Natural solutions for the management of grey water in buildings
Application to a case study at IST

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October, 2017

Abstract: In order for a sustainable development to occur, it is necessary to change one of the biggest paradigms in the current society, not only by reducing the consumption of resources, but also by increasing the treatment and reutilization of the residues generated by many activities around the world. One of the issues that have been questioned to minimize the impact on water resources is the centralized management of wastewater treatment in most developed countries. The adoption of decentralized sanitation systems is an alternative that has many advantages and is based on the principles of sustainability.

The present dissertation focuses on the case study that contemplates the feasibility of installing a treatment solution consisting of green walls and a system for disinfection by ultraviolet radiation in the civil pavilion of Instituto Superior Técnico.

The consumption of sanitary devices was estimated with the purpose of estimating the water for the sinks of the floors 1, 2, and 3 to be treated in the green wall, as well as the volume of water used to clean the pavements of the respective floors with the purpose of treated water to be reused for that purpose.

The estimated cost for the treatment solution was 36 747 €, so in year 11, after the implementation, it is possible to recover all the money initially invested. In an estimate of 15 to 20 years, there is approximately an economic benefit of around 9 000 € and 17 000 € respectively. It was concluded that the solution is economically viable.

Keywords: Grey water; Reuse on site; Green wall; Decentralized treatment solution; Economic viability.

1. Introduction

One of the major challenges of the early 21st century is directly related to the sustainability of water resources that have been intensely overexploited and polluted in the last decades in various sectors of activities such as agriculture and industry. Water is the main natural resource in the world and undoubtedly essential for the survival of any species on the planet and although it has a self-purification capacity, it is limited, which generates a decrease in the volume available under proper conditions for use or consumption. As such, there is currently an increasing attempt to minimize the impact on water resources through more sustainable management of urban water. Climate change and the rapid growth of urban populations are increasingly emerging challenges, which are very important to consider when guaranteeing water supply and protecting water environments. This is because, given that in the coming decades the population will continue to increase progressively, the demand for water will also increase globally. If there are no changes in the patterns of production and consumption of society and the use of this limited natural resource remains with the current inefficient characteristics, there will undoubtedly be the need for further future investments to meet the growth of demand. In addition to the problem of meeting the needs of the water that will be put, there is also the fact that the pollution generated will also increase.

The systems in their classical design were created solely to improve public health and to provide a basis for the economic development and quality of life of the population. However, these criteria are currently insufficient, since public water supply and sanitation systems should also have the principle of water conservation as an adjoining principle, and indeed, when such systems were created, they did not have this aspect as one of their priorities. Its design presents numerous weaknesses and has created considerable challenges throughout the 21st century such as floods in urban areas and increased pollution in the receiving environment (Saldanha Matos & Santos Ferreira, 2012). Decentralized sanitation is an innovative design that is based on the principles of sustainability and water conservation, always with the intent of creating a closed loop in the place where it is produced. With this approach, for the same purpose, smaller volumes of water are used, particularly in the transport of waste. (Saldanha Matos & Santos Ferreira, 2012). As a result, there is a decline in the degradation of the quality of natural resources, water, soil and air, which is ultimately the underlying principle in rational water management policy. In urban areas, the potential for introducing wastewater re-use to less noble purposes are striking and represents a way to reduce the consumption of potable water and its polluting burden on the environment.

Awareness of the importance of water savings is one of the first steps to alleviate these problems and, together with the encouragement of government agencies, will lead to changes in population habits for the rational use of water.

2. Grey water

At an urban level, wastewater can be divided into two distinct groups, black waters and grey waters. Wastewater is the sanitary component of wastewater and contains feces, urine and toilet paper. These will not be addressed throughout this dissertation. In turn, grey water is the non-sanitary component of wastewater, i.e. water produced in bathtubs, showers, hand basins, washing machines and kitchen sinks. (Eriksson, Auffarth, Henze & Ledin, 2002; Jefferson, Laine, Parsons, Stephenson & Judd, 2000)The contribution of the portion of the wastewater from the kitchen to this type of water is not consensual, and some authors do not include it because they have traces of organic matter, fats, oils and detergents (Matos, Sampaio & Bentes, 2012; Nolde, 2000). Treatment becomes more difficult and costly for the latter case. Grey waters are usually regarded as those with high volumes and low pollution.

