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The Use of Permeable Interlocking Concrete Pavement to Filter Stormwater for Non-Potable Uses in Buildings

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Abstract: A reduction in potable water demand in buildings could be made by using non-potable water for certain uses, such as flushing toilets. This represents a sustainable strategy that results in potable water savings while also using an underutilised resource. This work assesses the use of permeable interlocking concrete pavement to filter stormwater that could be used for non-potable purposes in buildings. Two pavement model systems were tested. One of the model systems presents a filter course layer with coarse sand and the other model system has no filter course layer. In order to evaluate the filtering capacity, the model systems were exposed to rain events. The amount of water infiltrated through the layers was measured to represent the potential quantity available for use. Stormwater runoff samples were collected from a parking lot paved with impermeable interlocked blocks and then, these were tested in both model systems. Water samples were subjected to quality tests according to the parameters recommended by the Brazilian National Water Agency. The model system with no filter course showed filtering capacity higher (88.1%) than the one with a filter course layer (78.8%). The model system with a filter course layer was able to reduce fecal coliforms (54.7%), total suspended solids (62.5%), biochemical oxygen demand (78.8%), and total phosphorus concentrations (55.6%). Biochemical oxygen demand (42.4%) and total phosphorus concentrations (44.4%) increased in the model system with no filter course layer. In conclusion, one can state that the filter course layer used in permeable interlocking concrete pavement can contribute to decreasing pollutants and can improve stormwater quality. The use of permeable interlocking concrete pavement showed to be a potential alternative for filtering stormwater prior to subsequent treatment for non-potable uses in buildings.

Keywords: permeable interlocking concrete pavement; stormwater; non-potable uses; buildings

1. Introduction

In the natural hydrological cycle, rainwater flows into soil, rivers, lakes, and oceans. However, urbanisation and the increase in impermeable surfaces alters the natural hydrological cycle. Thus, the urbanisation around a hydrological basin impacts its response to rainfall events, reducing stormwater infiltration and drainage time, which results in peak flows much higher than the conditions prior to urbanisation [1]. In extreme cases, flood peaks in an urbanised basin are six times higher than the peak in the same basin under natural conditions [1]. Urban stormwater flow must be managed to provide flood protection and this is often achieved through discharge into receiving water bodies. Population growth in large urban centres increases the demand for water resources. In recent decades, there was a high concentration of people in urban regions. For example, the urbanisation rate in Brazil from 1940 to 2010 increased from 31% to 84% [2].

The increase of impermeable surfaces and the consequent reduction of stormwater infiltration into the soil are some of the consequences of the urbanisation process. In this scenario, paved streets and buildings contribute to soil waterproofing in urban areas. Thus, when the surfaces do not allow stormwater to soak in, runoff volumes increase and overload the urban drainage system, which leads to floods. Using permeable surfaces, such as permeable interlocking concrete pavement, may be a good alternative to mitigate such problems. Nowadays, permeable interlocking concrete pavements are used mainly in parking lots and pedestrian areas [3,4]. However, such a type of pavement could also be used to filter stormwater for non-potable uses, such as flushing toilets and urinals, in buildings [3,4].

In recent decades, water management has become a concern in government agencies due to growing populations and climatic variations. Laws and regulations have been published to encourage the use of alternative water sources [1,5–8]. The use of rainwater collected from building roofs has become more frequent. However, the use of stormwater filtered through permeable pavements is still infrequent, even in cities with high rainfall and frequent floods [3,4,9,10].

Due to the scarcity of water resources, new concepts, technologies, and approaches related to urban planning have been developed. Some examples are Water-Sensitive Urban Design (WSUD) in Australia; Low Impact Development (LID) in the United States of America, and Sustainable Drainage Systems (SuDS) in the United Kingdom. They propose water management strategies integrated into the development of urban areas to minimise the effects of urbanisation in environmental regions. In this way, natural water regimes are restored and preserved. As a result, peak flows are attenuated with the improvement of runoff quality and depending on the system, there may be potable water demand reduction [5,6,11]. One of the strategies recommended by WSUD, SuDS, and LID is the use of permeable pavements. Permeable pavements are composed of a permeable surface layer that allows stormwater to infiltrate through all layers. All layers have interconnected voids in their structure, which forms an easy path for the flow of water. This type of pavement allows the stormwater to infiltrate naturally into the pavement structure, preventing floods and water puddles and also filtering the stormwater [12].

Figure 1 shows a typical section of a permeable interlocking concrete pavement and Table 1 presents the component layers and their corresponding functions. In permeable pavements, stormwater infiltrates from the surface to other drainage layers, which have a high interconnected voids volume, and in turn, allows the water to flow through them to be filtered. Each layer has specific functions depending on the structure and purpose and is optional, depending on the pavement purpose.

