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NATURE-BASED SOLUTIONS FOR URBAN WATER MANAGEMENT: APPLICATION OF FILTERING GARDENS, RAIN GARDENS AND BIO-CULVERTS

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Abstract: This article presents the planning process, implementation and preliminary results of the use of filtering gardens, rain gardens and bio-culverts for the treatment of effluents and management of rainwater at the Research & Innovation Center of L'Oréal Brasil, located in Rio de Janeiro. The research was carried out from 2015 to 2017, from project development to construction and operation of the systems involved. The research aimed to recognize the collaboration of phytoremediation, a Nature-based Solution (SbN) that makes use of plants for depollution, as a strategy for the composition of the urban landscape and water management, adding multifunctionality to spaces. As a result, the technical efficiency of the solutions, operational simplicity, enrichment of biodiversity and wide acceptance of green areas as spaces for conviviality and appreciation of the landscape were identified. The study also brought the collaborative and integrative tendency of professionals in the development of the multidisciplinary project, demonstrating the viability of a sustainable and systemic planning in the design of cities that are more integrated with nature. As warning points, as it is a natural and living system, vulnerabilities of plant species were mapped, which needed replacement through the division of clumps, in addition to the need for a period of maturation of the system to reach effluent treatment efficiency, considering that plants need time for growth and the formation of a robust root zone.
Keywords: Nature-based solutions; Phytoremediation; Green Infrastructure; Filtering Gardens; Rain Gardens; Biovalleys.

INTRODUCTION

Nature-Based Solutions (SbN) are more widespread in cities in recent years as viable alternatives to urban challenges such as climate change, urban degeneration and aging infrastructure. Examples of alternative solutions for urban water management are increasingly expressive, with growing evidence on the importance that knowledge about nature-based solutions can represent for policies and territorial planning (FRANTZESKAKI, 2019) In this context, landscape development multifunctional has been increasing with the aim of warming up the ecological current and the movement of sustainable urbanism, which values the environment in integration with urban design and natural systems (FARR, 2013). The adoption of interventions with techniques linked to the urban landscape is capable of preventing, treating and storing runoff and associated pollutants, acting not only to improve the quality and management of urban water, but also as a resilience mechanism in the human-human relationship. nature (CORMIER; PELLEGRINO, 2008).

Ecological urbanism is a concept that introduces us precisely to the principle of adapting and rebalancing cities through environmental solutions linked to urban design and the incorporation of natural processes to recover ecosystems and the landscape (SPIRN, 2000, 2011). Urban design is an adaptation tool for more resilient cities and allows for interrelated coexistence between city and nature, revealing to us that cities are part of the natural world and represent connected and dynamic ecosystems (PICKETT; CADENASSO; MCGRATH, 2013).

The natural processes act in the purification of the waters in a spontaneous way. The technique that explores the property of interaction between plants, bacteria located in the rhizomes and different types of contaminants is known as phytoremediation and basically consists of using gardens to remove, reduce or immobilize contaminants present in water, soil and air. This interaction promotes chemical transformations in the molecules that result in non-toxic forms, that is, harmless to the ecosystem (MENDES, 2018). The biological and chemical abilities of above-ground plants are well understood and widespread by most people. The concept that plants capture CO2 from the atmosphere and improve local air quality by releasing O2 as a product of photosynthesis is part of the content of biology classes in schools. However, the complex system of plants below ground is not so often considered and it is precisely in the root area that the most interesting purifying actions occur (TODD, 2013). The implantation of this technique in the urban landscape can be a strategy for the reduction of the contaminant rates in levels compatible with the human health, at the same time that it minimizes the dissemination of the pollution and plays an important structural role in the aid of the management of the urban waters, comfort environment and increase of biodiversity (MAHLER; MATTA; TAVARES, 2007).

Worldwide, the applications of the phytoremediation technique in designed systems are known as *"constructed wetlands"*, which can be translated as "constructed wetlands", whose objective is to mimic natural ecosystems in order to induce purification processes (DAVIS, 1994). Constructed *wetlands* are reproductions of *wetlands* in their natural state, nothing more than flooded areas found in nature in scenarios of topographic depression, banks of rivers and lakes, coastal areas, etc. Vegetation acts directly on hydrological variables, mainly in plant interception (tops, leaves, trunks and roots), capable of retaining 10% to 20% of total annual precipitation (MANNING, 1992).

In addition to technical efficiency with regard to treatment, phytoremediation projects applied to landscape architecture can be designed to integrate into the landscape, recreating areas of natural appearance. The aesthetic composition and integration of the gardens into the landscape allow for "re-vegetation" of the implantation site, increasing its green areas and bringing benefits such as: (1) support for rainy events and climate changes; (2) bringing people together, who start to interact more as they use a common space; (3) real estate appreciation, due to thermal and visual comfort; and (4) the improvement of pollution parameters and environmental demands (CORMIER; PELLEGRINO, 2008; FRISCHENBRUDER; PELLEGRINO, 2006).

Thus, phytoremediation, applied to landscape typologies, composes a Green Infrastructure (VI) and represents a sustainable intervention that can be adapted to each implantation region at different scales, according to the local reality and its specificities. In this context, phytoremediation is part of the set of Nature-Based Solutions, a term coined by the International Union for Conservation of Nature (IUCN) with the aim of re-signifying the relationship between man and nature, promoting actions to protect, manage and restore ecosystems natural or modified and that simultaneously provide environmental, social and economic benefits, creating resilience and adaptability (HERZOG; ROZADO; 2010).

Brazilian experiences in this area have intensified since the year 2000, with the application of phytoremediation in *wetlands* built for the treatment of wastewater, mainly in the experimental field (SEZARINO et al, 2015). There are still few case studies in the literature that present a complete follow-up of the application of these systems, especially in the field of Architecture and Urbanism. Thus, this article aims to collaborate through the detailed description of the processes and applied techniques involved and the sharing of preliminary results collected.

GOALS

This article presents the planning process, implementation and preliminary results of the use of filtering gardens, rain gardens and bio-culverts for the treatment of effluents and management of rainwater at the Research & Innovation Center of L'Oréal Brasil, located in Rio de Janeiro. The main purpose was to recognize the collaboration and importance of phytoremediation as one of the design strategies for improving the quality of urban water, through its incorporation in sustainable drainage devices. The research was carried out from 2015 to 2017, from project development to construction and operation of the systems involved. It aimed to identify the collaboration of phytoremediation as a Nature-based Solution (SbN) that makes use of plants for depollution, as a strategy for composing the urban landscape and water management, adding multifunctionality to spaces.

The main contribution of the work recognizes the design trends facing the challenges, thus establishing the set of phytoremediation applications and integrating it with landscape architecture studies and expansion of architectural knowledge in the environmental area. The expectation is that this study reinforces and expands the scope of phytoremediation for architects as a strategy in urban planning.

METHODOLOGY

This research was developed through the practical modality applied with a case study design for the recognition of design trends. This methodology allowed capturing the frame of reference and the definition of the situation, with a detailed examination of the organizational process in order to clarify factors particular to the case that can lead to a greater understanding of causality.

Information regarding the case study was obtained from the multinational company Phytostore Brasil, specialized in phytoremediation through the Jardins Filtrantes system, located in São Paulo, along with the monitoring and coordination of one of the authors in the implementation and development of the project between the years from 2015 to 2017, in Rio de Janeiro. Even the experience in the field and the consequent proximity to the project justifies the selection of the case study presented here.

The analyzed case portrays the project of the Center for Research & Innovation of L'Oréal Brasil, located on Ilha do Bom Jesus, Cidade Universitária - Ilha do Fundão, Rio de Janeiro/RJ – Brazil, a pioneer in the implementation of the phytoremediation technique in different typologies green for managing rainwater, wastewater and subsequent non-potable reuse, totaling 2,368m² of filtering area and more than 15,000m² of green area. The devices adopted were:

- Rain gardens, biotrenches and retention basin for collecting, transporting, storing and improving the quality of rainwater
- Filtering gardens for the treatment of wastewater from sanitary and industrial branches.

