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Proposal for Implementation of Green Roof Project Using the Wetland Technique

Lais A. Alves*[1], Elaine G. Vazquez[2], Larissa Peçanha[3], Assed H. Naked[4]

[1]Department of Mechanical Engineering, Federal Center for Technological Education of Rio de Janeiro, Av. Maracanã, 229 – Maracanã, Rio de Janeiro, Brazil
e-mail: lais.alves@cefet-rj.br

[2]Department of Construction Engineering, Federal University of Rio de Janeiro, Av. Pedro Calmon, 550 – Cidade Universitária, Rio de Janeiro, Brazil
e-mail: elainevazquez@poli.ufrj.br

[3]Department of Construction Engineering, Federal University of Rio de Janeiro, Av. Pedro Calmon, 550 – Cidade Universitária, Rio de Janeiro, Brazil
e-mail: laribraga@poli.ufrj.br

[4]Department of Construction Engineering, Federal University of Rio de Janeiro, Av. Pedro Calmon, 550 – Cidade Universitária, Rio de Janeiro, Brazil
e-mail: assed@poli.ufrj.br

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ABSTRACT

This work presents a study on methods of wetland systems and the design of a prototype of green roof design in a practical example, with the objective of presenting a sustainable technique for reuse of rainwater. The use of the wetland system as a technique for collecting and treating wastewater can be one of the possible solutions to the lack of potable water in large urban centres, since the system is capable of filtering rainwater. As a result, a proposed green roof design is presented using a wetland system built to retain and treat rainwater for reuse with non-potable purposes. This system, in addition to integrating landscape aspects of the environment, presents low cost of implementation and can be a viable alternative for water reuse. This study contributes to improve knowledge as this type of technique is not yet used in Brazil, allowing future work on the economic viability and construction of the prototype.

KEYWORDS

Water shortage, Rainwater reuse, Sustainability, Green roof, Wetlands, Prototype.

INTRODUCTION

The disorderly growth of cities, global population expansion, along with the urban trend, increasingly pressure cities and their support systems for the population [1]. As cities grow and environmental problems escalate, managing human demand for fresh water presents an increasing challenge [2]. In recent years, water shortage has become an increasing concern [3], with the growing imbalance between water demand and availability reaching critical levels [4].

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* Corresponding author

Research and studies on integrated water capitation and treatment systems have emerged due to the need to diversify water supply in urban areas given the imminent water crisis, leading to a tendency for water reuse [5]. In this context, rainwater, if assertively managed, can become a solution to the water supply problem, reducing the demand of public water supply systems and, simultaneously, reducing the volume of water in urban floods [6].

With the growing demand reaching ecological and economic limits, the need for innovative water management becomes clear [7]. To secure water supplies in the future, there is an urgent need to transition towards a more water-smart society and develop water-wise solutions to improve efficiency, reduce consumption and preserve resources [8].

There is an increasing attention on rainwater harvesting as an alternative source of water [9] for non-potable uses that require lower quality: landscape irrigation, discharge of toilets, washing hard areas or building facades [10, 11]. Its implementation in urban areas is considered a multi beneficial strategy for urban flooding control [12, 13], and for the reduction of potable water consumption [14, 15]. It can also decrease the pressure on urban drainage systems during heavy rain events [16], reduce and solve current water shortages, and the pollution of urban natural waterways [12, 13]. In terms of responses to the quality of rainwater, the top concerns are water quality and dust contamination, although there are other problems such as smell, turbidity, brackishness and taste [17].

Rather than a problem, rainwater can be managed as one of the solutions for decentralized supply. However, the solution should seek to use the precipitated water before it comes into contact with contaminating substances, storing it for domestic use, creating surplus infiltration conditions, restoring natural flows, providing another alternative for local and decentralized water supply [18].

In this context, research and studies on systems integrating the gathering and treatment of water for non-potable use have advanced, including the development of studies with the possibility of using aquatic plants and aquatic systems becoming increasingly relevant [19]. This alternative is a new application for sustainable urban biophysics and some solutions can be constructed using the ecological design principles of constructed wetlands [20].