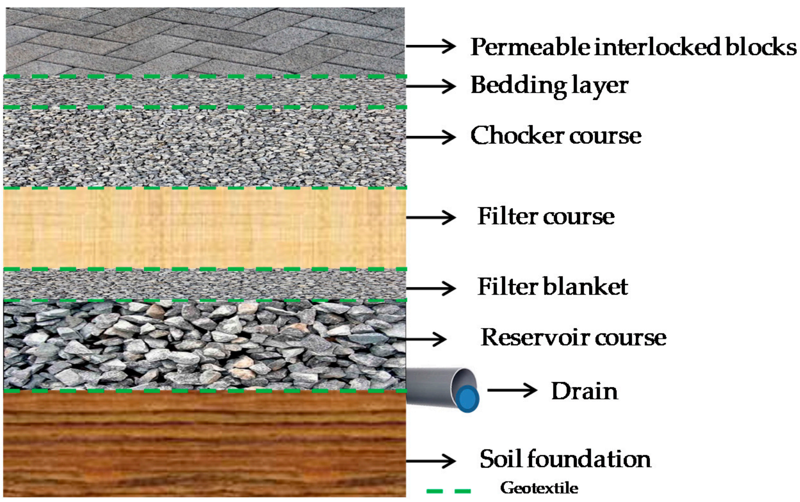


Figure 1. Cross section of a permeable interlocking concrete pavement.

Table 1. Permeable interlocking concrete pavement layers.

Layer	Function	Aggregates	Thickness
Bedding layer	As a permeable surface, for interlocked blocks accommodation and load distribution to the underlying layers	Coarse aggregate with uniform particle size and a maximum particle size of 9.5 mm [13] or between 3.0 mm and 6.3 mm [12].	5.0 mm [13–15].
Choker course	Mechanical support, surface levelling, reservoir layer, and filtration	Washed gravel aggregates containing few fine particles, continuous particle size with a minimum voids volume of 32%. When sized as a reservoir layer, the voids volume must be greater than 40% [13]. The particle diameter should be between 4.75 mm and 25.0 mm.	The thickness depends on the structural and hydraulic pavement design. In general, the thickness is 25.4 mm when used as a damping layer and 100 mm when it is also used as a temporary reservoir [14,15].
Filter course	This is an optional layer used for improving the quality of filtered water for non-potable purposes.	This layer consists of sand with a uniform grain size with a maximum diameter of 4.75 mm. The coefficient of permeability is between 3.5 × 10^{-5} and 2.1 × 10^{-4} m/s [6].	The minimum thickness is 300 mm.
Filter blanket	With the presence of the filter course, there is a need for an intermediate layer between this and the reservoir course, called a filter blanket. The presence of this layer avoids the likelihood of migration of thin material to the voids of the lower layer.	Granular material (maximum diameter 9.5 mm) with continuous gradation or particle size intermediate to the materials used in the filter course and reservoir course.	Minimum thickness is 80 mm [8].
Reservoir course	This is the layer to temporarily store the stormwater that is infiltrated in the structure.	Composed of coarse aggregate with continuous gradation and the void volume must be greater than 40.0% [13,14]. The particle nominal sizes range from 50.0 mm to 75.0 mm [15].	The thickness depends on the structural and hydraulic design.

Field and laboratory experiments have demonstrated the performance of permeable pavements. A study conducted by Nirmalaraja and Meyers [16] analysed the permeable pavement system in a parking lot located in a sports club in Australia. The stormwater that infiltrated through the pavement was stored and then used to irrigate sports fields. The study concluded that the system proved to be effective and cost effective compared to other water catchment systems.

Stormwater carries suspended pollutants in the atmosphere and when precipitation occurs, the pollutants are deposited on the surface. Therefore, it is essential to evaluate the stormwater and runoff quality and also, the types and concentration of pollutants.

Luo et al. [17] investigated the efficiency of geotextile as a filter layer in the removal processes of nitrogen and phosphorous from runoff collected from the porous asphalt pavement surface. Results indicated that geotextile placed under the bed course improved the removal rates of pollutants, in which phosphorous decreased by 80% after a 48 h retention time.

Valinski and Chandler [18] showed that permeable pavement with asphalt mixture and Portland concrete as a surface presented filtering rates greater than native soils. It has been shown that permeable interlocking concrete pavement can reduce stormwater runoff [10,19,20] and can filter and decrease pollutants concentrations [15,17–26]. Even the possibility of using a permeable pavement system to treat greywater for irrigation and toilet flushing has been studied [27]; it was found that permeable pavements can work as a treatment and storage unit in greywater reuse schemes, but they are inefficient in reducing total aerobic and total coliform bacteria.