The protocol developed for analyzing the case study was based on the highlighted macro categories observed in the bibliographic review carried out in the dissertation that originated this article and specification requirements within each category: **(1) general characteristics** – (a) liquid, (b)) substrates, (c) sediments, (d) vegetation, (e) microorganisms, (f) biodiversity, (g) enhancement of the landscape; **(2) purification capacity** – (a) sedimentation, (b) filtration, (c) adsorption, (d) absorption, (e) biodegradation, (f) disinfection; **(3)**

operation and maintenance - (a) vegetation pruning, (b) cleaning, (c) flow control, (d) flow measurement, (e) quality analysis, (f) waterproofing, (g) pests and mosquitoes, (h) monitoring; **(4) design and typology** – (a) surface flow, (b) subsurface flow, (c) hybrid flow, (d) constructive structure, (e) hydraulic infrastructure, (f) hydraulic retention time; **(5) hydrology** – (a) flow damping, (b) water storage, (c) nutrient cycling, (d) infiltration.

THE PROJECT CONCEPTION

The Research & Innovation Center was conceived through the values of innovation and sustainability embedded in the *core* of the L'Oréal group, among the differentials in the most diverse areas that provided the LEED PLATINUM certification for the building, the following stand out:

- Low environmental impact management of rainwater and wastewater, all site water must remain on site;
- Forest management with transplantation and environmental compensation of native species;
- Favoring native green areas and integration between landscape and architecture and
- Multifunctionality, reuse, regeneration, renewable resources and nature-based systems.

The project as a whole was developed in an integrated manner between the environment, architecture and engineering teams. The architectural design was developed with a view to freeing up as much green area as possible around the building for the implementation of green infrastructure integrated with the site's water management. The roof was also designed to facilitate rain runoff through a curved section that slopes towards the rear, directing this water to a gutter already integrated into the design of the roof section, to direct the water to the rain gardens.

The spatial distribution of the green infrastructure around the building was integrated with the architecture so that the building hydraulics were optimized. First, the rain gardens were positioned on the west side of the land, in the direction of drainage from the roof gutter, facilitating the transport of water. Based on this definition, the bioculverts were distributed according to the areas of rainfall, determined by the topography of the land and by the gray areas. This way, adjacent to the streets and the parking lot, bio-culverts were designed that go around the paving from northwest to south, connecting in the final stretch, by piping, to the rain garden. The northern area of the site also has bioculverts adjacent to the rocky hill, transporting rainwater to the rain garden to the west (Figure 1).

Due to the premise of reusing water on the site, the rain gardens were designed with waterproofing at the bottom, preventing infiltration into the soil. This garden is connected to the reuse tank by underground pipes, but also has a safety overflow (*overflow*) for the retention basin, located on the south facade of the land. In large rainy events, the retention basin acts as a rain peak buffer, with a capacity to store 800m^3 and high permeability due to the gabion mattress coating, favoring infiltration into the soil.

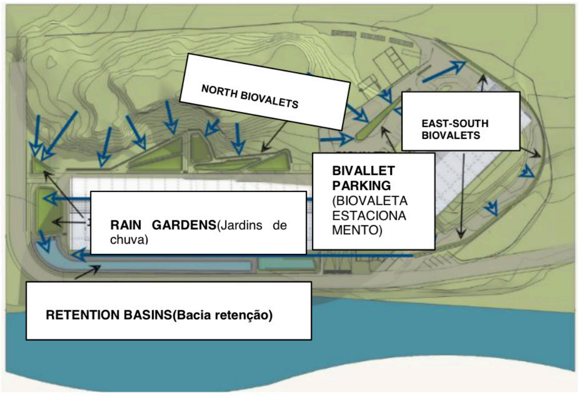

Figure 1 . Natural drainage of water from the site, roof drainage and positioning of rain devices. Source: prepared by the author.

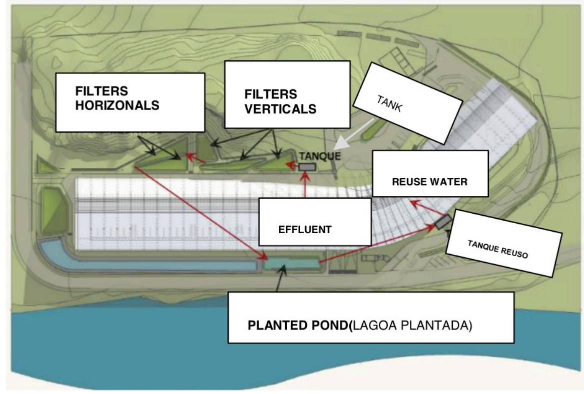

Figure 2 . Treatment flow of domestic and industrial effluents in phytoremediation devices. Source: prepared by the author.

Still in compliance with the site water management premise linked to the green infrastructure, the system of filtering gardens was adopted for the treatment of domestic and industrial effluents. The hybrid solution consists of three steps: (A) vertical filters, (B) horizontal filters and (C) planted pond. For the distribution of these gardens on the ground, it was fundamental to study the sun, since the efficiency of the system is directly linked to photosynthesis.

As the free area to the north of the land was not sufficient for the implementation of the three stages, it was decided to favor stages A and B, since in addition to being the filters with the largest number of plants, they are the most critical stages of the treatment due to the receipt of raw sewage (vertical filters) and semi-treated (horizontal filters). Stage C was located on the south façade, which represented an innovation in the way of designing by breaking up the stages of the system (Figure 2). In addition, it favored the composition of the landscape for the observer inside the building and facilitated the connection with the reuse tank.

The design of the gardens was inspired by the organic nature of Roberto Burle Marx's landscaping, which is very characteristic of Rio de Janeiro, and sought to honor one of the most beautiful postcards: the Sugarloaf Mountain. To complete the landscape, the plantation plan composes a design in waves, a reference to the wavy hair of Brazilian women and the city's beaches.

DESIGN ELEMENTS

The solutions for draining the water involved the following elements: bio-culverts, rain gardens, retention basin, aeration tank, vertical and horizontal filters and planted pond.

Biovalets (BV)

The bio-culverts (Figure 3) distributed throughout the site are responsible for the slow drainage of rainwater, infiltration into the soil and improvement of water quality through phytoremediation. They are linear ditches dug in the ground, filled with gravel or medium-sized pebbles (grain size between 19-38 mm), and between the soil layer and the gravel layer, there is a separating layer composed of a geotextile blanket. Above the gravel, there is also a layer of vegetable soil, rich in organic matter, to increase microbial activity. In addition, the soil's Water Holding Capacity (WHC) is high, around 300-700% of its weight in water, which means that moisture close to the roots is maintained for a prolonged period. Thus, even in periods of drought or water deficiency, the plant will have water and nutrients in greater availability.

Figure 3 . Perspective section of a bio-culvert. Source: Adapted by the author based on a collection provided by Phytostore.

At the bottom of the ditch, corrugated drainage pipes, preferably in PVC, are installed to facilitate free section flow. In addition, between one biovalet and the other, when there are cutouts, *overflow pipes are installed,* or safety overflows, above ground level, allowing the water to drain more quickly to the point of disposal in rainy events above the value adopted in project.

Rain Garden (JC)

The rain garden (Figure 4), located on the west wing of the site, receives water transported by the bio-culverts and drainage from the roof of the building. It is responsible for the amortization of peak rainfall, storage and improvement of the quality of rainwater. Because it is a garden intended for the accumulation of water, the environment that develops in the substrate (or support medium) is anoxic, promoting the growth of the anaerobic bacterial biofilm in the rhizosphere. Under these conditions, phytoremediation mechanisms reduce the concentrations of COD, BOD, N, P and SO_4 horizontal sub-surface flow filter. Built in excavation in the ground, the rain garden was waterproofed with the triple waterproofing geotextile-HDPE-geotextile complex and filled with medium granular material (19-38 mm). Above the gravel layer it is optional to place a thin layer of vegetable soil, depending on the rainfall characteristics of the region, it becomes a safety measure so that the plants do not suffer so much from the shortage. In this case, as the planting was carried out in the rainy season, the macrophytes were planted directly in the gravel and remain in a flooded environment unless the evapotranspiration rate is higher than the rainy events. In case of complete drought, the system has an operational mode that allows the recirculation of treated water from the planted pond to the rain garden.