Nowadays, use of constructed wetlands for wastewater or rainwater treatment has become increasingly preferable [21]. The most important reason behind this fact is its relatively low investment cost [22], over other treatment options, depending on economic conditions of the country, low-energy-consumption and effective technology for water pollution control [23].

MATERIALS AND METHODS

Constructed wetlands are manageable artificial systems. The term constructed gives the dimensions of a system designed under controlled conditions and with the principle of soil permeability to prevent infiltration [24]. In general, constructed wetlands can be used for the treatment of several types of effluents, such as domestic sewage at secondary and tertiary levels, industrial effluents, rainwater and even slurry treatment [25].

Constructed wetlands are artificial wastewater treatment systems consisting of shallow (usually less than one meter deep) ponds or channels which have been planted with aquatic plants, and rely upon natural microbial, biological, physical and chemical processes to treat wastewater or rainwater [26]. Wetland ecosystems have various functions and benefits such as flood-storage, purification of water quality, habitat functions, wetland products, environment beautification, biodiversity maintenance [27].

In short, it is the simulation of a natural ecosystem reproduced in a distinct environment where basic ecology mechanisms are manipulated through civil and sanitary engineering principles. Thus, the treatment mechanism of constructed wetland is based on natural wetlands, where microorganisms, plants and native animals work together to reduce water pollutants [28].

The principle of treatment in wetlands, either natural or constructed, is based on the interaction between the components of soil, water, plant and air, and involves physical, chemical and biological phenomena. The physical process involves the sedimentation and filtration of the suspended particles, being mainly responsible for reduction of the Biochemical Oxygen Demand (BOD). The chemical treatment process involves adsorption, agglutination and precipitation, responsible for the removal of phosphorus and heavy metals. The biological process is the key to the performance of the treatment, because the microorganisms are responsible for the degradation of organic matter, nitrification in aerobic zones and denitrification in anaerobic zones [29]. Thus, constructed wetland is considered as a polishing unit for water quality improvement through removal of suspended solids, organics, nutrients, pathogens and metals through interrelated physical, chemical and biological processes [30].

Numerous are the plants, or macrophytes, that can be employed in built wetlands. The term macrophyte ranges from vascular aquatic plants (angiosperms) to some algae, whose tissues can be visibly identified [31]. Macrophytes, like all other photoautotrophic organisms, use solar energy to assimilate inorganic carbon from the atmosphere in the production of organic matter that will serve as a source of energy for heterotrophic beings – animals, bacteria and fungi [31]. Their choice is basically related to plant tolerance to saturated water (or sewage) environments, their potential for growth, the presence of these plants in the areas where the system will be implanted, facilitation of the adaptation to the climatic conditions of the area in question, and low cost for planting and maintenance (regular pruning, reuse, etc.) [32, 33].

Among the several species of macrophytes that can be used in constructed wetlands systems, the following stand out: *Phragmites australis*, *Juncus spp.*, *Scirpus spp.*, *Typha angustifolia*, *Typha latifolia*, *Iris pseudacorus*, *Acorus calamus*, *Glyceria maxima* and *Carex spp*. However, although all these species are suitable, the most commonly used types are *Phragmites spp*., *Juncus spp*. and *Typha spp*. [34].

The use of constructed wetlands as wastewater treatment systems has intensified in recent decades. In general, constructed wetlands can be used for the treatment of several types of effluents, such as domestic sewage, industrial effluents and rainwater [35]. Compared with conventional treatment systems, constructed wetlands are low cost, easy to operate and maintain, and have great potential for application in developing countries, particularly in small rural communities [36].

This construction system is divided into three stages: rainwater abstraction, absorption and storage in the built wetland system, and effluent from the system for reuse. Wetlands systems constructed using macrophytes can be classified as: systems using floating aquatic plants, emerging aquatic plants and submerged aquatic plants (Table 1) [37].

Table 1. Classification of built wetland systems [37]

Classification of built wetland systems	
Systems using floating aquatic plants (macrophytes)	
Systems using emerging aquatic plants (macrophytes)	Surface flow Horizontal subsurface flow Vertical subsurface flow
Systems using submerged aquatic plants (macrophytes)	

Floating macrophytes cover a wide variety of plant species, which are usually applied to shallow channels, that may contain only one species or a combination of them.

