Tree specie	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Blooming Period												
Archontophoenix cunninghamiana	■	■	■	■	■	■	■	■	■	■	■	■
Ceiba speciosa			■	■	■	■	■					
Delonix regia										■	■	■
Dictyosperma album										■		
Eugenia uniflora								■	■	■	■	■
Ficus microcarpa	■	■	■	■	■	■	■	■	■	■	■	■
Jacaranda mimosifolia									■	■	■	■
Mangifera indica							■	■	■	■		
Morus nigra									■	■		
Persea americana							■	■	■			
Psidium guajava									■	■		
Schefflera actinophylla	■	■	■	■								■
Syagrus romanzoffiana	■	■	■							■	■	■
Tipuana tipu										■	■	■
Fructifying Period												
Archontophoenix cunninghamiana	■	■	■	■	■	■	■	■	■	■	■	■
Ceiba speciosa			■	■	■	■	■					
Delonix regia				■	■	■						
Dictyosperma album				■								
Eugenia uniflora	■	■	■	■					■	■	■	■
Ficus microcarpa	■	■	■	■	■	■	■	■	■	■	■	■
Jacaranda mimosifolia												
Mangifera indica											■	■
Morus nigra	■											
Persea americana								■	■	■	■	■
Psidium guajava	■	■	■									■
Schefflera actinophylla	■	■	■	■								■
Syagrus romanzoffiana	■	■	■							■	■	■
Tipuana tipu												
Superposed blooming tree events	6	5	6	7	4	4	3	3	4	4	5	7
Superposed fructifying events	7	6	7	7	4	4	3	3	4	5	6	8
Monthly average rainfall (mm)	226	203	151	64	65	41	43	29	68	130	142	189

It is worth noting that the year rainfall of 1,351 mm/year at the location, although not so high as a tropical forest itself, but still remarkable compared to most temperate climate regions. The rain is well concentrated in the meridional spring and summer (October to March), with maximum average daily rainfall of 7.3 mm in December. Most of the fructifying periods come along with the warm seasons; this is true for the blooming periods too. However, blooming of some surrounding trees happens every year or during drought seasons, leading the surface to be charge by dry organic matter any month during the year (Figure 4).

Figure 4. Debris over sidewalk porous concrete surface: dry leave (left); green leave (center); rotting organic matter in between aggregates (right).

4.2 Pervious concrete mixture used for the sidewalk test

The design of the concrete mixture for the pervious concrete pavement was the initial task to the sidewalk construction, and its conception and details such as permeability and strength can be found elsewhere [19]. In Table 4, the pervious concrete materials proportions as employed in the sidewalk test are presented. Table 5 offers summarized data for several physical, mechanical, and hydraulic parameters of the hardened concrete mix. Concrete porosity and initial infiltration rate fitted properly the model relating both parameters as proposed by Haselbach et al. [31].

Table 4. Pervious concrete mixture employed for sidewalks projects [19]

Mix Information	Amount/Type	Unit
Cement Type	ASTM Type III	-
Cement content	374	kg/m^3
Granite crushed medium aggregate content	1,660	kg/m^3
Maximum aggregate size	12.5	mm
Minimum medium aggregate size	6.3	mm
Aggregate size little than 4.8 mm	4.5	%
Aggregate specific mass	27.20	kN/m^3
Fineness modulus	6.046	-
Aggregate powder content	0.54	%
w/c ratio	0.307	-
superplasticizer	1,588	mL/m^3
Setting retardant	1,415	mL/m^3

Table 5. Hardened pervious concrete initial parameters [30]

Type of data	Parameter (unit)	Values
Physical indexes	Specific weight (kN/m3)	18.41
	Porosity (%)	25.0
Mechanical (28 days)	Compressive strength (MPa)	7.5
	Indirect tensile strength (MPa)	1.4
	Flexural strength (MPa)	2.2
	Modulus of Elasticity (GPa)	16.5
Hydraulic	Hydraulic conductivity in constant head (cm/s)	0.14
	Hydraulic conductivity in falling head (cm/s)	0.73
	Infiltration rate (cm/s)	0.56

One can note that, although 375 kg/cm of cement are used in the mix due to the chosen high porosity (25%), compressive strength is low, which is explained by the weak contact between aggregate grains and the voids in between. This affects seriously the compressive strength since for well-graded aggregates (with fines) the strength could, considering more water as a requirement for workability, 4 to 5 times greater. On the other hand, flexural strength, which is more dependent on the interfacial transition zone mortar/aggregate, resulted only 50% lower when compared to conventional concretes for paving. This is considered a nice achievement as the pervious concrete slabs have a good mechanical performance in flexure and the pressures over their surface exerted by pedestrians and bikes are usually as low as 0.1 to 0.5 MPa. The reasonable flexural strength of 2.2 MPa is ensured through a low w/c ratio, close to 0.3. Besides that, it is worth remembering that, in the lab, cylindrical specimens are molded by falling weight, which is not allowed in the field since it could cause the precipitation of the cement paste that might clog the bottom of the pervious concrete, i.e. an unacceptable *in-built* clogging. Prismatic specimens in lab are molded only by manual roll pressure over the open surface. In the field condition manually operated light rolls are used with the exclusive target of obtaining a smooth and flat surface but nothing more. Therefore, field resistance, especially compressive, tends to be smaller.