The use of stormwater filtered by permeable pavements is indicated for non-potable purposes such as irrigation, sidewalk washing, and flushing toilets and urinals [3,4,9,21]. Draining and filtering properties show that permeable pavements represent a suitable technology with great potential for application in stormwater harvesting [28]. This system is not widely used yet, especially with the use of the permeable interlocking concrete pavement. Studies about rainwater collected from roofs are widespread; however, the same is not true for permeable pavements. Thus, experiments related to stormwater harvesting from permeable pavements are still restricted to laboratory tests. Therefore, the objective of this work is to assess the use of permeable interlocking concrete pavement to filter stormwater for non-potable uses in buildings. The quantity and quality of stormwater filtered through two permeable pavement model systems were compared in order to identify if the filter course layer can improve stormwater quality.

2. Materials and Method

The case study was conducted in Florianópolis, southern Brazil. This city presents high rainfall throughout the year (1720 mm per year according to [4]) and frequently, there are floods over the summer, which typically has the greatest number of wet days. To evaluate the quantity and quality of stormwater, two permeable pavement model systems were assembled. In both model systems, permeable interlocked blocks were used as the pavement surface. The following draining and filtering layers were used: bedding course, filter blanket, filter course, choker course, and reservoir course. The main difference between the model systems is that the filter course and filter blanket layers are not used in one of the model systems.

2.1. Materials

2.1.1. Permeable Interlocked Blocks

The blocks are industrialized and follow the quality requirements specified in the Brazilian standard NBR 9781 [29]. Brazilian standards require that permeable interlocked blocks need to present a permeability coefficient greater than 10^{-3} m/s, a minimum compressive strength of 20 MPa, and a minimum thickness of 60 mm. The blocks are rectangular, classified as Type I, and have the following size: 200 mm length, 100 mm width, and 60 mm thickness. Six samples were selected to perform the tests required by the Brazilian standard. The blocks presented a compressive strength equal to 34.4 MPa (standard deviation equal to 4.6 MPa). The measured permeability coefficient was 9.34×10^{-3} m/s [13]. The blocks comply with the Brazilian standard requirements.

2.1.2. Permeable Layers

The crushed materials used in the composition of the drainage layers are granitic and were produced in a quarry located in the city of Florianópolis. Commercial sand was used in the filter course. Table 2 shows the maximum nominal size of the materials used in each layer.

Table 2. Maximum nominal size of the materials used in each layer of the model systems.

Layer	Material Type	Aggregates (Maximum Nominal Size)	Standard
Bedding layer	Coarse aggregate	9.5 mm	NBR 7211 [30]
Choker course	Coarse aggregate	19.0 mm	NBR 7211 [30]
Filter course	Commercial sand	4.75 mm	NBR 7211 [30]
Filter blanket	Coarse aggregate	9.5 mm	NBR 7211 [30]
Reservoir course	Coarse aggregate	37.5 mm	NBR 7211 [30]

2.1.3. Assembly of the Model Systems

Two permeable pavement model systems were assembled in crystal acrylic boxes measuring 50.0 × 18.0 × 53.0 cm. An empty box of the same size was used as a control to measure the amount of rainfall. To simulate a water storage tank, the pavement layers were mounted over the grids supported by metal bars. In this way, the bottom of the boxes remained free to store the stormwater infiltrated through the layers. The bars have an adjustable height to fit different layer thicknesses. Plastic hoses were fixed in the bottom of the boxes to collect the water after each rain event.

The pavement layers were confined laterally and vertically. They were covered with geotextile in order to simulate the confinement of granular materials, to avoid contamination between different types, and to ensure the thickness of each layer. Figure 2 shows the materials used in the pavements layers of both model systems (A and B). Table 3 shows the thickness of the layers in each model system.