The most studied species is *Eichhornia crassipes*, due to its characteristics that provide greater adaptability and excellent vegetative growth [38, 39].

Water purification systems using water hyacinth are sufficiently developed to be used in tropical and subtropical regions. The criteria for projects have been published [40, 41]. These plants cover the surface avoiding the penetration of light and the production of algae and plankton and also create more suitable conditions that favor denitrification. They are easy to handle and contain twice as much protein, fat, phosphorus and nitrogen as water [42, 43]. A scheme of a system using floating aquatic (macrophytes) plants is shown in Figure 1.

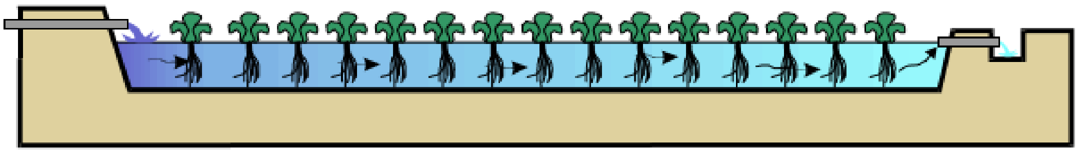

Figure 1. Schematic drawing of a channel with floating plants [44]

In the international scope, there are several models and criteria for designing constructed wetlands, most of which are focused on the removal of organic load [41]. Among the most relevant [45], constructed wetlands are considered as biological reactors of fixed biofilm, providing a removal of organic matter according to first order kinetics, applicable more specifically in constructed wetland with horizontal subsurface flow [46]. Systems with vertical flow modules followed by horizontal flow modules can also be used to obtain good nitrification in the vertical filters, which are well oxygenated, as well as a denitrification in the horizontal filters, where the anoxia conditions necessary to this reaction are present [41].

The species most used in systems using emerging aquatic plants are *Phragmites australis*, *Typha latifolia* and *Scirpus lacustris* [47]. All these species are morphologically adapted to develop in flooded sediments due to the large volumes of internal spaces capable of transporting oxygen to the root system. The typical species of emergent aquatic macrophytes are generally known by the name of reeds, which are herbaceous plants of several families. The use of this technique of emergent aquatic plants for the purpose of water purification is found in three basic schemes: emergent macrophytes with surface flow, horizontal sub-surface flow and vertical flow [48].

The wetland system constructed with emergent macrophytes with surface flow system, represented in Figure 2, is one of the oldest wetland systems built, with over 30 years of operation in the Netherlands [49].

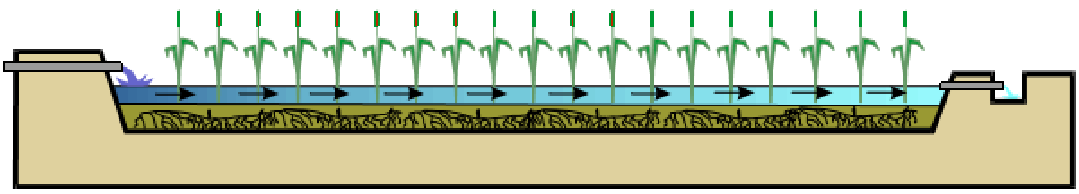

Figure 2. Schematic drawing of a channel with emergent macrophytes with surface flow [44]

Horizontal subsurface flow systems (Figure 3), used for wastewater treatment were initially employed as technology in Western Europe in surveys [50] in the early 1980s, and in the late 1970s and early 1980s [36]. Systems of this type, using *Phragmites australis*, were constructed in 1970 in Germany [36, 51]. Plants have two important functions in the process [52], providing oxygen to the microorganisms in the rhizosphere and increasing and stabilizing the hydraulic conductivity [53, 54].