3. Case study

The case study covered in this dissertation contemplates the feasibility of installing a green wall in the civil pavilion of Instituto Superior Técnico (IST) in Lisbon. The purpose of the green wall is to treat the grey water from the bathroom sinks on floors 1, 2 and 3. Since it is subsequently intended that the treated water be used to clean the floor of the interior spaces of the stages 1,2 and 3, it is necessary to complement this solution with a disinfection step of UV radiation. This is essential since there may be contact of the treated water with the cleaning staff or with the users of the pavilion and only with this tertiary treatment stage will the elimination of all pathogenic microorganisms be guaranteed. The building has a total of seven floors, three of which are buried.

It is important to note that the green wall was the selected treatment solution because, considering that the civil pavilion is already built, a natural solution was chosen that had a low implantation area and that, to a certain extent, adapts to the existing space. It is for this reason, due to these characteristics that, in urban centers, this solution is well indicated. In addition, the green wall offers advantages in controlling the internal temperature of the pavilion and its humidity, as well as an improvement in indoor air quality (Valesan, Fedrizzi, & Sattler, 2010). The choice of the pavilion was related to the fact that this is a space with high water consumption and this is used, mostly, for less noble purposes. In addition, a key factor has been the fact that universities play a very important role in the field of scientific training and these environmental initiatives contribute to the awareness of civil society.

3.1. Preliminary study of the water consumption of the civil pavilion

The quantity of grey water produced in a building is proportional to the volume of water consumed in that building. The volume of water consumed depends essentially on the specificities of the system, the number of people that usually circulate there and their behavior when using the various devices, as already mentioned in a previous chapter. Therefore, before implementing any solution of treatment of greywater is necessary to carry out a preliminary study, in which an estimate of the volumes of water consumed in the civil pavilion is made. Only in this way is it possible to dimension a technically feasible green wall.

With a direct visual reading of the meter of water consumed it was possible to see the water consumption of each month in the year 2016. It is then necessary to calculate the average monthly consumption of the pavilion to carry out the sizing of the greywater treatment solution. The average monthly consumption read in the meter is 741.76 m^3/month.

Since the purpose of the green wall is to treat the water coming from the bathroom sinks on floors 1, 2 and 3, it is necessary to discretize the monthly consumption which was measured by the meter. The values of each sanitary device must be known individually, since it is only in this way that it is possible to assess if the supply of water, which is the water produced by the lavatories of the toilets, is sufficient for the purpose of re-use. Since it was not possible to place counters at the level of the various sanitary devices, it is necessary to make an estimate for each of them, starting from values referenced in the bibliography and requesting information from the workers and cleaning staff of the pavilion. It should be noted that there is a high uncertainty associated with all the hypotheses introduced in the estimation of consumption of each sanitary device and in each floor.

The devices that generate consumption of greywater in the pavilion are only the taps. However, it is also necessary to consider the flushing systems and urinals in the estimation of the overall consumption of the pavilion. Dishwashers are included in the bar and canteen counter and there are no showers or washing machine in the civil pavilion. The average volume consumed for each use of taps is difficult to quantify, since there are several factors that directly influence it. Through various on-site measurements it has been possible to estimate that the taps have an average flow rate of 11 l/min for a maximum opening and of 7.5 l/min for a regular opening. It was assumed that, on average, each user kept the tap open for 20 seconds at a flow rate of 7.5 l/min. In Portugal, traditional flushing systems have discharge volumes that can vary between 7 and 15 l (Laboratório Nacional de Engenharia Civil com apoio do Instituto Superior de Agronomia, 2001). In the civil pavilion at the IST, flushing systems are not of the single discharge type as usually exists in the dwellings, there is manual discharge. The duration of the discharge is directly related to the push time of the button that comes from the habits of use of each person. It is assumed that people, on average, use a discharge volume of 8 l.