4.3 Sidewalk pavement Details – Design and Construction

The 8.65 m length by 1 m width sidewalk was built with light equipment (manual 60 kg roll over lateral steel forms) inside the above-described garden area, using a 150 mm-thick recycled aggregate base prepared from debris of demolition of an old civil construction building. It was not provided any specific sub-superficial drain pipeline to collect the rainwater passing through pervious concrete and this open-graded base; no geotextile fabric over the subgrade clay soil was used. Base aggregates were spread and lightly compacted over the natural subgrade. The pervious concrete thickness was 100 mm and was poured on December 3, 2015, [32], [33]. Pouring pervious concrete begins from the upper to the lower part, taking four batches to be completed in the project area. Figures 5a to 5e present some essential construction pictures from the sidewalk pavement construction steps and techniques used.

Figure 5. (a) Recycled aggregates sidewalk base and lateral metallic forms for concrete pouring; (b) in situ concrete provision with small concrete-mixer; (c) Concrete pouring and compaction with light roll; (d) concrete curing using polyethylene fabric (7 days); (e) Final pervious concrete sidewalk view (December 2015).

5 INFILTRATION TESTS ALONG THE PERIOD 2015-2019

5.1 Test Method and Locations

The determination of the infiltration rates over permeable concrete surfaces was performed through the procedures provided by ASTM C1701 [34] standard. The method uses a PVC infiltration ring of 300 mm diameter and 50 mm height, which is placed and sealed externally (at its external bottom) over the permeable concrete surface. In this ring, inside, there are two lines marked at the height of 10 mm and 15 mm.

The track test starts with a pre-wetting inside the ring. This procedure uses 3.6 L of water to preserve a standard water column between the two marks inside the ring (described above). The time elapsed between the first contact of water poured into the ring until it is completely absorbed by the permeable concrete surface is measured. If the measured time exceeds 30 s, the test is considered appropriate. Then, the test is repeated sequentially three times to determine an average of the obtained values. When the measured time is less than 30 s, it is required to use 18 L of water per test, repeating them equally three times. For the determination of the infiltration rate (I) - in mm/h - the following expression is used:

$$I = \frac{K' \times M}{D^2 \times t} \quad (1)$$

where M is the water mass (kg) infiltrated by the surface, D is the internal diameter of the infiltration ring (as already defined, 300 mm) and t is the (average) time measured in seconds of three successive tests. K' (not to be confused with permeability) is a factor for converting data into the units described herein, equivalent to 4,583,666,000.

In order to monitor the infiltration rate evolution with time, the location of repetitive tests over the pervious concrete slab surface were defined by six points, as represented in Figure 6. Most of the infiltration test locations were fixed close to slab borders except for one point. Infiltration tests were carried out during the period from December 11, 2015 to November 7, 2019 (46 months comprising 11 field measurements series). Criteria adopted for clogging evaluation along the period was to clean locally the surface prior to infiltration tests only, with no maintenance over months, as previously mentioned.

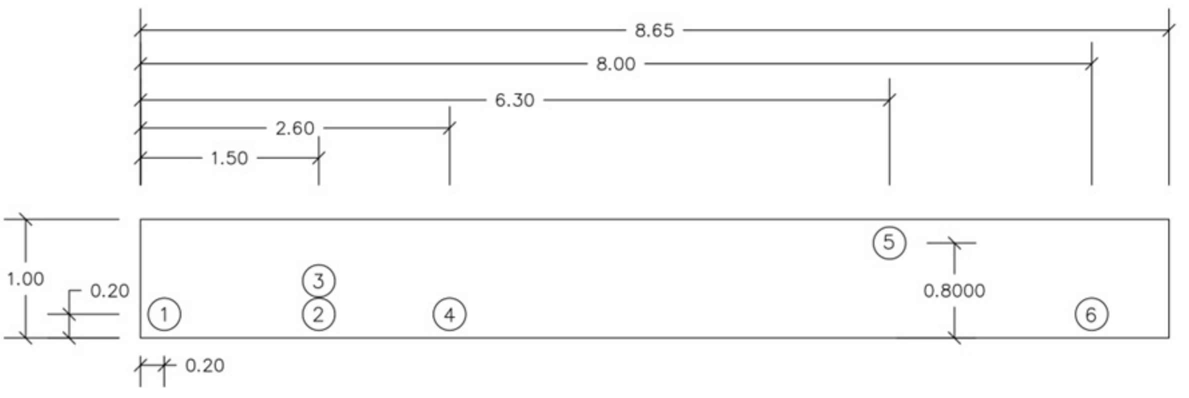

Figure 6. Plan view with the location of infiltration tests during the experiment (dimensions in meters)

For any series of tests along time, infiltration tests were taken three times for each point to define an average infiltration rate. The reasons for choosing such points were to test the slab corner, slab edges close to the corner and in remote to corner position, and center of the slab. Points 1 to 4 are located at the high-level position of slab (the slab is 1% steep) where water tends to not remain underneath flowing to the lower part of the slab. In opposition to such a situation, Point 6 was chosen. Point 5 is a particular case where the concrete, at the longitudinal slab edge, was non-uniform and water was flowing easily through the lateral face, inducing higher infiltration rates for any time during the experiments.