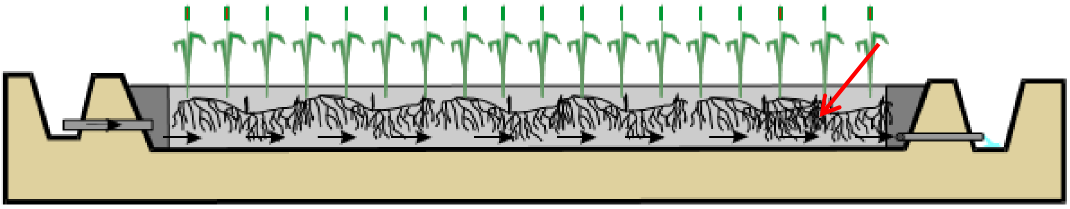

Figure 3. Schematic drawing of a channel with emerging macrophytes with horizontal sub-surface flow [44]

A system using emergent macrophytes with vertical flow, represented in Figure 4, can be used when higher hydraulic conductivity and greater oxygenation in the root system are required [55]. The information of the systems that use this technology indicates good removal of suspended solids, BOD, ammonia and phosphorus. An alternation of operation allows total drainage increases oxygenation of the rhizosphere and substrate [56].

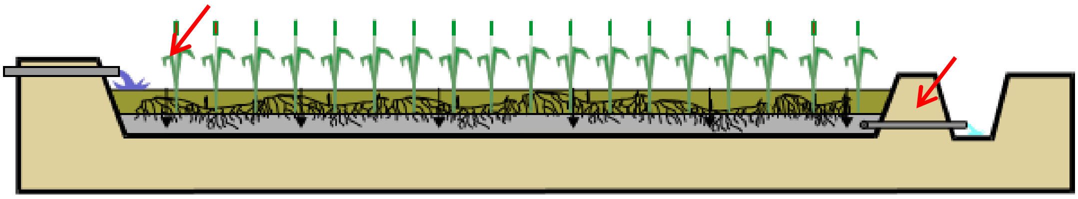

Figure 4. Schematic drawing of a channel with emergent macrophytes with vertical sub-surface flow [44]

The systems using the submerged aquatic macrophytes, represented by Figure 5, are completely submerged and when exposed to the sun, their photosynthetic active tissues are generally destroyed. The most commonly found species are the *Isoetes lacustris*, *Lobelia dortmanna* and *Egéria sp*. The use of these submerged aquatic macrophytes for water purification and quality control through constructed wetlands is done through narrow and long channels with variable depth [57].

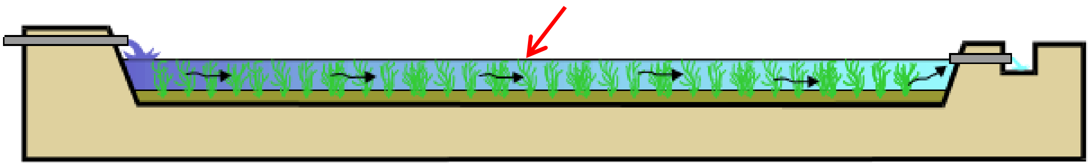

Figure 5. Schematic drawing of a channel with submerged fixed aquatic plants [44]

RESULTS FOR THE PROTOTYPE

In this proposal of application, the building where the civil engineering course from the Polytechnic School of the Federal University of Rio de Janeiro takes place, was chosen for the construction of the prototype. Located in the University City, in the city of Rio de Janeiro (Figure 6), due to the access for the students involved, as well as a place where the proposed system does not suffer from dry periods. The idea exposed in this work is to use the green area that already exists between the blocks, altering it with the purpose of expanding its sustainable use, bringing it closer to the students, thus transforming it into a space of sustainable coexistence.

As described previously, the construction system is divided into three stages: rainwater abstraction, absorption and storage in the built wetland system and effluent exit from the system for reuse. Rainwater gathering will be done through existing gutters in the building (Figure 7). Extensive coverage was chosen for this study because these coverings require little or no maintenance.

Figure 6. Case study building – Polytechnic School of the Federal University of Rio de Janeiro

Figure 7. Rainwater gathering – existing gutters

The two existing gutters collect the rainwater through the roof of the building and have eight descents (Figure 8) that lead the water to the public distribution network. In the case study the descents called AP-7 and AP-8 were chosen, which will be taken to the second phase of the process.