The purpose is that the global quantity of discharges per month is as close as possible to reality, that is, the average monthly consumption read in the meter (741.76 m^3/month). Each floor has different spaces with specific features and functions. As such, the number of individuals circulating on each of the floors varies greatly. In addition, they present a set of heterogeneous competences, which can be mostly teachers, students, laboratory workers, auxiliaries, cleaning employees or security guards, which causes variations in the period that remain in the building. To achieve the proposed objective, in addition to knowing the average volume of each discharge of each device, it is necessary to know the number of users of the devices and the number of discharges performed by each one of them in one day. The coordinator of the pavilion spaces provided the necessary information on the physical characteristics of the pavilion and the maximum occupancy values of the different spaces, and these were later verified on the spot. In view of this, it was necessary for each floor to be subject to an estimate of consumption adapted to the uses found there. The occupancy rate of each floor was the parameter that was varied to calibrate the global consumption estimate, which is intended to be as close as possible to the average monthly consumption value. In addition to the discharges made individually by the users, it was necessary to estimate the volumes of water consumed in the cleaning activities recommended in the pavilion, as these are also accounted for in the meter. Through the previous analysis, it is possible to estimate the overall consumption of the civil pavilion. Table 1 shows these values.

Table 1 - Global monthly consumption.

Floor	**Monthly consumption (m^3/month)**	**Global monthly consumption (m^3/month)**
3	86,7	987,5
2	84,9	
1	359,2	
0	250,8	
-1	128,0	
-2	77,9	

To sum up, the average monthly effective consumption of 2016, determined in the previous chapter was 741.76 m^3 /month. The estimate was intended to be as close as possible to this effective consumption value. However, the methodology applied for the determination of the overall consumption of the pavilion was dependent on the information available, so it should be noted that it was not possible to obtain effective data on the consumption of sanitary devices. As such, in the estimation of consumption, we assumed several hypotheses that may present some differences in relation to reality.

It is then necessary to determine the residual effluent flow rate. Given that there are losses in the drainage systems, the volume of water that flows into the domestic wastewater network is less than that consumed. According to *Decreto regulamentar nº 23/95 – Artigo 123*, the factor of affluence to the domestic wastewater network may vary between 0.7 and 0.9. An affluence factor of 90% was adopted. Thus, the flow rate of the residual effluent is shown in Table 2.

Table 2 - Residual effluent flow.

Piso	Residual effluent flow (m^3/month)	Global residual effluent flow (m^3/month)
3	78,0	888,70
2	76,4	
1	323,3	
0	225,7	
-1	115,2	
-2	70,1	

As previously mentioned, the goal of the green wall is to treat the water coming from the lavatories of floors 1, 2 and 3, and after the treatment, it is intended that these be reused in the washing of floors 1, 2 and 3 of the flag. In Table 3 is possible to compare demand and supply of water. It is important to note that only water used in floor cleaning was considered by the conventional method, bucket and mop.

Table 3 - Supply and demand of water in the civil pavilion.

Demand - Water needed to wash the floors 1,2 and 3	3736,7
Supply - Water consumed in the washbasins of floors 1,2 and 3 (l/day)	4135,1
Supply - Effluent flow from the washbasins of floors 1,2 and 3 (l/day)	3721,6

The value of 3721.6 l/day was used for the design of the green wall, not only because the estimated consumption for the pavilion was considerably higher than the actual consumption of the pavilion, but also because there is a portion of the water consumed that does not contribute to wastewater, for example in the filling of water bottles (a very frequent activity in the context of this university). As we can conclude, the water required to wash the floors of floors 1,2 and 3 is only slightly higher, so it is considered that this solution presents feasibility in terms of demand versus supply.

3.2. Preliminary design of the greywater treatment system

After determining the residual effluent flow to be treated, it is necessary to carry out preliminary design of the various components of the treatment system. The Figure 1 shows the treatment scheme.