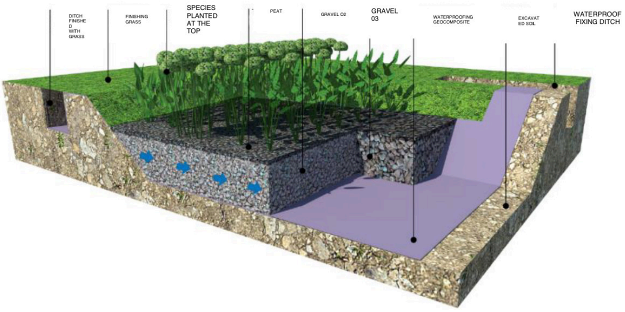

Figure 4 . Perspectiveed section of a rain garden. Source: Adapted by the author based on a collection provided by Phytostore.

The composition of the hydraulic installations inside the rain garden boils down to PVC pipes for supply (arrival at the top of the gravel) and drainage (pipe with slots at the bottom). Drainage is controlled by a valve, in case of any maintenance/operation that requires emptying the garden, otherwise the water outlet occurs by overflow (*overflow*) in the upper part of the gravel through a box with a grid lid.

Retention Basin (BR)

The retention basin, located in the southern part of the land, receives water from the rain garden. Its main function is to desynchronize runoff and peak rainfall, infiltration and groundwater recharge, storage and retention. The retention basin was designed to house vegetation adapted to situations of rapid flooding and longer periods of drought, and the landscaping was designed to compose islands, with imploded rocks in the work itself, when the basin was flooded.

The species that withstand a longer period of time and/or water depth of flooding were recommended for planting at the bottom of the retention basin, directly in the soil, as the tolerance decreased, gradually the species must be planted closer to the surface of the islands.

Aeration Tank (TQ)

The aeration tank, located in the northern portion of the land, comprises the first stage of effluent treatment – filtering gardens. Its main function is the temporary storage of the effluent from the building's sewage well and the aeration of the liquid through agitation with inserted air (submersible Venturi aerator). Constant aeration is essential to maintain an aerobic environment, avoiding odors, in addition to favoring the suspension of solid microparticles, preventing sedimentation.

Two aerators were installed, as it is always recommended to have a reserve equipment (*backup*), but it is not recommended that it remain unused, this way the aerators work in parallel and simultaneously during periods of 1h45 and 15 min intervals (off). The shutdown intervals cannot be the same for both aerators, preventing the effluent from running out of oxygen. In case of absence of effluent in the tank, the aerators must be turned off to avoid burning the equipment.

The vertical filter (PV) is fed in a controlled manner, by batches, which means that the sewage is released into the garden every time the design volume is reached in the tank. This automated batch control system uses level floats, like a water tank. For this, four level buoys are fixed: (1) minimum level; (2) maximum level; (3) minimum level of safety, in case the minimum level float (1) fails; and (4) maximum level of safety in case the maximum level float (2) fails.

Vertical Filter (PV)

The vertical filter (Figure 5) receives raw sewage from the aeration tank and initiates the biological treatment in an aerobic phase. As the name suggests, the hydraulic flow in the garden is vertical, that is, the hydraulic supply network is distributed in the upper part of the garden, 20 cm above the gravel supported by supports. The effluent infiltrates the substrate from top to bottom, and the estimated time for the complete passage of the sewage to the bottom of the garden (drainage) is 2 hours.

Just like the rain garden, the vertical filter has the basic composition of excavation in the ground, waterproofing using a geotextile-HDPE-geotextile waterproofing complex and filling with three different layers of granular material: fine gravel (9.5-19mm), medium gravel (19-38 mm) and coarse crushed stone (38-50mm), respectively in vertical layers of 20cm, 20cm and 30cm, from top to bottom.

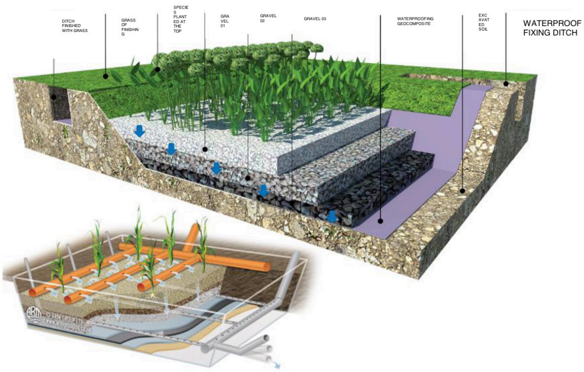

Figure 5 . Perspective section of a vertical filter. Source: Adapted by the author based on a collection provided by Phytostore (above); ARM GROUP LTD UK (below).

PV is characterized by high hydraulic conductivity, as the substrate is not constantly saturated. This way, this treatment step takes place in the presence of oxygen and allows the occurrence of important chemical and mechanical processes such as nitrification and mineralization of organic deposits resulting from Suspended Solids (TSS). and COD. The vertical filters are operated on a weekly basis so that each one "rests" for 15 days. This period of apparent inactivity is important for the biodegradation of the solids mechanically retained in the first layers of the substrate to occur, thus, even without receiving raw effluent for two weeks, the filters at rest are working.

The project was developed with three units of vertical filters to meet the rotation, this way, each entrance pipe in the gardens has a butterfly valve installed in passage boxes (or inspection points – PVs) in the technical path adjacent to the filters. As the three vertical filters work in weekly rotation, in normal regime two valves will be closed, while the third will be open to provide the passage of the effluent to a single FV. The valve opening change is done manually, by the Filtering Garden operator, every Tuesday at 9 am. This way, the FV that was in use until Tuesday has two weeks of break.

The vertical filter drain is designed under the bottom surface of the filters. Imagine this surface as a tray that must be tilted (i=0.5%), so that the liquid drained to the bottom slides to one of the desired edges. The hydraulic drainage network has a master pipe on the side with the largest diagonal of the filter and comb branches to the other ends. At the free ends of these perpendicular pipes, that is, those that are not connected to the master pipe, there are aeration terminals that allow the entry and circulation of air, favoring the aerobic environment.

All drainage pipes have special slots cut on site according to the executive project, following the pattern: slot width 5mm and slot length 1/3 of the pipe diameter. Finally, the last hydraulic network that makes up the PV is the natural aeration pipe, which is supported on top of the first layer of gravel, 30cm from the bottom. The tracing of these tubes is done in a checkered mesh every 6 meters. As these pipes are intended to allow the passage of air inside the filter, there is no connection to the drainage network. Aeration terminals are also installed at their ends.

After passing through the vertical filter, the effluent goes through an underground pipe to a central inspection point (PV), which gathers the drainage from all the vertical filter units and redistributes it from valves to the horizontal filter.

Horizontal Filter (FH)

The horizontal filter (Figure 6) receives the semi-treated sewage from the vertical filter (FV) and initiates the biological treatment in the anaerobic phase. As the name suggests, the hydraulic flow in the garden is horizontal, that is, the supply pipe is installed at one end, resting on the substrate, 40cm from the bottom, and the drainage at the opposite end, resting on the bottom. The semi-treated effluent percolates through the gravel and runs through the garden from one side to the other, and the estimated time for complete passage is 6 to 8 hours.

As with the other gardens, the horizontal filter has the basic composition of excavation in the ground, waterproofing using a geotextile-HDPE-geotextile waterproofing complex and filling with two layers of granular material: medium gravel (19-38 mm) and coarse gravel (38- 50mm), distributed in horizontal layers of 20%, 60%, 20% of the total volume.