5.2 Results for infiltration rates

Figure 7 presents the surface with accumulated vegetation debris as of the tests in April 2016. Prior to tests, as aforesaid, the circular position to fix the PVC ring was cleaned before every test. In Table 6, the average values for infiltration rates gathered along the months of permeability monitoring are presented.

Figure 7. Surface with vegetal debris before tests

Table 6. Infiltration rates (cm/s) from 2015 to 2019.

Test Locations	Dates for tests											
	Year	2015	2016					2017	2018			2019
	Month	Dec.	Apr.	Jul.	Sep.	Oct.	Dec.	Jan	May	Sep.	Dec.	Nov.
	Day	11	05	29	02	20	09	26	11	26	12	07
	Elapsed days	0	115	230	345	460	575	690	805	920	1,035	1,150
	SERIES	1	2	3	4	5	6	7	8	9	10	11
1	-	0.56	0.04	0.05	0.08	0.06	0.08	0.12	0.30	0.11	0.03	0.04
2	-	0.56	0.23	0.21	0.30	0.29	0.11	0.14	0.23	0.13	0.10	0 10
3	-	0.36	0.22	0.13	0.14	0.13	0.10	0.12	0.07	0.04	0.03	0.04
4	-	0.18	0.11	0.05	0.08	0.08	0.08	0.09	0.07	0.05	0.02	0.04
5	-	1.06	0.55	0.51	0.76	0.76	0.65	0.72	0.79	0.47	0.39	0.36
6	-	0.63	0.43	0.29	0.31	0.57	0.41	0.30	0.34	0.27	0.05	0.12
Average for data	cm/s	*0.56*	*0.26*	*0.21*	*0.28*	*0.32*	*0.24*	*0.25*	*0.32*	*0.18*	*0.10*	*0.12*
Standard deviation	cm/s	0.30	0.19	0.18	0.26	0.29	0.24	0.24	0.26	0.17	0.14	0.12
Coefficient of variation	(%)	53.09	73.31	84.90	92.48	91.81	100.12	97.79	83.57	93.70	138.33	106.61
Average for data*	cm/s	*0.46*	*0.21*	*0.15*	*0.18*	*0.23*	*0.16*	*0.15*	*0.20*	*0.12*	*0.05*	*0.07*
Standard deviation*	cm/s	0.19	0.15	0.10	0.11	0.21	0.14	0.08	0.13	0.09	0.03	0.04
Coefficient of variation*	(%)	40.45	71.89	71.44	63.17	94.00	91.40	54.25	62.41	77.53	69.38	56.87

*Outlier data from location 5 were excluded from statistics.

From the results presented in Table 6, several comments can be made. Three behaviors can be roughly distinguished. Location 1 (upper portion corner) presents a huge loss of infiltration rate from the beginning. Locations 2 and 3 (upper portion) show an intermediate initial permeability, followed by some loss over time. Location 4 exhibits, in general, small initial infiltration rates and a smooth loss during the time of tests. Locations 5 and 6 are in the lower portion of the sidewalk, with some similarities, but very different behavior compared to the firmer locations.

Location 5 presented a remarkable behavior because its higher infiltration rates, compared to the other test locations. It was the location that exhibited the smaller final loss of permeability by 2019, a residual of circa 33% of the original one, including a stable period (keeping similar infiltration rates) between April 2016 and May 2018. Location 6, with an intermediate stable period also, eventually presented a relevant loss of permeability.

Bias on data is remarkable. Results of coefficient of variation (COV) in Table 5, excluding data for location 5 (outlier data), are expected to be from 40% to 95%, some high values. Infiltration tests have some randomness and are subject to some types of systematic errors during measurements: values of means are scattered for most of the points, which leads to understanding that there exist different measures for this attribute. Important variation of porosity of the pervious concrete after placement due to paste precipitation, different homogenization of batches and compaction effort are due the material intrinsic nature and pavement production method (all manual). COV results tend to be highly biased using even different methods, frequently reaching practical values over 100% [35]. Infiltration rate tests using ASTM C1701 method [34] apply for much more controllable conditions in laboratory and small slabs, and, when it was adapted, reached deviations of about 35%. For Lederle et al. [36] it demonstrates the lack of repeatability inherent to this method.

The personal errors (human failures) are critical for infiltration measurements due to both possible carelessness during the water dropping and water highness readings within the ring. Poor repeatability of the method is also a problem to affect individual results. All the mentioned errors may occur in pervious concrete infiltration tests, which is to be mitigated by three successive measurements at the same point as specified by ASTM C1701 standard [34].

Despite this standard directive, the lateral divergence of water flow underneath the ring, which is subjected to porous structure variation of the concrete, completes the bias explanation since tests could be more precise using large PVC rings (e.g., more than 500 mm diameter) over plane surfaces. Besides that, there is an almost 50% difference from the horizontal permeability to the vertical one [37], pointing out anisotropic fluid flow, turning into a more complex interpretation of results. Based on a multi-scale *in situ* approach, Vaddy et al. [38] proved that the greater the ring diameter, the lower the infiltration rate, pointing out the intrinsic difficulties for the test interpretation.

Boxplots of the infiltration rates over time are shown in Figure 8. It is worth noting that the observations from the location #5 are identified as outliers. A scattered plot of infiltration rates over time per location is shown in Figure 9.