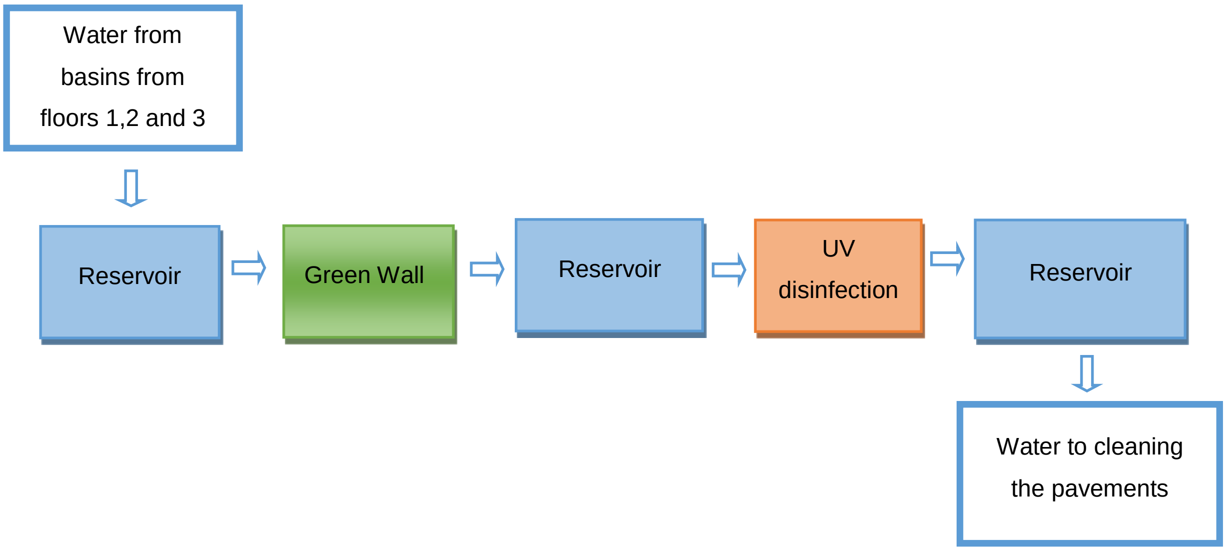

Figure 1 - Schematic representation of the greywater treatment solution of the IST civil pavilion.

3.2.1 Reservoir

The activities that the users perform in the washbasins of floors 1,2 and 3 occur at different times of the day, which, consequently, causes a short-term variation of the water flow. Since greywater flows to the green wall at periodic intervals with a predefined flow rate, it is necessary to dimension a reservoir to compensate the gap between its inflow and the consumption of the green wall. However, there is usually some stability between the production and greywater needs, which means that it is sufficient to scale the tank to approximately the average daily consumption of the respective bathroom. The Table 4 shows the dimensions of the reservoirs to be installed per floor.

Table 4 - Reservoir volume.

Floors	Reservoir volume (l)
2+3	300
1	750

3.2.2 Green Wall

It is intended to install four treatment units per tower. There are three towers in the pavilion of civil, so it is intended to install 12 green walls. By tower, the green walls that intend to carry out the treatment of the greywaters of floors 2 and 3 consist of two matrices 20 x 10 pots (200 pots), each connected to the respective reservoir of the bathroom. The green walls that intend to treat the greywater of the floor 1 consist of four matrices, and are connected two by two. It was not possible to scale them continuously because of the lack of available space. The first consists of a 25 x 13 pots matrix (325 pots) and the second one in a 25 x 7 pots matrix (175 pots), each of these sets being connected to the respective reservoir.

Figure 2 shows a schematic representation of the green walls in the central tower with the number of pots for each treatment unit.