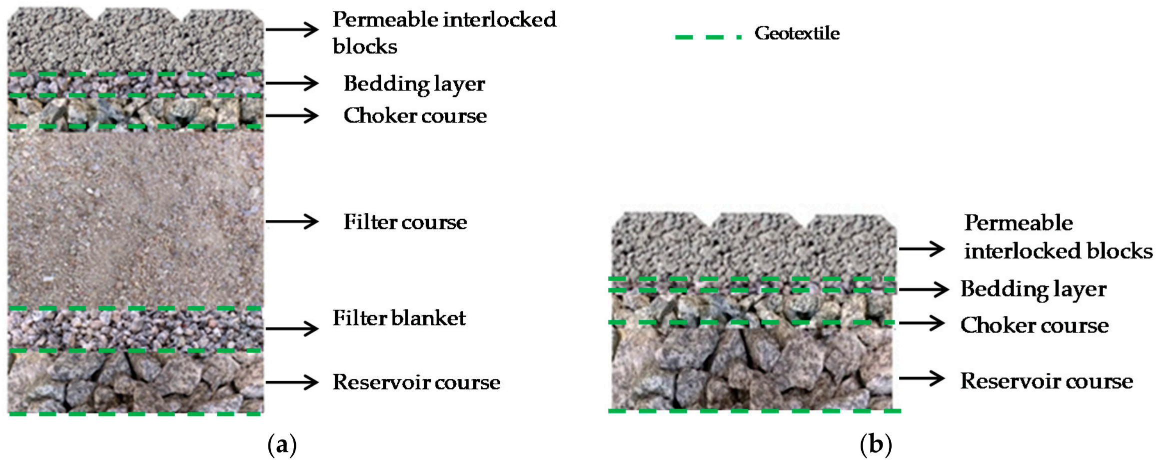


Figure 2. Pavement layers in each model system. (**a**) Model system A; (**b**) Model system B.

Table 3. Thickness of the pavement layers.

Layer	Thickness (cm)		Thickness Range	Reference
	Model System A	Model System B		
Surface (Permeable interlocked blocks)	6.0	6.0	6.0 ± 0.03 cm	[31]
Bedding layer	3.0	3.0	Minimum 2.0 cm	[31]
Choker course	3.0	3.0	2.5 to 10.0 cm	[14,15]
Filter course	25.0	-	20.0 to 30.0 cm	[8]
Filter blanket	4.0	-	Up to 8.0 cm	[8]
Reservoir course	5.0	5.0	-	-

2.2. *Method*

The method was developed in three main phases as shown in Figure 3. In phase 1, the quantity analysis was performed. The model systems and the control box (Figure 4a) were exposed to 17 rain events in order to evaluate the filtering capacity. After each rain event, the water height in the model systems was measured and compared to the water height in the control box. The water height in the control box represents the total amount of rainfall. Rulers were placed in the internal surface of the boxes to promote standardised heights reading (Figure 4b).

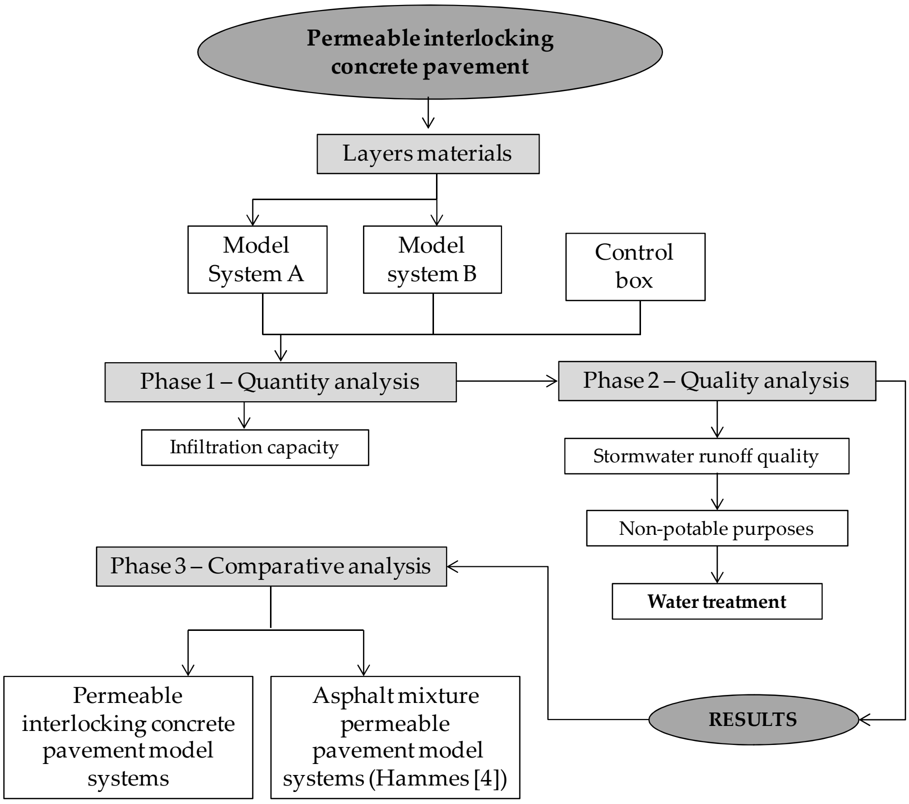
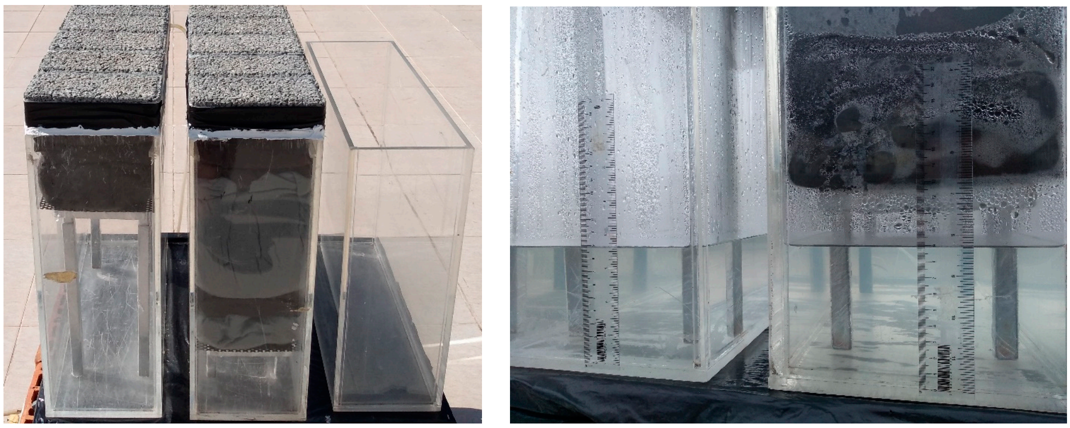