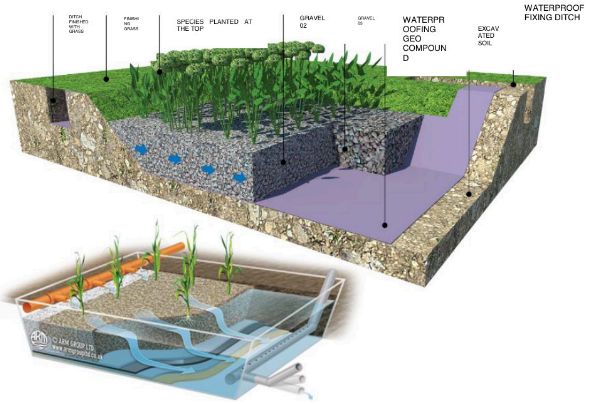

Figure 6 . Perspective section of a horizontal filter. Source: Adapted by the author based on a collection provided by Phytostore (above); ARM GROUP LTD UK (below).

The horizontal filter is characterized by high hydraulic stability as the substrate remains constantly saturated. Thus, this treatment step takes place in an anoxic environment and, as a result of the low oxygen transfer capacity, the chemical processes involved in the denitrification and solubilization of phosphates stand out. This way, the FH is very satisfactory in reducing the Total Nitrogen, Total Phosphorus, BOD and COD parameters.

The horizontal filters are also operated on a weekly basis, but in this case, as the concentrations have already been reduced in the previous step, the "rest" lasts 7 days. Thus, the project was developed with two FH units to meet the rotation, and each entrance pipe in the gardens has a butterfly valve installed in PV in the technical path.

Under normal operation, one of the valves will be closed and the other open, allowing the passage of effluent to a single FH. The valve opening change is done manually, by the Filtering Garden operator, every Tuesday at 9 am. This way, the horizontal filter that was in use until Tuesday is one week off.

Drainage of the horizontal filter is simpler when compared to the vertical filter, as it is composed only of the master tube, positioned at the opposite end to the supply, preferably on the smaller side. "Cap" pieces are placed at the free ends of these pipes to prevent hydraulic flow, as all pipes have special slits cut on site for better flow distribution along their length.

The hydraulic principle adopted for draining the horizontal filters is Pascal's Principle, called communicating vessels (Figure 7), in which the pressure exerted on a liquid is transmitted integrally to all points of the liquid, that is, the set U-shaped hydraulic system maintains balance, as the same volume of liquid that enters one side exits the other side. In the Filtrating Gardens, this principle was converted into a drainage system that keeps the FH saturated, that is, the liquid level inside the filter is always equal to the gravel level (h=0.5cm). Thus, when effluent enters (to be treated) at one end, the same volume of effluent (already treated) is drained at the opposite end.

This system, called by Phytostore as a "rustic valve", due to its simplicity, is nothing more than a set of hydraulic parts composed of a tube and a "T" connection installed in a PV. The rustic valve still has a butterfly valve attached to the opposite end of the "Tee" to allow emptying the filter in case of maintenance.

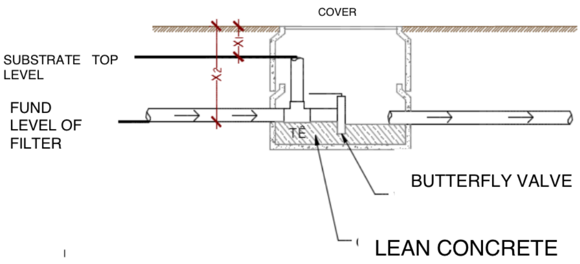

Figure 7 . Section of a PV with rustic valve installed. Source: Adapted by the author based on a collection provided by Phytostore.

After passing through the FH, the effluent goes through an underground pipe to a central inspection point (PV), which collects the drainage from the two horizontal filters and redistributes it from valves to the Planted Lagoon (LP), the next stage.

Planted Pond (LP)

The planted lagoon (Figure 8) receives the treated sewage from the horizontal filter and works to polish the water. In this last step, the flow is superficial, that is, as in a natural lagoon, the water depth is apparent. Due to the extended TDH of 3-5 days, the hydraulic stability favors sedimentation and disinfection through the penetration of UV solar rays. In addition, the plant species *Nhymphea* planted at the bottom of the pond, with floating leaves, works as an air pump that inserts 8 to 10 liters per hour of oxygen in the water, raising the DO level to up to 9mg/L (SARAIVA; CALMON, 2011).

The presence of water lilies also helps to control solar radiation under the water layer, with their floating leaves, a shaded area is formed that inhibits the growth of algae, in addition to this the small depth of the lagoon (80cm), also designed to prevent the proliferation of algae. It is important that the proportion of approximately ¼ of the area of the water surface covered by lily pads is maintained so as not to compromise the treatment.

In the lagoon, emerging macrophytes are also planted on a perimeter bank, with a height of 0.5 m above the bottom. These plants collaborate in the final reduction of nitrogen and phosphorus, act as a shelter for the natural habitat and, depending on the design strategy, also function as a safety barrier, in case of accidental falls.

Like the other elements, the lagoon is shaped by excavation in the ground and waterproofed with a geotextile-HDPE-geotextile waterproofing complex, but it is not filled with substrate, it only has a layer of 30cm of washed white sand at the bottom and over the bank. This stage operates with only one unit that constantly receives water from the active horizontal filter.

The hydraulic flow in the pond requires great care so that there are no areas with standing water, therefore, the feed is positioned on the largest edge so that it works as a funnel, directing the effluent to the smallest edge, on the opposite side. The feed tube is installed above the water depth (1cm-5cm) and, in order to obtain good landscaping results, stones are added to simulate waterfalls and hide the tubes. The drainage of the lagoon follows Pascal's Principle, which is why the outlet occurs at the top, at the top of the water depth (1.10m from the bottom), so that with each recharge in the feed the volume that rises in level overflows through the tube, which in turn it is connected to an output PV on the path adjacent to the pond.

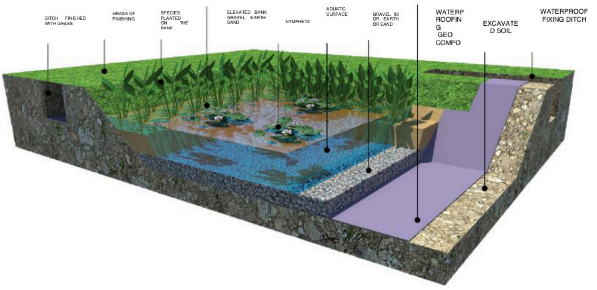

Figure 8 . Perspective section of a planted pond. Source: Adapted by the author based on a collection provided by Phytostore.

There is also a second pipe for maintenance supported at the bottom, completing the rustic valve. The treated effluent leaving the pond is sent to a pumping station, which will pump the water to the reuse tank. In this lift, there is also the possibility of recirculating the liquid, pumping it back to the aeration tank, as a safety option, for emergency operations.

GUIDELINES FOR SIZING SYSTEMS

Rainwater

The first step in sizing the rainwater bioretention devices (Figure 9) was the analysis of the region's rainfall history. The directorate of studies and projects, management of special programs and alert systems of Rio de Janeiro, together with the Fundação Instituto de Geotécnica of the Municipality of Rio de Janeiro, launched in 2014 (time of project development), the report GEO-RIO/ DEP/GPE - No. 01/2014, with rainfall data for the year 2013 in the city of Rio de Janeiro. Based on this document, the annual average rainfall was 127.9mm, the highest rainfall in 24h was 198mm and the highest rainfall in 1h of precipitation was 92.2mm, both in December.

In order to understand the history of rainfall in the city, rainfall data dating back to 1997 were taken into account, therefore TR=5 years (for the time of project development). The result of the analysis was an annual average between 1997-2012 of 107mm of rain, revealing a difference of +19.6% compared to the annual average of 2013. This study demonstrated that the year 2013 was of great rainfall when compared to the previous years. historical averages of the previous 5 years, confirming that the 2013 data represented the maximums and, therefore, it was safe to adopt the numbers as a basis for sizing. For this purpose, the highest rainfall in 1 hour of precipitation was used, as the main objective was to desynchronize the rainfall peak and storage to improve water quality (phytoremediation) and subsequent reuse and infiltration.