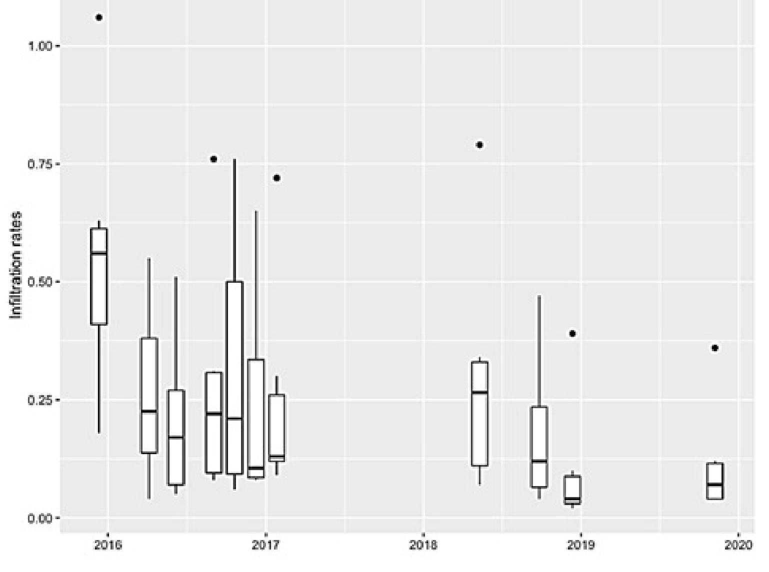

Figure 8. Boxplot of infiltration rates over the time.

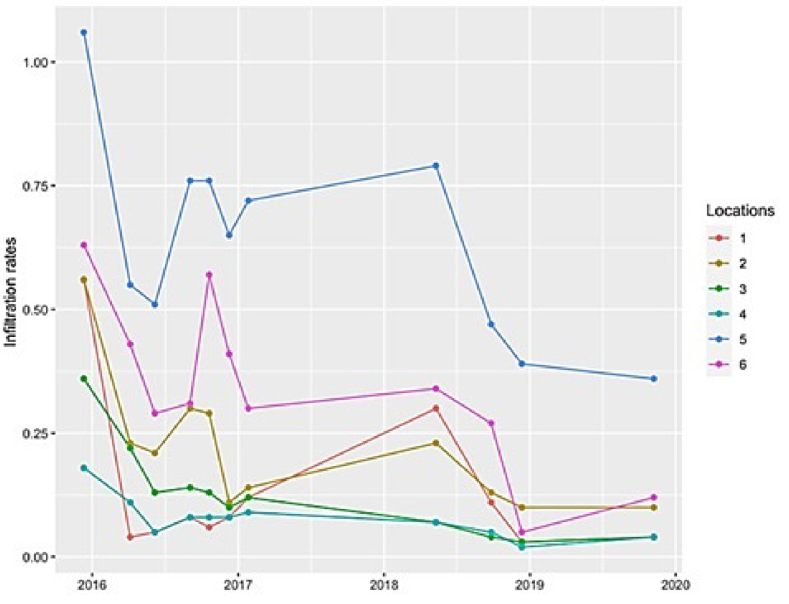

Figure 9. Measurements of infiltration rates over the time.

6 FITTING A MIXED LINEAR MODEL FOR THE INFILTRATION RATES

In this section, a mixed linear model is fitted for the infiltration rates since repeated measurements are made on the same locations (it is a longitudinal study). As the infiltration rates decrease, exponential distribution is assumed for describing them. Moreover, to take into account the variability among the locations, a random intercept γ_i is used. That is, conditioned on the location i, $Y_{ij}|\gamma_i \sim Exp(\mu_{ij}), i = 1, \ldots, 6$, where Y_{ij} is the infiltration rate in the location i at the time t_j (# days after the beginning of the experiment), μ_{ij} is the average infiltration rate in location i at time $t_{j,}$ $j = 1, \ldots, 11$. Due to the restriction $\mu_{ij} > 0$, a logarithm as link function is chosen expressed as:

$$\log(\mu_{ij}) = (\beta_0 + \gamma_i) + \beta_1 t_j \tag{2}$$

with $\gamma_i \sim N(0, \sigma_b^2)$ independently for location $i = 1, \ldots, 6$; $j = 1, \ldots, 11$.

The parameters of the model (2) are obtained by using the package *GAMLSS* from the freeware statistical software R. The estimated values of the coefficient with its respective standard error are presented in Table 7.

Table 7. Output of the mixed exponential model

Parameters	Estimate	Standard error	z value	p-value
Fixed Effects (Intercept) (β_0)	-1.02900	0.22172	-4.641	< 0.001
Fixed Effects (time) (β_1)	-0.00118	0.00029	-4.118	< 0.001
Random intercept standard deviation	0.71822	-	-	-

The fitted model can be written as follows:

$$\log(\hat{\mu}_{ij}) = -1.0290 - 0.00118\, t_j + \gamma_j, \text{ where } \gamma_j \sim N(0; 0.71822^2) \tag{3}$$

It can be highlighted that, for each location, the infiltration decreases averagely at a rate of ≅ 0.00118 cm/s (1-exp(- 0.00118)=0.00118) per day. To evaluate the goodness of the fit, some diagnosis procedures were conducted. Frequently residual analysis by using normalized randomized quantile residuals is used to evaluate the adequacy of the model [39], [40]. Figure 10 to 11 show the diagnostic plots. All residuals appear satisfactory, as the quantile residuals follow the normal distribution. Estimated means and medians of infiltration rates are obtained using the expression (2) and plotted together with the Boxplots (drawn with the observational data previously show in Figure 8) in Figure 12.