Figure 3. Phases of the method.



(**a**) (**b**)

Figure 4. Model systems exposed to rain events. (**a**) Model systems and the control box; (**b**) Infiltrated rainwater measure.

It was considered that rainfall presents the same distribution over the surface of the boxes. From this, to assess the filtering capacity through the model systems into the box, the rainwater collected in the control box was compared to that infiltrated through the model systems after each rainfall event. The filtering capacity was obtained by using Equation (1).

$$I = \left(\frac{h_1}{h_2}\right) \times 100, \quad (1)$$

where I is the filtering capacity of the model systems (%), h_1 is the height of rainwater stored in the box that contains the model system (mm), and h_2 is the height of rainwater stored in the control box (mm).

In phase 2, the water infiltrated into the model systems was analysed. The quality analysis aimed to evaluate the filtering efficiency of each model system as follows:

- During rain events, stormwater runoff was collected from the surface of a parking lot paved with impermeable interlocked blocks;
- During each rain event, 15 L of stormwater runoff was collected manually and stored in sterilised plastic bottles;
- The samples were maintained below 4 °C and analysed within two hours of sampling;
- Five litres of stormwater runoff were infiltrated into each model system. The water was discharged over the model systems at a rate of 50 mL per minute (on average, the precipitation was 0.8 mm in 15 min. Thus, the rainfall intensity was 0.05 L/min, which corresponds to 50 mL per minute);
- After that, the water that infiltrated through the model systems was collected and the quality analysis was performed;
- The quality analysis was also performed for the remaining five litres of stormwater runoff collected from the parking lot.

The quality of such water was assessed considering quality parameters required by Brazilian standards for non-potable purposes [7]. The parameters evaluated in the quality analysis were pH, total suspended solids, colour, turbidity, odour and aspect, oils and greases, organic volatile compounds, nitrate, ammonia nitrogen, nitrite, total phosphorus, biochemical oxygen demand, and fecal coliforms. The quality analysis was performed before two hours from each stormwater runoff collection. The tests were performed in the Integrated Environment Laboratory of the Department of Environmental Engineering of the Federal University of Santa Catarina. Table S1 in the Supplementary data shows the measurement methods used for each parameter.

Hammes et al. [4] conducted a similar study, but the model systems surface was composed of permeable asphalt mixtures. In phase 3, a comparison was performed between the results obtained herein with those obtained by Hammes et al. [4].

3. Results

3.1. Quantity Analysis

The model systems and the control box were exposed to rain events from 17 January to 30 April 2019. This period corresponds to summer and autumn seasons in Brazil. Table S2 in the Supplementary data shows the measurements and the results. The filtering capacity, calculated using Equation (1), showed that model system A presented an average filtering capacity equal to 78.8% (standard deviation equal to 13.2%) and model system B, 88.1% (standard deviation equal to 6.9%).