The second stage of the dimensioning was the tracing of the contribution areas of the terrain and the respective runoff coefficients, determined by the permeability of the soil (Table 1 . Site contribution areas and expected rainfall. Source: Elaborated by the author). In this case, the following coefficients were considered: 0.05 for permeable interlocking pavement applied on the internal access street to the building and parking lot; 0.2 for areas of natural terrain, as the soil of Rio de Janeiro has a lot of vegetation between rocks; 1.0 for coverage that is fully waterproof. Knowing that the retention basin must have thecapacity to fully store the precipitated volume, volume (v) = 685m³ was adopted.

Area Contri-bution	Areas Reais (m^2)	Runoff Coefficient	Areas Active (m^2)	Rainfall Volume (m^3)
Natural ground	5073.31	0.20	1014.66	93.55
street and parking	3125.12	0.05	156.26	14.41
Roof of the building	6250.25	1	6250.25	576.27

Table 1 . Site contribution areas and expected rainfall. Source: Elaborated by the author.

For the design of the rain garden, the 1:1 ratio between volume and area was considered, that is, for every $1m^3$ of rain, $1m^2$ of rain garden is needed to improve water quality. This relationship comes from studies carried out by Phytostore in France, in which it was concluded that rainwater (in urban environments) needs between 15 and 20 minutes of retention in the rain garden to present the first improvements in quality.

As the purpose of the bio-culverts, in this project, was the slow forwarding of rainwater, a maximum slope of 0.01% was considered, and in sections whose terrain has a slope greater than this value, the bio-culverts must be fragmented and compensated in height to interconnection, like a ripple effect. All bioretention devices have an overflow *so that* in rainy events greater than estimated there is no flooding.

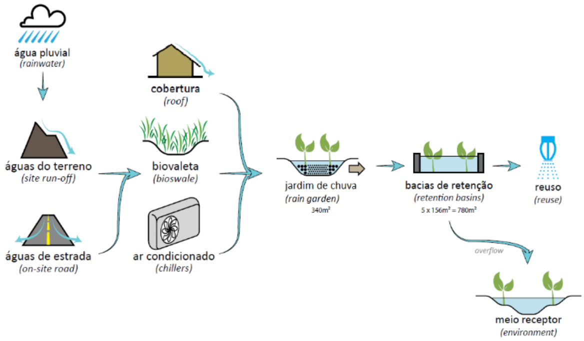

Figure 9 . Distribution scheme of rainwater by phytoremediation devices. Source: Adapted by the author from a collection provided by Phytostore.

Wastewater

The dimensioning of filtering gardens for the treatment of domestic and industrial effluents (Figure 10) was based on estimated data for work dynamics in international laboratories and regional habits of per capita water consumption for activities such as restaurants and bathrooms, since activities in Brazil had not yet been established.

To this end, a fixed population of 400 people was considered, including employees and third parties, and 150 visitors, making up the daily floating population, a total of 650 people. According to the water booklet of the Federation of Trade in Goods, Services and Tourism of the State of São Paulo (Fecomercio SP), water consumption ranges from 50 to 80 liters/ inhab.day. Thus, it was considered the most critical scenario because it is a research center with a laboratory for the development of new products. In other words, the estimated daily flow of domestic and industrial effluent for sizing the treatment system was 52,000L/day, or $52m^3$/day.

On the other hand, the characterization of the effluents (Table 2) was estimated in two stages, integrated into the architectural project to survey the number of toilets, sinks, workstations in the laboratory, showers for product testing and movement in the restaurant. In the first stage, the characterization of the domestic effluent was estimated based on the physicochemical characteristics of the sewage provided by METCALF AND EDDY, 1991. In the second stage, the characteristics of the industrial effluent from international research centers were analyzed, adjusting to the expected work pace for Brazil. Below, the total estimate for the characterization of the mixed effluent:

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Parameter	Items.	Value
BOD $_{5.20}$	mg/L	400.00
BOD $_{5.20}$ (load)	g/day	20800.00
COD	mg/L	1000.00
COD (load)	g/day	52000.00
SST	mg/L	600.00
SST (load)	g/day	31200.00
$_{non-}$ ammonial	mg/L	33.70
$_{Ammonia}$ N (cargo)	g/day	1752.40
Total Phosphorus	mg/L	26.67
Total Phosphorus (load)	g/day	1386.66
O&G Total	mg/L	115.00
O&G Total (cargo)	g/day	5980.00

Table 2 . Mixed effluent characterization estimation. Source: Elaborated by the author.

After estimating the flow and characterizing the domestic and industrial effluents, it was necessary to convert these data to the unit of inhabitant equivalent (EH), or population equivalent (EP). This term is usually used in the area of sanitation as a reference value for the ratio of biodegradable organic load per inhabitant of the agglomeration. By default, according to NBR 12209 - Design of sanitary sewage treatment plants, 54 g of BOD $_{5.20}$ / inhab.day is adopted. In continuity, the EH can be defined as the daily load (g) of BOD in the effluent, over the load (g) of BOD per capita (inhab): EH = 20.800 / (54) = 385,19.

The relationship between inhabitant equivalent and treatment area in constructed wetland systems varies according to the practice and unique knowledge of each company or researcher. Phytostore Brasil, responsible for the project in the case in question, applied an EH:m^2 ratio of ≈1.5m^2 for each EH unit. This number is not a standard to be replicated, as each solution is unique and takes into account a range of parameters, mainly plant species, which are part of the technology's confidential content.

According to the calculations above, the total area of phytoremediation treatment is 578m^2, distributed in three vertical filters of 116m^2/each and two horizontal filters, equally 116m^2/each. In the same way, the proportion of distribution of the dimensioned area between the types of filters meets a relationship of specific knowledge and practice of each company or researcher. In this case – again, not a pattern to be replicated – the ratio was 0.9 FV:0.6 FH, totaling 1.5 in total area.

To complete the sizing of the system, the planted pond, the last stage, follows a different logic in calculating areas. Because it is a stage where the treatment is no longer fully carried out in the root zone and, therefore, does not depend on the degradation ratio of the organic load per area, the dimensioning of the planted pond is not done by EH, but by time of hydraulic detention (TDH). The TDH must be sufficient for the penetration and dissolution of oxygen, sedimentation, stabilization of residual organic matter (from the previous steps) and disinfection by exposing the water to UV sunlight.

Phytostore Brasil defined, exclusively for this project, a TDH of three days, that is, the daily flow of the project must be stored in the lagoon for three days, totaling 156m^2, average depth of 80cm and water depth area of 195m^2.

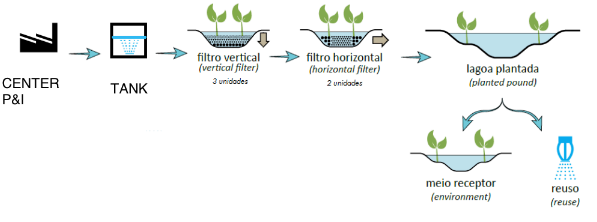

Figure 10 . Effluent treatment flow by phytoremediation devices. Source: Adapted by the author from a collection provided by Phytostore.

CIVIL WORK FOR PROJECT CONSTRUCTION

The civil work lasted ten months, from July/2016 to April/2017. The work's greatest difficulty was related to the type of rocky soil, very common in Rio de Janeiro, but which made some earthworks unfeasible and required specific adjustments to the project, without jeopardizing the design concept. In addition, the former area occupied by the Army revealed surprises hidden in the ground, such as rubble from past constructions and military objects.

Earth Moving

Earth movements (Figure 11) were limited to cutting, filling and storing soil for later backfilling and planting grass. The cuts consist of the operations of excavation of the material constituting the land in places where the implantation of the projected geometry requires its removal, or excavation of areas where material is borrowed, including loading and transport to its final destination. Only those materials were transported to constitute the landfills that, due to the classification and characterization carried out in the cuts, were compatible with the specifications for the execution of the landfills.

