Green Wall Potential for Gray Water Treatment **Novembro/2019**

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Abstract

The increase in world water consumption and the consequent increment in the generation of urban and domestic waste water currently encourages the improvement of the management of these resources, seeking new forms of treatment and reuse. The use of green walls for the treatment of gray water for reuse in less noble purposes has been studied and new discoveries have been made regarding the substrates, their proportions and the types of plants most suitable for this purpose. The presente work conducted a survey of the solutions of green walls available in the market, highlighting their main features, strong points and limitations. The possible adaptations to these structures were also explored, in relation to the type of irrigation, drainage and disposal, in order to potentiate the greywater treatment. In addition some deliberations were made for the diagnosis of the problems identified in a green wall installed in a restaurant building in the Lisbon area, and adjustments were proposed for the use of gray water generated by the building itself.

Key-words: Green walls; Greywater; Water treatment; Reuse; Vertical gardens; Green facades

1. Introduction

1.1. First Deliberations

Water supply in terms of quality and quantity has been presented as a difficult management activity for urbanized cities around the globe, and the increased wastewater generation is another negative impact of this urbanization. In addition sometimes is impracticable, due to costs, increase treatment capacity of the existing infrastructure and the expansion of centralized systems. Recycling and reuse of wastewater is an attractive way to manage urban wastewater so that 10% to 50% of use savings can be achieved (Pradhan *et al.* 2019). However, the possible presence of toxins, heavy metals and pathogens, harmful to human health, in the whole wastewater, presentes itself as the best strategy for its treatment and reuse the separation in gray (less polluted) and black (more polluted) waters.

If the concept of gray water recycling in building can be applied on a large scale to a city, this approach could mean a reduction in dependence on very expensive structures by optimizing - and decentralizing treatment - overall wastewater management and operating conditions for the treatment itself. Masi *et al*. (2016) explored in his study the potential of green walls as a viable treatment for gray water, which is made by percolating the water through the support and filling of the plants. This process would enable not only reduction of the carbon footprint of treatments, but a number of benefits in the urban landscape, such as increased green areas, carbon trapping, oxygen production, positive effects on the local microclimate and sound and thermal insulation in houses.

1.2. Purposes

The main objective of this research is to evaluate the potential of green walls for use in grey water treatment. To this end, the following partial objectives were defined: Survey and classification of the types of green wall solutions available in the market; Critical analysis of the main advantages and disadvantages presented by each system in relation to its application for the treatment of gray water; Evaluation of a case study estimating the performance of a green wall already installed in a restaurant in Lisbon.

2. Characterization of Gray Water and its Reuse Potential

2.1. Gray Water Definition

Urban wastewater is, according to current legislation, domestic wastewater or a mixture of these with industrial wastewater and/or rainwater. In contrast, domestic wastewater can be classified into two groups, gray water and black water. According to Jefferson *et al.* (2000), Otterpohl *et al.* (1999); Eriksson and Ledin, (2002) and Ottoson and Stenström (2003), gray water is defined as domestic wastewater from bathtubs, showers, washbasins, washing machines, dishwashers and kitchen sinks, excluding toilets, which are considered black water. Due to the nature of the activities that gave rise to them, the gray waters have a low content of organic matter, nitrates and phosphates, as well as a reduced bacteriological component.

2.2. Gray Water Characterization and Volume Production

According to Eriksson *et al.* (2003) and Friedler and Hadari (2006) gray water may constitute between 50 and 80% of the total domestic wastewater produced and Karpiscak, Foster and Schidt, (1990) claim that black waters are less than 30% of the total produced. Yet, according to Hansen and Kjellerup (1994), the total gray water compared to total wastewater was estimated to be approximately 75%. Morel and Diener (2006) indicate that the typical volume of gray water produced can vary from 90 to 120 L/person/day depending on lifestyle, consumption patterns, population characteristics, customs and habits, water facilities and water availability. However, they also state that the volume of gray water in countries with water scarcity and/or simpler supply structures, this volume can reach 20 to 30 L/person/day.