The average filtering capacity between the model systems differed by 9.3%. This difference was due to the presence, in model system A, of the filter course layer, which slowed the flow of water to the other layers. On average, the water retained in the filter course layer (model system A) in relation to model system B was 11.6%. It was observed that when rainy days occurred in a sequence, the amount of water retained in the model systems decreased. This is due to the saturation of the layers caused by the previous rainfall. In general, the model systems presented high filtering capacity, especially when the rainfall was high.

3.2. Quality Analysis

Stormwater runoff samples were collected in four rain events. Table 4 shows the results of the quality analysis before and after filtering through the model systems, according to non-potable water quality parameters.

Table 4. Results of water parameter concentrations and limits [7].

Parameters	Concentrations			
	Runoff	Model System A	Model System B	ANA [7] Recommendations
pH	8.0 ✓	6.7 ✓	8.3 ✓	Between 6.0 to 9.0
Total suspended solids (mg/L)	16	6	7	Lower than 5
Colour (TCU)	179	172	151	Lower than 10
Turbidity (NTU)	31.2	26.9	17.9	Lower than 2
Odour and aspect	nd ✓	nu ✓	nu ✓	Not unpleasant
Oils and greases (mg/L)	nd ✓	nd ✓	nu ✓	Lower than 1
Organic volatile compounds	<dl ✓	<dl ✓	<dl ✓	Inferior to detection limit
Nitrate (mg/L)	0.33 ✓	0.72 ✓	0.92 ✓	Lower than 100
Ammonia nitrogen (mg/L)	0.83 ✓	1.12 ✓	1.37 ✓	Lower than 20
Nitrite (mg/L)	0.05 ✓	0.06 ✓	0.12 ✓	Lower than 1
Total phosphorus (mg/L)	0.18	0.08 ✓	0.26	Lower than 0.1
Biochemical oxygen demand (mg/L)	3.3 ✓	0.7 ✓	4.7 ✓	Lower than 10
Fecal coliforms (mg/L)	1716.5	777.8	1493.6	Not detectably

✓ Average concentrations comply with ANA [7] recommendations; nd means not detectable; nu means not unpleasant; <dl means inferior to detection limit.

As for the filtering capacity, i.e., pollutant retention efficiency, the results showed that some parameters complied with ANA [7] recommendations. Model system A, with the filter course, was more efficient than model system B. A considerable variation was observed between some quality parameters over the rain events. The results for each parameter are shown in the Supplementary data.

Table S3 in the Supplementary data shows the results for the pH tests. All samples complied with the ANA requirement (6.0 to 9.0) [7]. However, after stormwater runoff infiltrated in model system B, the pH increased. The alkalinity of cement, the material used in the production of the blocks, may have contributed to this increase. On the other hand, the presence of the filter course layer (sand) was able to reduce the pH, as can be observed in model system A. As for the colour, the model systems were not able to effectively reduce this parameter. Table S4 (in the Supplementary data) shows the results. It is essential to point out that part of the parking lot is unpaved and dust from this area may have affected the results.

Turbidity values were higher than the recommended maximum limit (2 NTU) after being filtered by the model systems (Table S5 in the Supplementary data). Model system B was more efficient than model system A. Considering that the stormwater runoff was spilt over the model systems, it is possible that fine grains of sand (filter course layer) may have been carried to the lower layers and contributed to increases in this parameter. Concerning the total suspended solids parameter (Table S6 in the Supplementary data), both model systems were efficient in reducing the concentration, even with an average above the recommended maximum limit (5 mg/L) by ANA [7].

It was observed that the average concentration of fecal coliform (Table S7 in the Supplementary data) in the stormwater runoff was high, but the concentration was reduced due to the filtration of stormwater through the model systems. Model system A was more efficient in reducing the level of the fecal coliform parameter compared to model system B. It was considered that the filter course layer in model system A had a direct influence on this reduction. Biochemical oxygen demand (Table S8 in the Supplementary data) was lower than the recommended maximum amount of 10 mg/L. In general, in the samples filtered by model system B, there was an increase of the concentration, with an average equal to 4.7 mg/L, compared to runoff samples (3.3 mg/L). Model system A presented a better filtering capacity, indicating that the filter course contributed to the reduction of biochemical oxygen demand.

Nitrate and ammonia nitrogen concentrations are shown in Tables S9 and S10, respectively (in the Supplementary data). In general, nitrate concentrations increased in the samples filtered by both model systems. Nitrate and ammonia nitrogen concentrations increased in the samples filtered by model system B in all events. In the case of samples filtered by model system A, there was an increase in ammonia nitrogen concentrations in two events and nitrate in three events. Both model systems were not efficient in reducing nitrogen compounds, but model system A performed better in retaining these pollutants. However, nitrate and ammonia nitrogen concentrations in all samples were lower than the maximum limits recommended by ANA [7]. An additional water treatment method is recommended in order to decrease the concentration of such parameters.