In general, all the soils were excavated by tire excavator tractors, pushed by crawler tractors of compatible weight or by hydraulic excavators. The cutting activity was carried out in sections of sedimentary soils, there was no use of explosives to detonate rocks, when necessary, the design of the project was minimally adjusted to make excavations feasible, bypassing the rocks.

From the beginning, protection against the erosive action of rainwater was considered, ensuring efficient drainage; that's why the biovaletas were the first excavations. Then, the excavations of the vertical and horizontal filters, rain garden, planted pond and retention basin, respectively, began. This order was established by the difficulty of accessing the machines to places with restricted space, such as the area to the north of the land destined for the Filtrating Gardens, between the rocky hill and the building.

Figure 11 . Beginning of earthworks in August 2016. Source: Personal collection.

The landfills were made up of soil from the excavation of cuts, as the earthworks project was developed with a balance between cut/fill so that there was no need to buy land. The embankments were carried out in successive layers, with a loose thickness of 30 cm, resulting in a compacted thickness of at least 15 cm, granting the required minimum degree of compaction of 95% in relation to the Normal proctor, according to NBR 7182.

Installation of coatings

<table>
<tr><th>TYPOLOGY</th><th>COATING</th></tr>
<tr><td>Biovalets</td><td>Geotextile/Geosynthetic, non-woven, 100% polyester, 130g/m²</td></tr>
<tr><td>Rain Garden</td><td rowspan="4">Bottom layer: Geotextile/Geosynthetic, non-woven, 100% polyester, 300g/m²
Intermediate layer: 1mm HDPE Geomembrane
Top layer: Geotextile/Geosynthetic, non-woven, 100% polyester, 300g/m²</td></tr>
<tr><td>Vertical Filters</td></tr>
<tr><td>Horizontal Filters</td></tr>
<tr><td>Planted Lagoon</td></tr>
</table>

Table 3 . Coating application by typology. Source: Elaborated by the author.

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The gravel layer of the bio-culverts was wrapped in a draining geotextile (Figure 12) to protect against clogging and to prevent the stones from mixing with the soil over time. The geotextile is highly permeable, allowing the infiltration of part of the drained rainwater. The geocomposite used for waterproofing the other elements is a complex of 3 overlapping layers positioned above the earthworks, the first and last layers consisting of geotextile and the middle layer composed of HDPE geomembrane blanket.

To ensure quality control and tightness of the waterproofing complex, a "testimonial drain" system was installed, which aims to identify possible leaks. This system consists of a central trench (h=0.5m) filled with corrugated drain (DN 50mm) and coarse granular material, to facilitate the flow of the infiltrated liquid, and a checkered grid of draining geocomposite (hollow HDPE mesh covered with geotextile). every 5m.

Figure 12 . Placement of crushed stone in the witness drain ditch in August 2016. Source: Personal collection.

Immediately above the waterproofing protection system, layers of 300g/m² geotextile, 1mm HDPE geomembrane and again 300g/m² geotextile were positioned. The installation followed the recommendation of the Brazilian Association of Geosynthetics - IGSBRASIL - for the Installation of Geomembranes in Geotechnical Works and Environmental Sanitation - IGSBR-IGMT-01, where, firstly, the surface was completely cleaned to ensure that no residue or sharp material could damage the waterproofing or even interfere with the installation services.

Then, the blankets were evenly spread out, covering the entire area to be waterproofed (Figure 13). The amendments were made through thermofusion, using specific equipment and a technician specialized in the service. The greatest precautions are: avoiding seams in areas of greater stress or traction and leaving a gap so that the coating can accommodate the mold of the ground when filled with layers of granular material.

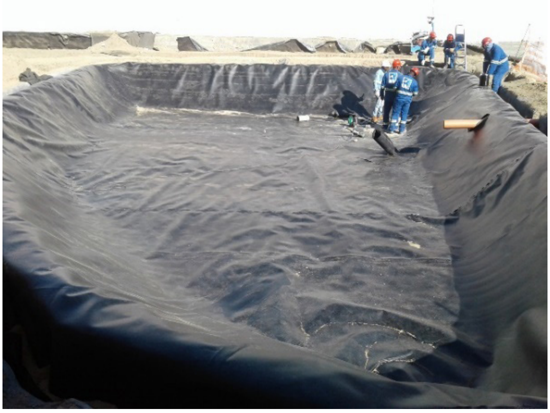

Figure 13 . Installation of the waterproofing blanket in September 2016. Source: Personal collection.

Two techniques were used to anchor the waterproofing complex, depending on the height of the slope and the space on the adjacent paths for digging the ditches. Thus, in the vertical and horizontal filters, the trench and backfill anchoring technique was used, as the filters had small slopes and sufficient space for excavation. In the planted pond and rain garden, the anchoring technique was used using a trench structured with steel bars

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in a "tee" shape, placed every 1m and buried 20cm in the ground. In this technique, the trench must then be filled with concrete until it reaches the level, saving space and material waste.

Interferences between waterproofing and pipes of the hydraulic network internal to the gardens were treated by fixing/wrapping the waterproof complex with a galvanized clamp and stainless steel screws, forming a kind of collar on the pipe (Figure 14).

The finalization of this stage was completed with the tightness test called Spark test, "also known as Holiday detector. In this test, an operator walks across the entire waterproofed surface with a low-amperage, high-voltage source (20 to 100 KV, depending on the thickness of the geomembrane), which acts as an insulator between the ground and the metal rod, and any discontinuity is detected by a spark (spark), accompanied by a beep sound, indicating the failure.

Figure 14 . Installation of a clamp to mount the waterproofing collar on the pipe in September 2016. Source: Personal collection.

Internal hydraulic network and support media (SUBSTRATE)

The entire hydraulic network was assembled by manual fitting with rigid PVC (polyvinyl chloride) pipes, special series for sewage and integrated elastic joint, varying the diameters according to the dimensioning of the project, except for the aeration pipe, composed of drain-type PVC pipe. corrugated. Connections, valves and other parts were also installed in PVC with a flange, when necessary, and stainless-steel screws. The assembly of the hydraulic network took place in parallel with the placement of the layers of granular material, as they are intercalated.

In the vertical filters, for example, the work sequence was: (1) Installation of the DN 150mm drainage mesh, with equally spaced and equal sized slots, cut on site according to the executive project guidelines, supported under the waterproofing geocomposite ; (2) Placement of washed coarse granular material (38 to 50mm), composing a 30cm high layer; (3) Installation of the corrugated DN 100mm aeration mesh, supported under the layer of coarse gravel; (4) Placement of washed medium granular material (19 to 38mm), composing a 20cm high layer; (5) Placement of support feet for the feed pipe, supported under the medium gravel layer; (6) Placement of washed fine granular material (9.5 to 19mm), composing a layer 20cm high, under the medium gravel layer; (7) Assembly of the DN 150mm supply pipe, suspended 20cm from the layer of fine gravel, supported by the support feet (Figure 15 . Installation of hydraulic network and intercalated granular material, October 2016. Source: Personal collection).

Figure 15 . Installation of hydraulic network and intercalated granular material, October 2016. Source: Personal collection.

All typologies followed the same logic in this "filling" stage, that is, both the vertical and horizontal filters, rain garden and planted pond were built in parallel, with the placement of hydraulic layers and granular material according to the specificity of each, as appendices. An exception was the retention basin (Figure 16), which was suppressed during this period of the work. In mid-November/2016, during the excavations of the south wing of the land, rubble of old military buildings was found that caused strong instability in the land. As the depth of the retention basin is large (1.5m deep), it was decided to build a structural bed with a gabion mattress, also known as a reno mattress, in order to cover, protect and stabilize the land at this point.

Figure 16 . Installation of the gabion mattress in the retention basin, November/December 2016. Source: Personal collection.