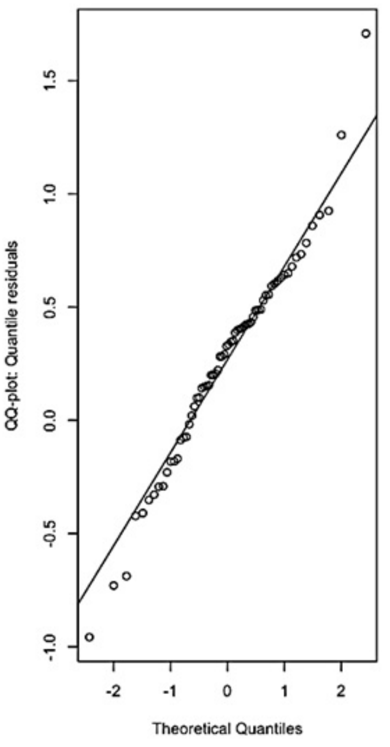

Figure 10. Diagnostic plots - QQ-plot of the quantile residuals

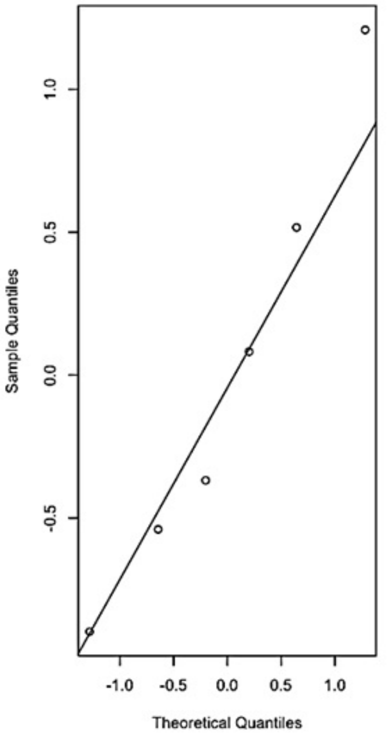

Figure 11. Diagnostic plots - QQ-plot of the random intercept

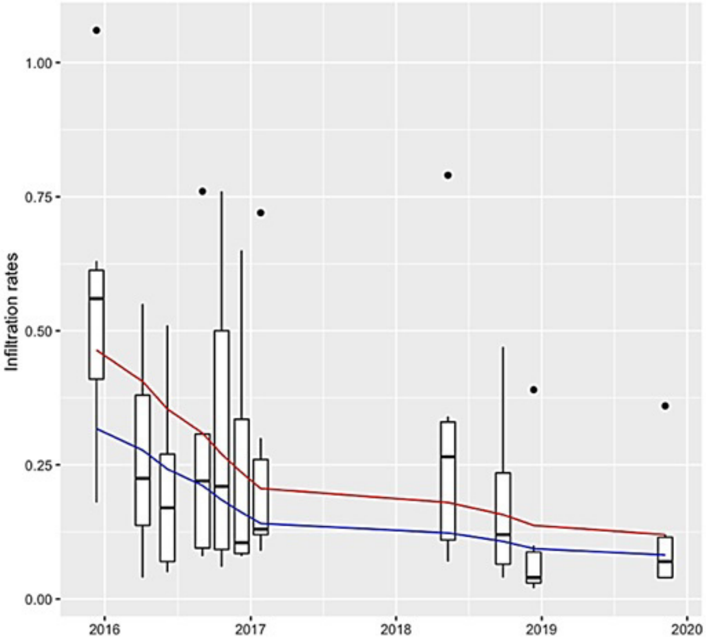

Figure 12. Boxplots of infiltration rate versus fitted values (mean per locations, color red and median per locations, color blue) over the time.

7 DISCUSSION OF RESULTS

7.1 Acceptable Infiltration Rates and Maintenance Issues

Years from now, at the very beginnings of uses of pervious concrete in urban pavements and testing clogging, several researchers and public actors studied the clogging problem in such a layered system, most of them by means of laboratory simulations. Montes and Haselbach [41] observed, by inserting sand at the top of lab samples and simulation of raining events, sharp reduction of permeability, falling from 2.2 and 1.0 cm/s to 0.002 and 0.005 cm/s. Similar study was conducted by Joung and Grasley [42], verifying that high porous concretes (at least 33% porosity) were not affected by fine sands, with negligible clogging. However, for porosities under 30%, more of 40% loss was reported during lab tests. Neithalath et al. [43] reached values like 30% loss of porosity in lab samples subjected to sand clogging. Drake et al. [44] studied clogged pervious concrete pavements with severe loss of hydraulic serviceability as low as de 0.001 cm/s and verified that, even in such level, it could be possible to increase six times this infiltration ate by means of intensive maintenance with surface suction and intense pressure washing.