According to researchs by Christova-Boal *et al.* (1996); Almeida *et al.* (1999); Eriksson *et al.* (2002); Jamrah *et al.* (2008) and Burnat and Mahmoud (2004), to survey turbidity levels, total solids and total suspended solids in countries such as the United States, Australia, England, Palestine and other Middle Eastern locations, Bazzarella (2005) presents a summary table in which it is possible to observe that the effluents from kitchen and dishwasher sinks present the highest concentrations of total suspended solids, a parameter that should be observed in collection and reuse systems. Meanwhile the effluent from the washing machine has proved to have the highest concentrations of non-filterable solids.

Chemical analyzes in international gray water surveys evaluated indicators such as total nitrogen concentration, total phosphorus concentration, presence of organic compounds, pH, conductivity, dissolved oxygen, alkalinity, hardness, presence of chlorides and oils and greases. And according to

Schönning (2001), 80% of the nitrogen found in domestic wastewater comes from urine. In the case of total gray water (including those from the kitchen), their main source is kitchen sink effluents (Eriksson *et al.*, 2002). Also, in the case of gray water where these effluents are excluded, the largest source comes from the shower, where there may be the presence of urine..

The drainage points, the products used by the users and the supply water pH are the main factors that influence the gray water pH, having been observed in Christova-Boal *et al.* (1996), Jamrah *et al.* (2008) and Burnat and Mahmoud (2004) that this pH is close to a neutral value in effluents from kitchen showers and kitchen washbasins and alkaline in washing machine and bathroom washbasin effluents. Also, the dissolved oxygen in gray water is between 0 to 5.8 mg/L (Almeida *et al.* 1999).

Finally, the presence of organic and inorganic materials in gray waters can be considered significant, even considering that there is no contribution from the sanitary basins. Most of the organic matter found comes from body waste, hair, soap, oils and greases. Meantime, chemicals and detergents used for household cleaning are mainly responsible for the presence of inorganic matter in these waters (May, 2009).

2.3. Reuse Types

The use of treated gray water for flushing toilets and urinals is a possibility as the water used for this purpose in many countries has water quality for human consumption and it is estimated that approximately 30% of total water consumption could be saved if this adaptation was made (Karpiscak, Foster e Schidt, 1990). Besides that noteworthy is the outdoor uses for irrigation of lawns on university campuses, sports fields, cemeteries, parks, golf courses and in home gardens (Okun, 1997). Car washing, window washing, fire protection systems such as boiler feeders and concrete production are other suggested examples (Santala *et al.,* 1998).

3. Green Wall Classification

3.1. General Aspects

It was assumed that the green walls can be divided into two main groups, the green facades and the living walls. The most striking differentiation between these two types of system is that on green facades, climbing plants are commonly employed, which grow along the wall, covering it. And on the living walls are added the materials and technologies necessary to fix the support the varieties of plants that can be used, creating a uniform growth along the entire surface on which it is installed (Manso e Castro-Gomes, 2015).

3.2. Green Facades

Green facades can be classified into two types, direct and indirect. The direct ones are those in which the plants are properly fixed to the wall or are based on the soil, while the indirect ones need a vertical support structure to enable the development of the aerial part of the vegetation. Indirect systems can be further divided into continuous or modular systems according to the type of support. The continuos are often based on a single support structure that allows the plants to develop along the entire surface, whereas the modular ones are usually trusses or similar solutions where several modular elements are installed along the wall surface (Manso e Castro-Gomes, 2015).

3.3. Living Walls

Living wall systems as well as green façades can also be classified as continuous or modular according to the method of application. Continuous systems are based on the application of a panel with a light and permeable culture medium that allows plants to be inserted individually. Modular systems, on the other hand, are composed of elements with specific dimensions, including the culture medium in which the plants will grow (Manso e Castro-Gomes, 2015).