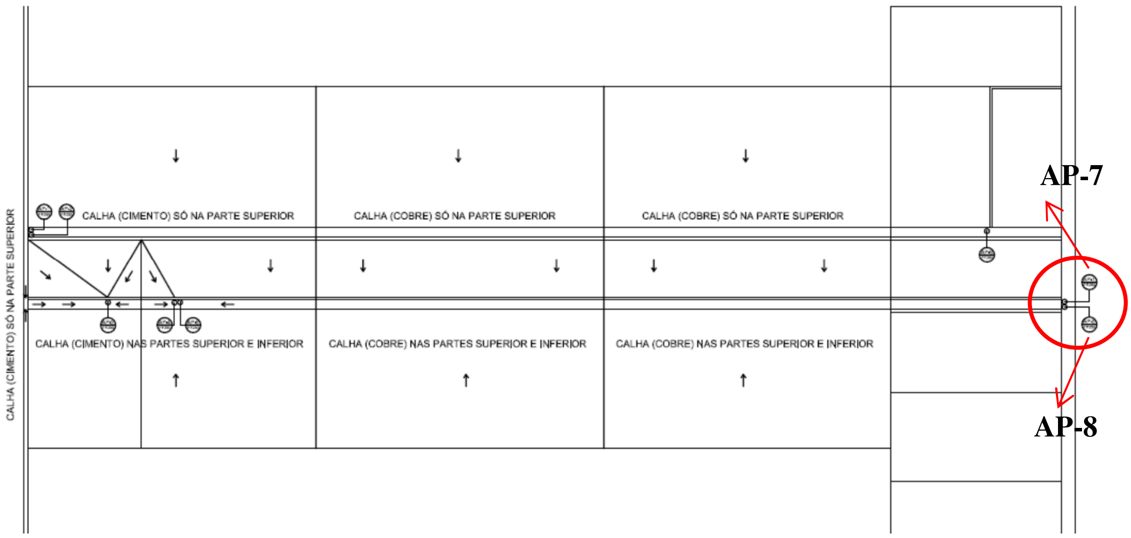

Figure 8. Rainwater system – D building

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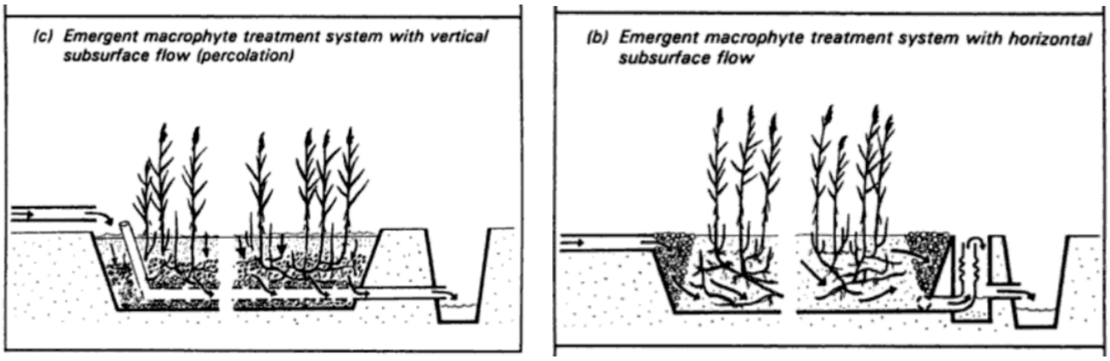
The second stage is aimed at the absorption and storage in the built wetland system, where effectively the treatment of the water, captured by the aquatic plants that make up the wetland system, takes place.

In the application proposed, a constructed wetland system was chosen, using emerging aquatic plants, and in order to increase the use of all the properties of emergent macrophytes, a two-stage system was suggested, where the first consists of a system with vertical subsurface flow (Figure 9a) and the second in a system with horizontal subsurface flow (Figure 9b).



(a) (b)

Figure 9. Emergent macrophytes with vertical sub-surface flow (a) and emergent macrophytes with horizontal sub-surface flow (b)

The collected water will pass through the system, first by the vertical flow and then a second stage with horizontal flow (Figure 10 and Figure 11).