Civil

It was named as civil, the concrete elements and the electrical infrastructure part. First, the aeration tank was built in reinforced concrete with a waterproofing additive on the internal faces, and access to the inside of the tank was made possible through hinged trapdoors in checkered galvanized iron and polyurethane varnish paint. External access from the path to the top of the tank (H=3.5m) is via an aluminum sailor ladder with yellow electrostatic painting (safety) and a protection ring for external access. Access from the top of the tank to the internal compartment (H=2.3m) is via fiberglass ladder, a material resistant to contact with raw sewage.

The inspection points (PVs), also called passage boxes, were built in structural masonry with 14x19x39cm concrete blocks laid with mortar mix 1:2:9 (cement, lime and sand). Only PVs with a height of less than 50cm were not structured. Due to the contact with raw and semi-treated sewage, the PVs were waterproofed on the inner surface with a waterproofing additive in the mortar.

The electrical part of the project is quite simple. In the engine room, an electrical panel with 380V three-phase power supply and two panels were installed; from them it is possible to control the aerators installed in the tank, the automated butterfly valves, located in the engine room itself. In addition, the system has sound and light security alarms in case the level switches fail or any equipment collapses.

External hydraulic network

The entire hydraulic network was assembled by manual fitting, buried, with rigid PVC (polyvinyl chloride) pipes, special series for sewage and integrated elastic joint, varying the diameters according to the dimensioning of the project. As the interconnection between the elements is done by gravity, the pipes followed a minimum inclination of 0.5%. The external hydraulic network interconnects the sequenced elements, as shown in the project, this connection often passes through redistribution points, which are the PVs, where the hydraulic control parts are installed, such as valves (Figure 17 . “Rustic valve”, hydraulic drainage of the filtering garden, March/April 2016. Source: Personal collection).

Figure 17 . “Rustic valve”, hydraulic drainage of the filtering garden, March/April 2016. Source: Personal collection.

Vegetation

The vegetation planted in phytoremediation devices are called aquatic macrophytes (Figure 18), they are plants that are resilient to the flooded environment and include all plants whose photosynthetically active parts are all the time, or for some period of time, submerged in water or floating in their surface. They play the role of biophysical base for the formation of the ecological niche in the transition zone between the aquatic and terrestrial environments, serving as a hiding place for predators, resting places and reproduction of aquatic fauna, birds and reptiles, that is, they promote a very rich for biodiversity (PINHEIRO, 2017).

The presence of plants helps to reduce water pollution rates through the physical and biological processes of phytoremediation. Roots make up a favorable ecosystem for the development of fungi and bacteria, responsible for transforming complex organic matter into bioavailable nutrients for plant assimilation. This happens because favored microorganisms consume and digest organic contaminants for their nutrition and energy production, promoting the degradation of various compounds and complex substances into simpler components, thereby reducing the degree of toxicity and enabling absorption by plants (MATTA; TAVARES; MAHLER, 2007).

Degradation of organic compounds can also occur through root enzymes (product of exudation) capable of degrading the compound. The mineralized products resulting from this breakdown are partly absorbed by the plant as nutrients necessary for its development. For Brix (1994 and 1997), Reed et al (1995), US EPA (2000b) and Tanner (2001) apud (BRASIL; MATOS; SOARES, 2007) (2007), aquatic macrophytes must perform the following functions: (1) facilitate the transfer of gases such as O_2, CH_4, CO_2, N_2O and H_2S; (2) stabilize the bed surface by developing a dense root system; (3) absorb the macronutrients and micronutrients that allow the photosynthesis process of the plant, (4) supply the demand for biodegradable carbon through the exudates and by-products of the decomposition of the plants, making the denitrification process feasible; (5) provide habitat for wildlife and (6) enhance the aesthetic aspects of the landscape.

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Figure 18 . Planting of macrophytes, April 2017. Source: Personal collection.

During the work, the macrophyte seedlings were distributed around the site shortly before planting, still packaged and having received intense irrigation, with the proper identification of the species and close to the final positioning areas, according to the distribution defined in the project. It is necessary to pay attention to the way of picking the seedlings, which must be by the package, never by the stem. The transport to the filters was done manually, with the aid of a wheelbarrow.

It is fundamental to fill the gardens with water up to the level of the top of the substrate, guaranteeing a favorable environment for the development of the plants until, in fact, the contribution of sewage and rainwater begins. In this case, the seedlings were planted 3 months before the population occupied the P&I center, and in the flooded environment the species developed and started the system's maturation process.

The planted pond was filled with water in stages to facilitate the planting of seedlings. After positioning the substrate, water was added to form a layer of 10 to 20cm above the sand for planting the *nympheas* in the bottom and other species in the bank. Then, the water level was completed until reaching the height of the design sheet, totaling 80cm of total sheet (30cm substrate + 50cm water). The bioditches are not filled with water, as they are not waterproof elements, however, just like the grass, the irrigation of the planted species must be constant, until the plant is rooted in the substrate.

The marking of the pits was done by determining the exact point of each of the planting pits on the gravel surface at the top of the filter, or on the peat for bioditches. The pits were marked with the aid of nylon lines and pickets that simulate the layout of the executive project in order to reproduce the two-dimensional design on the gravel surface.

Once the areas of each species were delimited (Table 4), the pits were dug manually in the gravel (or earth) respecting the spacing defined in the project, with a limit of 5 (five) seedlings/m² of surface. The pit was dug approximately 20 cm deep and wide enough to house the seedling clod. The upper part of the clod was gently covered with gravel from the substrate, preventing the seedlings from suffocating, but in sufficient quantity for their fixation.

MACROPHYTE		TYPOLOGIES				
Scientific name	**Popular name**	**JC**	**BV**	**FV**	**FH**	**LP**
Andropogon bicornis	donkey's tail grass		X	X		
Canna generalis	beri	X	X	X	X	X
cyperus giganteus	Brazilian Papyrus			X	X	X
echinodorus macrophyllus	Leather hat	X	X	X		
Equisetum giganteum	horsetail	x			X	X
Heliconia psittacorum	parrot heliconia	X	X	X	X	
Heliconia rostrata	marsh plantain	x		X	X	
limnocharis flava	Mureré				X	X
Pontederia cordata	water hyacinth	x				x
bridge parviflora	water hyacinth				X	
Thalia geniculata	Talia		x	X	X	
Nympheas spp.	water lily					x

Table 4 . List of plants and their distribution by system elements. Source: Prepared by the author, survey of species in the field on August 23, 2017.

RESULTS

After the completion of the work (Figure 19), the operation and maintenance were monitored for the next 6 months, from July/2017 to December/2017. During this period, activities were carried out to operate manual valves to rotate the supply of filtering gardens, analytical monitoring of effluent treatment and basically gardening actions, such as pruning, weed removal, division of clumps to replant species that eventually died, which is considered normal, as it is a living system in adaptation.

Vegetation response to pruning, clump division and replanting were successful. All species adapted to the climate, but as development occurs at different speeds, it was observed that more robust species, such as the biri, tended to dominate the space, killing some nearby seedlings. Due to cleaning pruning, species control was successful and the original landscaping design was maintained. At the end of the case study follow-up period, the gardens were almost completely filled, with medium-sized vegetation.

Figure 19 . Horizontal filters on the left, Lagoa Plantada on the right, in December 2017. Source: Image courtesy of the private collection of Phytostore Brasil.