3.4. Green Wall Type Selection

The choice of the most suitable green wall system is directly related to the building characteristics and weather conditions, as well as the type of plants and substrate to be used. Therefore it is important to understand the differences in the composition of existing systems and their main characteristics. The cost of systems is also a significant impact variable in solution selection, with living walls typically more expensive when compared to direct and indirect green facades, which can cost less than 75 euros/m². Modular living wall systems have a cost dependent on the materials used and can cost up to 1200 euros/m² in complex systems (Manso e Castro-Gomes, 2015).

4. Cataloging of Green Wall Types

Were found a total of 18 companies supplying green wall mounting frames, some of which have products that fall into two or more classifications by type. Four types of products of indirect green facades, four types of continuous living walls and 13 types of modular living walls were found. In Annex A, Table A.1 (main text) you can see a summary of the survey of these products and their main characteristics.

4.1. Green Facades

4.1.1. Direct

Direct green facades, as previous explained, have their system formed basically by the wall that will function as a support for plant growth, the plants themselves and the soil that acts as the substrate. Therefore, there is no specific product available on the market for the installation of this type of structure.

4.1.2. Indirect

Two suppliers of indirect and continuous green facades were found, namely Scotscape and Greenwall, and two suppliers of indirect and modular products, namely Mobilane and GreenScreen. Products generally have no advantages over their use for water treatment, as the water inserted for irrigation does not pass or remain in a filling medium (only rests on the ground) and therefore the treatment has reduced effect. Moreover, as the large amount of gray water that should be inserted into the structure by this means, as manual irrigation systems, the treatment by this means is not viable.

4.2. Living Walls

4.2.1. Contínuous

Four types of continuous living walls suppliers were found: Scotscape, Green Studios, Sagegreenlife and Vertical Garden. The common advantages of these systems is the existence of a continuous medium through which water circulates with longer retention time, as well as the existence of irrigation lines in each panel, allowing the injection of greater water flow into the structure. The absence of a recirculation tank already built into the supplied pumping system can be considered a minor drawback of the products, with only the Sagegreenlife brand having a product with the existing tank concept. The pressure of drainage only at the bottom of the walls and, consequently, the greater amount of water received by the lower plants compared to the higher ones is another disadvantage.

4.2.2. Modular

Five potted modular living wall products were found: Gsky, Mobilane, Wallgreen, Minigarden and Modulo Green; four modular trays: Green Profile, Greenwall Pro, LiveWall and TreeBox; two of the flexible bag modular type: Scotscape and Florafelt; and two more of the ceramic tile modular type: Urban Growth and Urbio Wall Planter. Each of the suppliers presented different drainage and irrigation systems, as well as support structures of different materials and operating methods for particular water circulation. Furthermore, the advantages and disadvantages with respect to each of them as regards their use in the treatment of gray water were also determined.

4.3. Review of the Main Features

Most systems are irrigated by drip, which has the advantage of reducing the risk of splashing and providing individual water to the plants. However, if gray water feed treatment is profess, drip may not be the best system as it provides for a water saving that is neither necessary nor desired in this structure. Another feature shared by most of the systems presented is the drainage of runoff water only at the base of the walls, making use of gutters that have a slope directed to a drain, for subsequent routing of water to the common drainage system of the site. Since systems with runoff water recirculation are likely to have greater treatment efficiency, the drainage channels already present in most of the systems surveyed can be exploited by making only slight modifications.

5. Proposals of Adaptations in the Existing Systems

5.1. Initial Deliberations and Fitter Systems

Some of the products researched have greater viability for adaptation than others, already existing in some of them the guidelines necessary for use in the treatment of gray water. Among them, we highlight the suppliers, presented in order of relevance and easeness of adaptation. It should be noted that, as they are recommended in all solutions, water collection and recirculation tanks were not individually indicated.