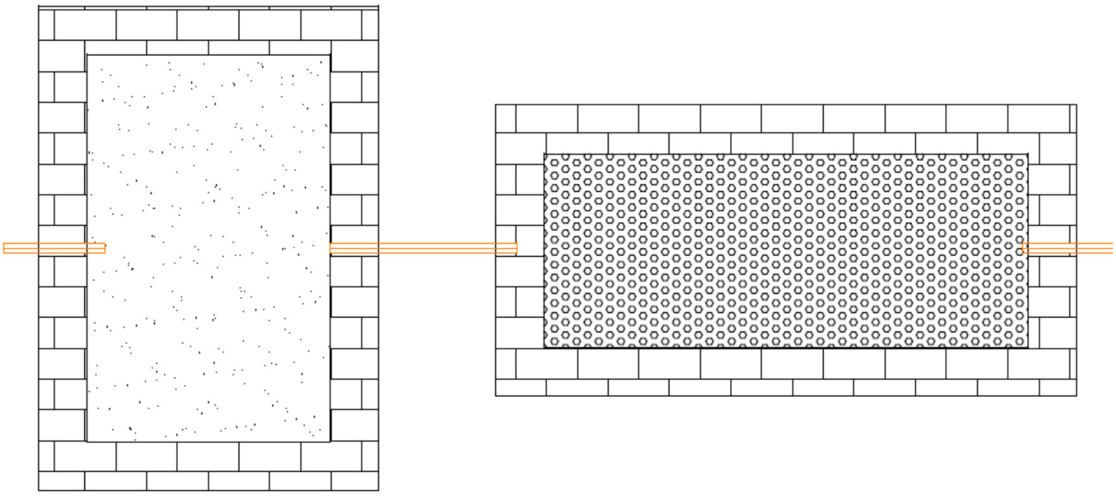


Figure 10. Schematics of the proposed constructed wetland system [58]

The third stage refers to the piping system for effluent exit for reuse for non-potable purposes, followed by a small storage tank with the purpose of analysing the effluent and, if necessary, adding any supplementary treatment, ensuring that it is ready for use. The reservoir selected in this case was a model of water tank made of polyethylene, due to the ease of purchase and the lower cost when compared to other materials.

Establishing all these criteria of the project methodology, the complete prototype can be observed in Figure 12. Throughout its elaboration, the choices were based on the optimization of quality and cost, seeking to aggregate the maximum that each parameter could provide to the system.

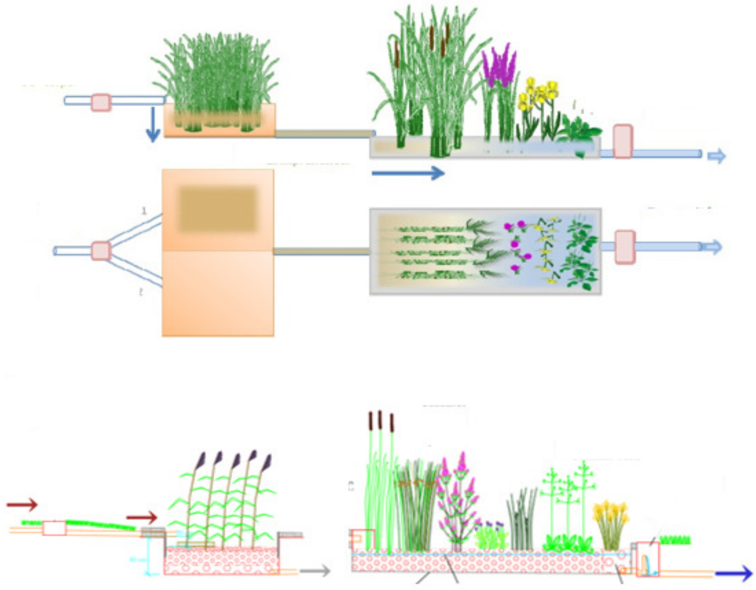


Figure 11. Absorption and storage in built wetland system [59]