By considering values of loss of infiltration rates observed in past studies as well as acceptable values for the parameter, most of them determined through laboratory simulation of clogging, it is remarkable that, even after four years, an average value for final infiltration rate of 0.12 cm/s observed on the experimental sidewalk is still fair and acceptable among conventional values from 0.1 to 1.2 cm/s [45]. However, this can be taken only for the average value for all locations for tests, since if one not considers the location 5, the final average is under expected way of loss of infiltration rate.

That means that decisions on maintenance (suction and water pressure, combined or not) are not simple to take even based on nondestructive tests for defining permeability parameters. One should remember that the reservoir volume design for pervious concrete pavements is carried out based on porosity parameters of base and even the own concrete layer. Employing the experimental relation for porosity (P in %) and infiltration rate (I in cm/s) developed by Haselbach et al. [31], given by the above equation, an estimation of average porosity for location 5 is 22,5%, and for location 1 is 15%.

$$P(\%) = 27{,}146 \times I^{0{,}1884} \tag{4}$$

Such values are roughly related to the actual pervious concrete porosities measured over samples cored from the sidewalk, close to 30% and higher compared to the mix proportion preliminary study anticipating 25%. But the infiltration test results are prone to define the system infiltration capacity, that is, pervious concrete slab plus open-graded base (with natural porosity up to 40%). Therefore, the infiltration rate can be a parameter representing the overall permeability of the pavement system and the use of Equation 3 is not the best way to verify the joint concrete-base layers porosity.

This remark is important since clogging reduces somehow the volumetric capacity of the pavement system of storing rainwater, more likely due to base clogging since the retention of fine material in the porous concrete has shown to be little based on given porosity for cored samples after four years of effective use of the sidewalk, without any maintenance approach during that period.

Analyzing average results for infiltration rates in Table 6 after exclusion of location 5, it is clear that acceptable values for such parameter were retained up to May 2018, suggesting that, for a dense gardened area in tropical climate regimen without any maintenance effort (not even cleaning surface monthly to avoid organic matter rotting over it), full maintenance procedures should be taken every two years for the sake of permeability behavior of the system. Locations 1 and 5 are strong indicators that, due to variability of the permeability itself when the pervious concrete is poured, that, in wooded parks, maintenance through the use of a potent vacuum cleaner (ascensional extraction) followed by high pressure water jet every three months (to recover and keep infiltration capacity over 0.1 cm/s) is recommended; and infiltration tests shall be promptly done to verify the cleaning service effectiveness. Considering the recommendation of the National Ready Mix Concrete Association [28] in US, which states that the use of pressure water jet is recommended when the infiltration rate is reduced to 25% from its initial rate, the three-month period for maintenance herein suggested is justified.

Clogging and maintenance on the presented scenario deserve some comments also. Average data for infiltration points out a value of 0.12 cm/s, which could be taken as acceptable as a minimum requirement (close to 0.1 cm/s). However, even for a single and monolithic-built sidewalk data disclose values as 0.08 to 0.11 cm/s after one year of the construction. That is a clear signal for maintenance demand in periods as every three to four months in the conditions as herein analyzed, for dense vegetation surrounding the concrete surface and falling of leaves, flowers, and fruits almost during all year long, typical for tropical hot-humid areas. Therefore, values of loss of infiltration capacity around 75% are achieved, for such a peculiar condition, as soon as close to 180 days, what is a relevant information for public preservation of porous sidewalk facilities in parks and streets; and it requires team, equipment, and budget, to be considered in a continuous pavement management process. On the other hand, Hunt and Collins [21] suggest that it is possible to achieve long-term minimum performance with infiltration rates over 0.007 cm/s, which obviously depends on the rainfall characteristics of specific regions of the world, as well as what is considered an intense rain for a specific project, making it possible to suggest that the conclusions herein stated on the basis of a tropical climate is not to be taken as a golden rule for any design.

7.2 Interpreting clogging as three-stage phenomena

Even with the scattered data due to aforementioned reasons, it is possible to split the loss of infiltration rate during the tests in two different periods: a first phase with and abrupt loss and a second phase where the infiltration rate decrease is gentle. Decreasing rates are shown in Table 8 where the two-phase scenario presents some evidence by the numbers, including location 5 with higher infiltration rates as discussed.

Table 8. Loss of infiltration rate during the tests

Location	Test position	Loss from 1st to 2nd measurement (%)	Loss from 2nd to 11th measurement (%)	Initial abrupt rate of loss (cm/s/month)	Medium term rate of loss (cm/s/month)
1	Corner	-92.9	0.0	0.14	0.000
2	Longitudinal edge	-58.9	-56.5	0.09	0.004
3	Slab center	-38.9	-81.8	0.04	0.005
4	Longitudinal edge	-38.9	-63.6	0.02	0.002
5	Longitudinal edge	-48.1	-34.5	0.13	0.006
6	Longitudinal edge	-31.7	-72.1	0.05	0.009
			Average	0.08	0.005

Some comments are necessary at this point. For location 1, at the high-level slab corner, it is remarkable the loss of infiltration capacity in few months (four as reference), possibly due to the corner, in contact with soil and water flowing slowly in the contact soil to get an intensive and too much quick clogging condition. Such a condition led to an early almost complete loss of permeability. Whether one considers location 1 or not for achieving the average loss during the abrupt initial clogging (short-term) the rate is around 0.08 cm/s/month. The remaining data permits fixing an average loss of infiltration rate at 0.005 cm/s/month.