1. Gky, where it would be necessary to add pipes to the irrigation system in order to function by levels, increasing water flow and enhancing treatment. The most suitable models are Versa Wall and Versal Wall XT;

2. Minigarden, automating the irrigation system and allowing water to flow from the upper vessels to those immediately below them

3. Greenwall.pro, where recirculation would be the most important feature to adopt;

4. Green Profile and Treebox, make an adjustment to the system to allow water to be directed from the upper to the lower trays. Or, without major changes, use the current system (with recirculation);

5. Scotscape and Sagegreenlife, being necessary to optimize the substrate to be applied to the continuous wall, in order to increase the retention time, reinforcing the treatment.

This is followed by the submission of proposals in relation to the above modifications, emphasizing the importance of irrigation systems in section 5.2 and drainage in section 5.3 in relation to the other aspects of the green wall structure itself, which do not require major modifications for their intended use.

5.2. Irrigation System

The proposed suggestions in this paper can be divided into two categories, the first one in case the wall is a continuous vertical garden and the second one in case is a modular system with vases, trays or flexible pouches.

In the case of the structure of a continuous vertical garden, it is possible to adopt a wick system, as shown in Figure 5.1. The gray water would circulate through a porous medium system located behind the wall itself, and the plants would be supplied with the necessary water and fertilizer through the contact of the wicks with the mentioned system and with the vegetation roots. This system has the advantage of increasing retention time and amount of water for treatment in the porous medium, since its volume is much larger than the vessels, trays and flexible pouches used in modular systems.

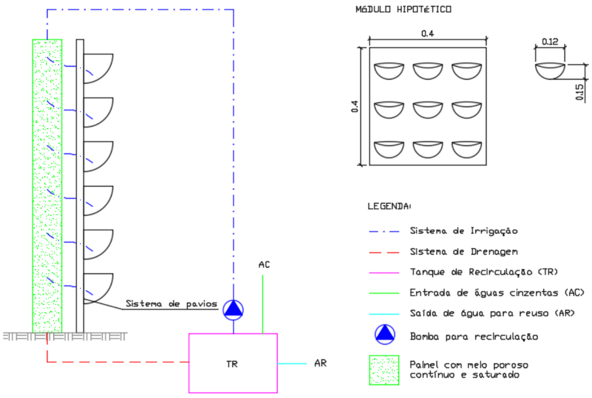

Figura 5.1: Sistema adaptado com irrigação por pavios e recirculação

In the second case, the advantage is in increasing the amount of water circulating in the system at the same time, consequently increasing the volume that can be treated in the same time frame. As a disadvantage, it should be noted that a system without the recirculation structure would be practically impossible, since the retention time of the water circulating between the nearest ground irrigation pipe and the drainage pipes would be very small, being extremely importante implanting recirculation in the system for successful treatment. Also noteworthy is the need for more piping to pass through the continuous porous media system, increasing installation costs and possible maintenance.

In the case of a modular system for pots, trays or flexible pockets, the proposal is to position the irrigation pipes by height levels or continuously bypassing the levels, as can be seen (the first case) in Figure 5.2, and introduce a recirculation system that would allow the drained water to be inserted back into the system. The recirculation works by directing the pre-treated water into a tank where it is combined with untreated gray water and possible fertilizers and, through a pumping system, the mixture is introduced back into the irrigation system.