As for nitrite (Table S11 in the Supplementary data), the concentrations were lower than the maximum limit recommended by ANA [7]. In all rain events, runoff samples showed total phosphorus concentration equal to or higher than the recommended maximum limit of 0.1 mg/L, with an average concentration of 0.18 mg/L (Table S12 in the Supplementary data). Model system A presented a better retention capacity of this parameter. For flushing toilets and urinals, the water should not have an unpleasant odour and appearance. However, the evaluation of these parameters is subjective and depends on the interpretation and sensitivity of the user. In all events analysed, none of the samples had an unpleasant odour. The runoff and also the samples filtered by model system B showed a yellowish colour, while in model system A, they were transparent, as shown in Figure 5.

(**a**) (**b**) (**c**)

Figure 5. Stormwater appearance. (**a**) Runoff; (**b**) Model system A; (**c**) Model system B.

3.3. Comparative Analysis

Hammes et al. [4] conducted a similar study, but the surface layer of the model systems was composed of asphalt mixture. The other layers of each model system contained the same materials and thicknesses as presented herein. In order to perform a comparative analysis, runoff samples were collected in the same place as Hammes et al. [4].

Table 5 shows a comparison of the filtering capacity of the model systems. The asphalt mixture surface used in model systems A and B from Hammes et al. [4] presented lower filtering capacity in relation to the same model systems in which interlocked blocks were used as a surface. This result showed that permeable interlocked blocks have higher permeability than porous asphalt mixtures.

Table 5. Filtering capacity among the model systems.

Filtering	**Interlocked Blocks**		**Asphalt Mixture (Hammes et al. [4])**	
	Model System A	**Model System B**	**Model System A**	**Model System B**
Average (%)	78.8	88.1	70.1	80.0
Standard deviation (%)	13.2	6.9	13.0	7.7

Table 6 shows the quality analysis for model system A and Table 7 shows the results for model system B. Although in both studies the stormwater runoff was collected in the same area, the periods were different. It is possible to observe that the concentrations of runoff pollutants evaluated in this study were, in general, higher than those observed in Hammes et al. [4], as shown in Figures S1 and S2 in the Supplementary data.

Table 6. Comparison of quality results for model system A.

Parameters	Interlocked Blocks			Asphalt Mixture (Hammes et al. [4])		
	Runoff	Model System A	Efficiency (%)	Runoff	Model System A	Efficiency (%)
pH	8.0	6.7	−16	7.6	5.3	−31
Total suspended solids (mg/L)	16	6	−63	98	8.0	−92
Colour (TCU)	179	172	−4.0	144	5.0	−97
Turbidity (NTU)	31.2	26.9	−14.0	51.7	1.7	−97
Nitrate (mg/L)	0.33	0.72	+116	0.28	0.52	+86
Ammonia nitrogen (mg/L)	0.83	1.12	+35	0.67	0.80	+19
Nitrite (mg/L)	0.05	0.06	+25	0.04	0.01	−75
Total phosphorus (mg/L)	0.18	0.08	−56	0.40	0.31	−23
Biochemical oxygen demand (mg/L)	3.3	0.7	−80	8.2	5.0	−39
Fecal coliforms (mg/L)	1716.5	777.8	−95	1020.3	6.5	−99

Table 7. Comparison of quality results for model system B.

Parameters	Interlocked Blocks			Asphalt Mixture (Hammes et al. [4])		
	Runoff	Model System B	Efficiency (%)	Runoff	Model System B	Efficiency (%)
pH	8.0	8.3	+3	7.6	7.5	−2
Total suspended solids (mg/L)	16	7	−54	98	17	−83
Colour (TCU)	179	151	−16	144	145	+1
Turbidity (NTU)	31.2	17.9	−43	51.7	23.2	−55
Nitrate (mg/L)	0.33	0.92	+177	0.28	0.30	+7
Ammonia nitrogen (mg/L)	0.83	1.37	+65	0.67	0.95	+42
Nitrite (mg/L)	0.05	0.12	+130	0.04	0.06	+50
Total phosphorus (mg/L)	0.18	0.26	+40	0.40	0.17	−58
Biochemical oxygen demand (mg/L)	3.3	4.7	+41	8.2	8.0	−2
Fecal coliforms (mg/L)	1716.5	1493.6	−13	1020.3	352	−66

The comparison with the model systems of Hammes et al. [4] proved to be relevant once the influence of the presence of the filter course layer on pollutant retention was shown. For example, the filter course influenced the reduction of fecal coliforms. Although the model systems were effective in reducing fecal coliforms, the removal of these bacteria by model systems A (both studies) was high, in the range of 95–99%.