While the statistical general mixed linear model represented by Equation 3 describes, with good fitness, the loss of infiltration rate, alternatively, the phenomena can be dealt as a single two-stage model as suggested ahead. Data obtained also can well attach to some kind of three-stage model to describe the phenomena; this is shown graphically in Figure 13 and with plotting all the infiltration rates at location points making possible some comparison among then. Overall results allow the graphical description of the observed phenomena as a bilinear model like follows:

$$I = I_0 - 0.08 \times t \ (if\ t_a \geq t) \quad (5)$$

$$I = I_0 - 0.32 - 0.005 \times t \ (if\ t_a < t) \quad (6)$$

where I is the estimate infiltration rate at any time (cm/s), I_0 the initial infiltration rate (cm/s), t is the elapse time (months) for infiltration rate estimation and ta the initial abrupt period of clogging herein taken as 4 months. By looking Figure 13 is evident that there happens some intermediary stabilization of the infiltration rate loss. For its assembly it was sectioned the first stage by 115 days, when it is observed a very quick loss of infiltration rate for any location. From 115 days ahead locations 1, 2 and 6 were taken to the limit of 920 days; location 3 to 690 days; and locations 4 and 5 to the limit of 80 days.

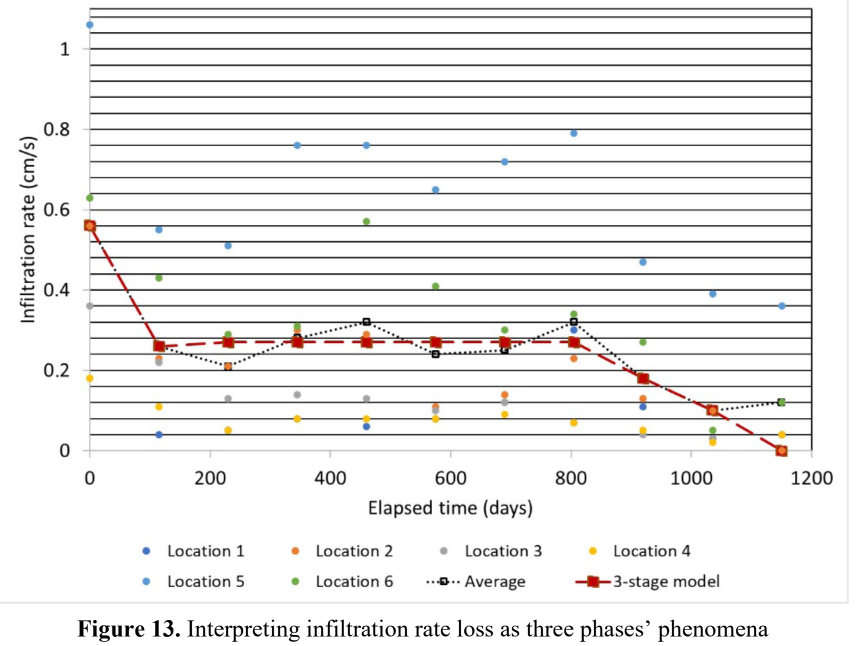

Figure 13. Interpreting infiltration rate loss as three phases' phenomena

Cui et al. [27] described, after their laboratory accelerated tests and two field tests for calibration, a three phases approach. The second field test was performed one year after the first, during summer storm events at the city of Jinan (China), where the stronger rainy period is from mid-July to mid-August, with stuffy days, with average of 159 mm rainfall in 30 days, year rainfall of 673 mm. The winter is typical of temperate climates (Jinan is 430 South of Benji), with snow and dry conditions, hence, quite different from Sao Paulo area in South America (under the Tropic of Capricorn). The study suggested that the continuous clogging process in pervious concrete takes three phases: the first stage when clogging was taking place quickly compared to the ensuing ones; the second, called a mitigation phase, suggesting a strong decrease in clogging velocity compared to phase one; and the last stage was called a progressive phase.

The present data suggests that a three-phase model for clogging prediction is a fair alternative, especially for the case when very quick clogging (like the sidewalk amid a very wooded area surrounding it), to determine the first low point in terms of infiltration rate, making aware of the need of maintenance intervention other than sweeping (note that locations 1 and 4 meets the minimum infiltration rate requirement at this point). Therefore, two-phase model described through Equations 5 and 6 has the same usefulness. However, to take a future time prediction to the beginning of the third stage is uncertain because the clogging tends to be differentiated over the entire area of the porous pavement. As aforementioned, Figure 11 was built on assuming different times for beginning of the third stage on the basis of the numerical results presented in Table 6. Therefore, the end of the supposing mitigation phase as proposed by Cui et al. [27] could not be defined precisely through the carried experiment in field. Hence, Equations 1 and 2 can be used as a second slow phase for prediction of clogging for medium term analysis and management.

7.3 Porosity Variation after Pressure Washing

By January 2019, three cores of pervious concrete were extracted from the sidewalk for porosity measurements in lab; values of in-field laced porous concrete voids did not match to estimated ones during concrete mixes preliminary studies (25% as shown in Table 2). For porosity tests in laboratory, it was employed the simple method of hydrostatic scale, testing the cored samples prior and after its intensive washing by water pressure device. Tests were carried out with the superior 50 mm of the cylindrical samples. Table 9 presents the results for weights and porosity of samples.