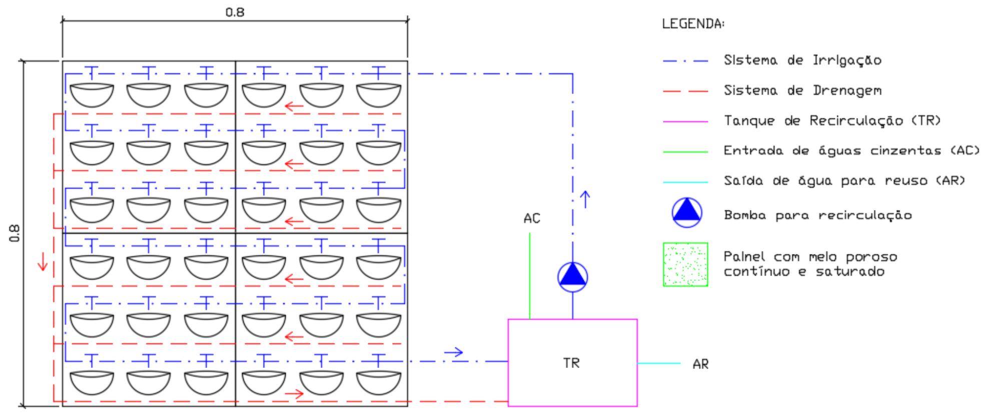

Figura 5.2: Sistema com irrigação em zigue-sague e drenagem por níveis

5.3. Drainage System

Most of the previously presented vertical garden systems have a drainage system located at the base of the wall that materializes in the form of a gutter, collecting and directing water directly to the building drainage network or recirculation tank, in some cases. The suggested modifications to this part of the system structure are also proposed in two options, depending on whether the system is a vertical garden with tiered irrigation or just the top of the wall, as mentioned above.

If the system is the first to be mentioned, water collection could also take place in tiers, later directing it to the recirculation tank or, where a modular structure is present, allowing the collection of water directly to the vessels, trays and flexible pouches located at the lower levels. Otherwise, under the condition of the top-only irrigation system (either continuous or modular), the drainage should be located at the bottom of the wall, allowing the gray water introduced into the vertical garden to circulate throughout the system, expanding the retention time.

5.4. Chapter Overview

From the proposals presented in this work and their respective advantages and limitations, it can be inferred that those that would possibly have higher performance in the treatment of gray water would be, in the case of modular walls, the systems with irrigation by levels and drainage at the bottom, which may be with the water transmitted from one module to another at levels or not, and with recirculating water tanks. These structures are believed to have the most potential because they introduce larger amounts of water into the system and have a longer retention time of the mixture in the substrate and plant roots. The wick system would possibly be a good solution for continuous walls, also introducing the recirculation tank and with the same advantages mentioned above.

Also, considering a wall already built and installed in a building can be identified as the most easily adaptable systems with modular systems that have irrigation system at the top or level and drainage at the base. In this case, it is only necessary to increase the flow of the drippers and the irrigation network (if only at the top) and the addition of the recirculation tank near the installation of the structure. Continuous systems are more difficult to adapt if its considered the proposed wick suggested.

6. Case Study

6.1. Initial Deliberations

This chapter will present the green wall project already installed on the exterior surface of a building in Lisbon area, highlighting two main characteristics, classifying it according to the systems shown in chapters 3 and 4 and identifying the problems presented by structure and possible solutions for them. An estimate of the potential evapotranspiration calculation was also performed to assess the water requirement of the installed plants and to compare it with the current irrigation flow rate. Terracell's records regarding maintenance activity, including daily water consumption, are also presented and analyzed. In addition, a preliminary study was made for the use of gray water from the toilet closest to the green wall located inside the building.

6.2. Green Wall Description

The wall has 300m² of vertical area, being divided into five sectors, identified from 1 to 5, as can be seen in Annex B, Figure 1 (original text), in order to facilitate irrigation and maintenance of the structure. It is made up of modules containing three flexible pouches of permeable geotextile material measuring 28 cm x 56 cm x 7 cm (ends) to 15 cm (center). The set of flexible pouches is attached to a metal frame that supports these and the pipes of the irrigation system, which is composed of a set of pumps and pipes located behind the wall, which has five registers separated by sectors. arranged in height by bag levels and according to sections, running by drip. The system is drained by gravity due to the permeability of the pockets and the water that reaches the base of the wall is collected by a polymer concrete gutter.

6.3. Diagnosis of Current Operation

According to the company that manages the wall maintenance, watering occurs daily at two times, in the morning at 6:00 and in the evening at 22:00. Watering times are defined according to the water needs of the installed plant species, humidity, season and rainfall in the preceding days, and are usually adjusted weekly from visual wall evaluation. The average daily consumption per zone in the referred months was obtained from the average of the indicated watering times, the number of drippers and the defined flow rate, and the results can be seen in Table 6.1.