In general, the model systems were not effective in removing nitrogen compounds. There was an increase in nitrate, ammonia nitrogen, and nitrate concentration in the filtered water in all model systems, except for the reduction of nitrite in Hammes et al. [4]. Brown and Borst [24] also observed weak performance of permeable pavements with different surfaces in reducing nitrogen compounds. On the other hand, the change in total phosphorus in the filtered water was not expected. According to Song et al. [32], increasing pH promotes more significant precipitation of dissolved phosphorus in the water. Thus, the surface that contains cement in its composition, in general, performs well in removing this nutrient. However, in model system B of Hammes et al. [4], there was a 3% increase in pH and 40% of total phosphorus in the filtered water, while in model system B, there was a 2% reduction in pH and 58% in total phosphorus. The sand layer was effective in reducing phosphorus, with a decrease of 56% in model system A (of this study) and 23% in model system A of Hammes et al. [4].

In Florianópolis, due to high rainfall levels and urbanised areas, there are frequent floods. On the other hand, there is a lack of potable water over summer due to the high number of tourists. The use of permeable pavements, especially in impermeable areas such as parking lots, could be an alternative to minimise floods and filter stormwater for non-potable uses in buildings. In general, parking lots are paved with asphalt mixture pavements, but the use of permeable interlocking concrete pavement could be even more attractive due to low costs.

It is important to remark that the analysis of few rain events represents a limitation in evaluating the water quality. Thus, it is necessary to perform more analysis, considering individual rainfall events rather than only average values to evaluate the permeable interlocking concrete pavement benefits.

4. Conclusions

In this work, quantity and quality analyses of permeable pavement model systems with interlocked blocks were performed. Stormwater runoff was collected from a parking lot and infiltrated through the model systems. The infiltrated water analysis was compared with the quality parameters established by Brazilian standards [7], aiming to use it for non-potable purposes in buildings. The two model systems differed by the presence of the filter course layer (model system A) and with no such layer (model system B).

Quantity analysis showed that model system A obtained an average filtering capacity equal to 78.8% and model system B equal to 88.1%. The filtering capacity difference between the model systems was attributed to the presence of the filter course in model system A. Due to the presence of this layer, water remains inside the model system longer while flowing through it.

In general, the model systems were effective in reducing the concentration of parameters such as fecal coliforms, suspended solids, biochemical oxygen demand, and total phosphorus. In model system B, there was an increase in biochemical oxygen demand and total phosphorus concentrations. On the other hand, the model systems were not efficient in reducing nitrogen compounds.

The runoff filtered by the model systems did not meet all the requirements established by Brazilian regulations for use in non-potable purposes, especially regarding colour, turbidity, total suspended solids, and fecal coliforms. On the other hand, biochemical oxygen demand, nitrate, ammonia nitrogen, and nitrite complied with the standard. Model system A was more efficient in the retention of pollutants than model system B due to the presence of the filter course layer.

The comparative analysis with the results of Hammes et al. [4] was essential to verify and confirm the influence of the filter course in filtering stormwater. As for the surface type, interlocked blocks showed better filtering capacity when compared to the asphalt mixture one.

It is important to emphasise that the results obtained in this study represent a part of a major research, in which a small number of rain events were evaluated. However, this is the beginning of a study that will extend for a long time to verify the filtering capacity of the different layers that make up the permeable pavements. In conclusion, after additional treatment such as chlorination, the use of permeable pavement proved to be a good alternative for filtering stormwater for non-potable purposes in buildings.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/7/2045/s1, Figure S1: Runoff concentrations for parameters nitrate, ammonia nitrogen, nitrite and total phosphorus from the studies; Figure S2: Runoff concentrations for parameters pH, Total Suspended Solids (TSS), colour, turbidity and Biochemical Oxygen Demand (BOD) from the studies; Table S1: Measurement methods; Table S2: Filtering capacity of the model systems; Table S3: pH test results; Table S4: Colour test results; Table S5: Turbidity test results; Table S6: Total suspended solids test results; Table S7: Fecal coliform test results; Table S8: Biochemical oxygen demand test results; Table S9: Nitrate test results; Table S10: Ammonia nitrogen test results; Table S11: Nitrite test results; Table S12: Total phosphorus test results.

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