The treatment efficiency of the filter gardens (Table 5). Result of the analytical monitoring of sewage from July to December, 2017. Source: Prepared by the author based on laboratory analyzes provided by Phytostore. The laboratory responsible for collecting and analyzing the samples is Mérieux NutriSciences, located in Piracicaba-SP. The analyzes are certified by commercial process No. 9601/2017-8) was measured monthly,

parameters	Items.	Prohibited	Exit	Efficiency	Prohibited	Exit	Efficiency
			07/18/2017			08/23/2017	
pH (at 25°C)	-	6.87	7.36	-	7.05	6.90	-
BOD (mg/L)	mg/L	394.00	29.20	92.6%	476.00	26.20	94.5%
COD (mg/L)	mg/L	988.00	64.00	93.5%	986.00	74.00	92.5%
Temperature	°C	21.90	19.60	-	23.10	23.40	-
non- ammonial	mg/L	97.30	26.80	72.5%	96.80	34.40	64.5%
n_{total}	mg/L	106.00	26.80	74.7%	111.00	44.50	59.9%
P_{total}	mg/L	2.15	1.20	44.2%	19.90	15.90	20.1%
coliforms	(NMP/ 100mL)	2.42E+06	3.55E+04	98.5%	2.42E+06	5.91E+04	97.6%
			09/21/2017			10/11/2017	
pH (at 25°C)	-	7.10	6.91	-	7.35	7.15	-
BOD (mg/L)	mg/L	226.00	24.9	89.0%	418.00	28.50	93.2%
COD (mg/L)	mg/L	578.00	76.00	86.9%	962.00	72.00	92.5%
Temperature	°C	25.90	25.40	-	26.90	25.60	-
non- ammonial	mg/L	27.80	18.80	32.4%	131.00	29.00	77.9%
n_{total}	mg/L	53.50	29.00	45.8%	149.00	38.60	74.1%
P_{total}	mg/L	7.35	5.90	19.7%	13.30	10.70	19.5%
coliforms	(NMP/ 100mL)	2.42E+06	3.50E+02	100.0%	2.42E+06	2.65E+04	98.9%
SST	mg/L	336.00	5.00	98.5%	207.00	5.00	97.6%
			11/14/2017			12/18/2017	
pH (at 25°C)	-	7.11	7.10	-	6.33	7.16	-
BOD (mg/L)	mg/L	567.00	22.90	96.0%	490.00	24.50	95.0%
COD (mg/L)	mg/L	1300.00	134.00	89.7%	1930.00	60.00	96.9%
Temperature	°C	26.60	25.50	-	27.60	26.70	-
non- ammonial	mg/L	113.00	28.20	75.0%	85.90	39.50	54.0%
n_{total}	mg/L	139.00	37.30	73.2%	119.00	46.40	61.0%
P_{total}	mg/L	14.40	8.16	43.3%	29.40	12.20	58.5%
coliforms	(NMP/ 100mL)	2.42E+06	5.10E+03	99.8%	2.42E+06	2.00E+03	99.9%
SST	mg/L	212.00	5.00	97.6%	596.00	5.00	99.2%

SUBTITLE:

- Parameter with higher input than expected in the sewage characterization estimate
- Parameter with output that meets the requirements of CONAMA 430/2011
- Parameter with output that does not meet the requirements of CONAMA 430/2011

Table 5 . Result of the analytical monitoring of sewage from July to December, 2017. Source: Prepared by the author based on laboratory analyzes provided by Phytostore. The laboratory responsible for collecting and analyzing the samples is Mérieux NutriSciences, located in Piracicaba-SP. The analyzes are certified by commercial process No. 9601/2017-8.

with the collection of composite samples over the commercial period of one day in the month. The monitored parameters were: BOD, COD, temperature, pH, total nitrogen, ammoniacal nitrogen, total phosphorus and thermotolerant coliforms; and every 3 months the complete parameters specified in CONAMA 430/11 Art. 16.

In general, when analyzing the results, it was concluded that the system was not yet at a complete maturity level, since, according to the experience of Phytostore Brasil, the peak of performance happens after 8 to 12 months of operation, when the development of microorganisms and the robust formation of root zones are consolidated, characterizing an "adult" garden. Thus, it was expected that the results were still not completely satisfactory. In addition, it is possible to observe that in some months the parameters BOD, COD and, mainly, ammoniacal nitrogen entered the treatment with concentrations above the estimates foreseen in the sizing.

Even without reaching complete maturity, the system was very satisfactory in reducing BOD/COD and thermotolerant coliforms, and even in the months of August, October and November, when inputs were above the base estimates for sizing (BOD<400 mg /L and COD<1000 mg/L), the result was satisfactory. In September, when the intake of ammoniacal nitrogen was within the forecast (Namoniacal <33.70 mg/L), the result was also satisfactory.

The sustainable drainage system also performed well, and in 6 months of operation, the system experienced one of the rainiest months in 2017 and the detention basin did not reach its maximum storage capacity (Figure 20 . Retention basin after intense rainy event (November/2017). Source: Image courtesy of the private collection of Phytostore Brasil). There was no flooding or overflowing in the rain gardens and bio-culverts. According to data from the Alerta Rio System – City Hall of Rio de Janeiro, the accumulated amount for the month of November/2017 reached 92.2 mm of rain, and the retention basin was dimensioned to store this precipitation in 1 hour of a rainy event. The month with the highest rainfall in 2017 was January, with a monthly accumulated of 113.2 mm.

Figure 20 . Retention basin after intense rainy event (November/2017). Source: Image courtesy of the private collection of Phytostore Brasil.

In terms of biodiversity, the presence of pollinators, various insects such as grasshoppers, dragonflies, butterflies, birds, amphibians and garden spiders was observed. It is estimated that there was no attraction of venomous and/or wild animals because it is a system in a private area, surrounded by walls/rails and due to the daily presence of the gardener in the operation and maintenance. However, the presence of these animals can happen at any time, so it is recommended that visitors walk the delimited walkway for pedestrian access, without entering the gardens, unless they are wearing appropriate PPE.

CONCLUSION

The phytoremediation technique proved to be a natural technique, little intrusive, efficient and widely compatible with green areas such as gardens and parks, promoting the enhancement of the landscape (Figure

21 . Central biovalet of the parking lot in December 2017. Source: Image courtesy of the private collection of Phytostore Brazil), in addition to the enrichment of local biodiversity. Precisely because it is a natural process, we can also observe some adversities related to the vulnerability of plants to climate variations and diseases/pests. In addition, it takes time for the complete maturation of the system, considering the growth of the plant and the formation of the rhizosphere, and the ideal performance of phytoremediation is not immediate.

Far beyond the issues of phytoremediation efficiency, the case study brought the participatory and integrative tendency of architecture professionals in projects that involve the management of urban waters and the composition of green infrastructure. In addition, monitoring the work and the first 6 months of operation confirm the constructive and operational simplicity of this solution, potential for savings and meeting environmental demands, fulfilling what is expected of an SbN.

Figure 21 . Central biovalet of the parking lot in December 2017. Source: Image courtesy of the private collection of Phytostore Brazil.

Recognition of the technical collaboration of phytoremediation defines it as a viable alternative for composing strategies related to urban water management and mitigation of the effects of urbanization and climate change on a local scale. Although this research has focused on the application in private land, the presented typologies can be applied in the urban scale of the hydrographic basin. One of the great advantages of adopting this system is the flexibility of typologies and arrangements, as well as different ways of dimensioning and designing according to the objective of each project. When designing for already consolidated metropolises, for example, where space is limited, it would be possible to consider bio-culverts that integrate with rain gardens, widening their section at times and then returning to a narrower section. It is important that the professional understands the creative freedom that this strategy presents, as this is a bias that values its application even more.

Based on the learning with the case study in question and the theoretical references of the theme, the main recommendations are highlighted:

- It is essential that the design phase of the project be developed in an integrated manner between architects and other work fronts. In this stage, the interdisciplinary compatibility promotes technical and financial gains and enhancement of the landscape;
- The layout of the gardens must take into account the topography of the land, hours of sunlight, human-nature interaction and dimensioning of the system (areas);
- Garden design is related to its typology, although there is freedom for creation, minimum guidelines must be met to ensure efficiency. This way, the horizontal filters must follow a rectangular proportion, so that the water travels the longest path, and the planted pond must avoid designs with hydraulically inert corners to achieve water efficiency and avoid stagnant water;

- Phytoremediation systems are sized to meet a specific event, selected according to design criteria, which allows for spatial and financial viability; that is, a reserve system (backup) must always be provided in case of events above the calculated or crises;
- As it is a natural system, certain variables cannot be controlled by anthropic actions, the system depends on time for maturation and must respect the speed of symbiotic reactions in the roots;
- Filtering gardens are natural systems designed for maximum use, so you cannot make the mistake of neglecting operation and maintenance because it is a nature-based solution.

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