Table 1: Average daily consumption by sector

Sector	Jan	Feb	Mar	Aprl	May	Jun	Average

1	0,093	0,126	0,214	0,153	0,181	0,263	0,172
2	0,120	0,156	0,276	0,198	0,233	0,339	0,220
3	0,083	0,128	0,268	0,179	0,211	0,306	0,196
4	0,089	0,138	0,289	0,220	0,227	0,330	0,216
5	0,117	0,213	0,330	0,220	0,261	0,385	0,255

Among the visible problems identified in three technical site visits are excessive leaks through the material of the modular pockets causing water to accumulate on the sidewalk surfaces near the wall in the areas between the metal frame and the support wall and external to the metal frame, visible slippage on the support surfaces and through the drainage gutter, water accumulation at some points of the gutter and excessive moisture in the pockets, causing small mosses to appear and favoring insect proliferation.

6.4. Green Wall Water Needs Assessment

To estimate the theoretical need for green wall water was used the calculation model presented by the University of California Department of Water Resources, which includes the use of the Landscape Coefficient Method in conjunction with the Water Use Classifications of Landscape Species (or WUCOLS III). The method consists of determining the Reference Evapotranspiration (ET0), corresponding to considering an open field acreage and multiplying it by a landscape coefficient (kL), resulting in the total landscape evapotranspiration (ET) which, at this study, was considered as an estimate of the water requirement of the analyzed wall. The reference evapotranspiration was determined from the Penman-Monteith formula.

From the comparison of the daily estimates of water requirements obtained here with the consumptions (Table 6.1), presented in Table 6.2, it can be concluded that the amount of water consumed by the irrigation system (irrigated volume) is slightly higher than the actual needs. of installed vegetation. Also, in sector 5, the largest difference between the values is observed, thus inferring that the plants located in this zone possibly need na amount of water lower than the one currently supplied.

Table 2: Comparison of water needs and consumption by sector

Sector	Average Need [m^3]	Average Consumption [m^3]
1	0,104	0,172
2	0,175	0,220
3	0,157	0,196
4	0,125	0,216
5	0,093	0,255

6.5. Proposed Solutions

Depending on the results obtained, partial waterproofing solutions of the pockets can be inferred, at least inside the wall, since the product was recommended for direct installation on the wall and not with a gap between the building and the wall (which occurs in this case). In addition, the problems of water accumulation in the drainage gutter of the wall base are undoubtedly due to poor execution of the slopes, which should be redone so that excess water can flow freely to the collection box.

6.6. Preliminary Study for Gray Water Use

It been estimated that daily water consumption only from the taps in these bathrooms will be 157.68 liters. Disregarding water losses in the use of washbasins, it is estimated that this volume is equal to the daily value of gray water produced. Therefore in a month it can be verified that the total volume of gray water produced will be 4.73 m^3. Based on the data presented in section 6.4 it can be estimated that 0.654 m^3/day is required for the whole wall (sum of the sectors needs) and therefore 19.62 m^3 per month.

Thus, it is demonstrated that the use of gray water produced by the external bathrooms alone would not be sufficient to provide all the volume of water needed for irrigation of the green wall. Even so, if this use were chosen, it is possible to predict an average monthly water saving of around 24%, which is quite significant considering the dimensions of the wall.

7. Conclusions

Major technological advances and innovations in the available green wall market are still needed, to be able to be used for the treatment of gray water. Concerns about the quality of the wall effluent water are also significant and further research on the most suitable materials, fillers and plant types for this use is of utmost importance.

In the case study it is possible to highlight the large discrepancy between the estimated results of the wall water consumption and the actual data provided by the company responsible for maintenance. This is probably due to the limitations of the calculation model used and most likely to the large evaporative losses in the flexible pockets, due to its configuration in the support structure and its porous matter, increasing these rates.

Future developments should focus on testing the systems proposed here, analyzing production volume and water quality for reuse and the costs associated with adopting these systems on a large scale. The development of better irrigation, drainage and overall structure systems designed specifically for this purpose is expected to potentialize and popularize this type of decentralized treatment.

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