Table 9. Porosities of field extracted pervious concrete samples.

Sample	Diameter (mm)	Average highness (mm)	Porosity before cleaning (%)	Porosity after cleaning (%)	Porosity variation (%)
1	100	41	30.62	32.38	5.75
2	100	41	31.48	32.52	3.30
3	100	42	25.55	27.19	6.42

The above results show that, in field, the pervious concrete did not reach the expected porosity during lab mixture proportion tests of 25%; porosity in field was scattered, more than the anticipated one due to material heterogeneities as well as field compaction procedure, what is significantly different and less energic than the falling weight compaction methods. It was observed by comparing dry weights before and after cleaning, the sample that incrustation of spoiled organic matter. Indeed, porosity after more than three years still was good for a pervious concrete, with small changes.

Results in Table 9 are crucial to bring up another hypothesis and discussion on the experiment. It is recognized that the infiltration test, taking some time to exhaust the water from the ring surface, is preceded by an initial wetting, which is done to fill not only the pervious concrete layer, but the pavement system porosity. Therefore, it is trusted that the field test, when the system is overloaded by water, results in infiltration rate values relative to the resistance to water flow of both the pervious concrete layer and the open graded base layer. This understanding is shared by some authors, e.g., Lederle et al. [36]. Also, Cui et al. [27] demonstrated, by data accessed through electrical conductivity measurements in porous concrete in laboratory, that the water depth on the system affects clogging velocity.

Loss of infiltration rate observed in field over months are strikingly different from the observed loss of porosity measured over the concrete samples extracted from the sidewalk surface, what incites the question about the actual signification of the field test results using rings: what has been measured? Results are resourceful to ascribe the loss of infiltration rate in field to the clogging of the base layer and not the concrete alone, what denotes the extreme relevance of monitoring the pavement system ability to drain surface water as a tool for modeling infiltration rate loss along time. It holds the understanding that, for the system durability, not only the concrete layer porosity is a dominant characteristic [31].

8 CONCLUSIONS

It was built a sidewalk section of pervious concrete pavement in a wooded garden in a typical tropical area in 2015. In this location area, several types of tropical threes (native and exotic) blooms and fructifies in different seasons, ensuring deposition of organic matter over the porous pavement surface all year long. Over the course of four years, infiltration rates of the pavement surface were monitored periodically in order to better understand the prediction of clogging. Porosity tests were carried out during the last year to verify the amount of material adsorbed within the porous interstices. The following conclusions were derived from the study interpretation:

- Based on infiltration tests along the period of four years (11 successive measurements in field), it was possible to statistically define a mixed linear model for describing loss of pavement permeability; such model describes the data with goodness of fit; all the model residuals appeared satisfactory, as the quantile residuals followed the normal distribution. For the specific studied field conditions, the model can be taken as a management tool since permits to anticipate the loss of permeability of the pervious concrete pavement due to clogging.
- Infiltration tests does not measure the pervious concrete permeability alone. Porosity evaluated from concrete cores did not show the key for the loss of infiltration rate along time since changes were non significative at the top 40 mm (close to surface) of the concrete samples.
- Loss of infiltration rate resulted from clogging of all the pavement system (slab+base) since data denotes important decreasing along time without evidence of loss of porosity at concrete surface.
- At the experiment site (repeatable only in similar conditions), the clogging process could be interpreted easily in three stages: one rapid clogging in few months and then continuous processes at a too much lower rate following the initial one. This result supports, based on field actual results, former studies in temperate zone, that concluded for a fast-clogging initial phase followed by a mitigation stage.
- Dense wooded areas with intense fall of leaves and fruits along the year requires frequent cleaning of the surfaces of pervious concretes to avoid organic matter decay over the material; besides this periodic surface cleaning (by brooming every week, for instance), data shown that every three months heavy cleaning is required to keep the permeability of the pavement system.

Authors acknowledge that the scope of this study was limited and data treatment for modeling clogging predictive equation was somehow modest. However, the research permitted to fully understand the significance of infiltration rate tests (denoting the response of a full pavement structure) and its lack of direct correlation to porous concrete layer porosity. Further studies correlating the loss of water volume available in closed pavement system (only draining water through underneath soil foundation) will lead to a better understanding about clogging progress along time, since the underneath reservoir (open granular bases) are constantly being obstructed by the penetration of fine solid materials as well by spoiled organic matter and other particles that are fixed between grains at voids or adhered to aggregates surfaces.

It is counter-productive to promote the employment of the pervious concrete for paving, with its intrinsically potential towards urban sustainability, without to notice and counseling architects and engineers about its extreme need for periodic infiltration measurements, and prompt maintenance when required, otherwise it would be a useless investment if it loses its hydraulic functionality. This maintenance, since the more clogged the material is the worst the cleaning results effective, shall be programmed from three to four times a year on the basis of infiltration rates assessment every 90 days under similar conditions as verified in this study. For prediction, this research offered two manners of establishing maintenance activities according to predictable infiltration rate with two different ways of interpreting the phenomena.

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