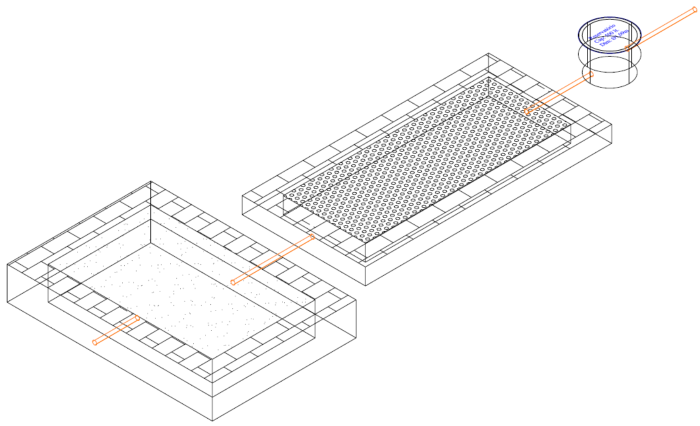


Figure 12. Schematics of the proposed constructed wetland system

Figure 13 shows the location of the final model that will be installed in the space between buildings C and D, thus being close to the water gathering location and easily accessible for the required analysis of the project.

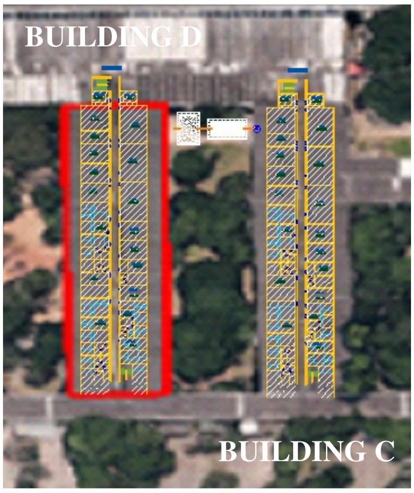


Figure 13. Location of the final model in between buildings C and D

CONCLUSIONS

Many studies have been directed towards urban sustainability issues, aiming on promoting alternative solutions including reuse of rainwater, global warming, water crisis and numerous other consequences that rapid development and expansion brought, without urbanization awareness.

Following this perspective, wetlands constructed systems appear as a very affordable solution, given their economic feasibility, besides helping in urban drainage with the delay of the return of rainwater to the public system. In addition, it provides treatment with the aid of aquatic plants returning green spaces to the urban centres, that help reduce the greenhouse effect with the thermal comfort that it provides.

The prototype of the wetland system constructed on the study case proposal in building D of the Polytechnic School brings several economic, environmental and social benefits. Considering the environmental aspect, this system brings an increase of the green area, improvement in the quality of the air, minimizes the effects of islands of heat, combats the greenhouse effect, reduces the runoff as well as the consumption of drinking water for non-potable use. Undoubtedly, it has a great social importance. In relation to the economic aspect, it presents a simplified construction and operation methodology, in addition to the low costs of implementation, operation and maintenance, when compared to other more conventional techniques.

Because of its visible location, it plays a role of awareness of the reuse of water and sustainability in general, besides the aesthetic contribution of the common area, bringing improvement to quality of life.

This work is presented as an effort to stimulate the adoption of these social and environmental practices in a concrete and practical way, opening space for a greater dissemination of the theme in Brazil. It contributes to future work related to the economic feasibility, prototype construction, to the benefits generated by the installation of this system, such as the analysis of the quality of the water after its passage, and to the economy generated by the reuse of water.

The built wetland system will give support to students from different courses related to sustainable water management, development and sustainable resources to guarantee water security, in addition to the recovery of the environmental liabilities deposited in the water bodies. For this reason, this study was focused on this technique that brings innovation and sustainable development focused on the reuse of water, a resource that is essential for our society, and can make feasible the reuse of water abstracted for non-drinking use in university grounds.

The proposal of the wet land system is intended to test a new methodology for Brazil, that already shows results elsewhere, as seen in the bibliographical research. This paper aims to show the feasibility of the system, as well as the benefits that can be observed with its implementation. It has a low maintenance cost and the chosen location allows the aquatic plants to act during all the seasons.

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