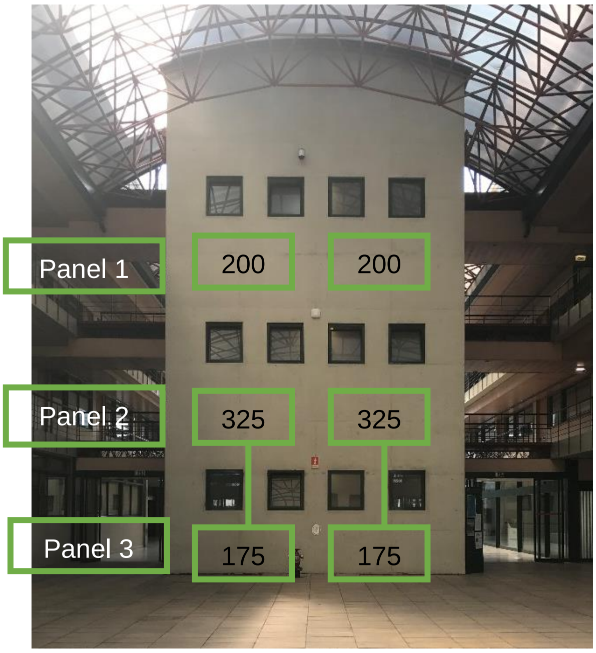

Figure 2 - Schematic representation of the green walls.

Photograph taken on the pavilion

3.2.3 Reservoir

Thereafter, a storage structure is required to regulate flow rate to feed the UV radiation disinfection system implemented in the next step. It is intended that it is installed on the 3rd floor of the civil pavilion. It was decided to dimension the reservoir with store capacity for two days. As such, it is intended to have a capacity of at least 7443,22 l. It should be noted that it is preferable that it will not be buried, so that the least possible changes are made to the existing space in the pavilion. After consulting several catalogs, we chose a reservoir with a capacity of 8500 l.

3.2.3 UV system

The effluent flow rate to be treated is 3721.61 l/day, that is, 3.721 m^3/day which is the flow rate from the green wall stored in the previous reservoir. We opted for a compact disinfection system that treats 1 m^3/hour.

3.2.4 Reservoir

After the process of treatment of the greywaters, they are directed to this reservoir. The reservoir is intended to store the treated water, from which the water will be reused. We chose a similar reservoir to the reservoir selected between the green wall treatment and the UV disinfection system, that is, 8500 l.

3.2.5 Global cost of the solution

The overall cost of the solution being studied is given by the sum of each of the constituents of the system and the labour. It was estimated that for the accomplishment of the work it was necessary to hire a team of workers. It was also necessary a scaffold to construct the structure of the green wall.

For conservative reasons, all costs that were estimated were multiplied by 1.05. Thus, there is some margin, in case any of the constituents have costs higher than what was determined. The Table 5 shows the costs of each of the constituents before and after, as well as a percentage of the total cost.

Table 5 - Estimated total cost of solution.

Constituents of the treatment solution	Cost estimate (€)	Conservative cost estimate (€)	Percentage of total cost	Estimated total cost of solution (€)
Reservoir	4 620,00	4 851,00	13%	36 747
Green wall	8 893,24	9337,90	25%	
Scaffold rental	6 873,57	7 217,25	20%	
Reservoir	1 333,33	1 399,99	4%	
Disinfection system	642,43	674,55	2%	
Reservoir	1 333,33	1 399,99	4%	
Piping system	404,80	425,04	1%	
Labour	10 896,00	11 440,80	31%	

4. Final remarks

According to the information provided by the Engineer Mário Matos, the price that IST pays per m^3 of water consumed is 1,67€ and the variable sanitation rate is 1.64€ per m3. The overall cost, considering also the fixed sanitation tariff, rate of water resources, additional fee for the City Council and the service quota, is 3.50 €/m^3 billed. Likewise, according to the data provided by Engineer Mário Matos, the water consumption value for the year 2016, compared to the meter previously studied, was 8489 m^3. As such, the amount payable for its consumption was 14 177€ and the cost of its sanitation was 12 530€. With the treatment solution there is thus a saving of 2278€/year in water consumption and, in the case of sanitation, a saving of 2228€/year. Then, although this treatment solution is self-sustaining, it is expected that it will require maintenance services. It was decided to consider as maintenance costs approximately 5% of the constituents of the green wall per year.

It is also necessary to consider the energy cost that the UV disinfection system has over the years in which it will be implemented. Considering that the average flow rate that the green wall intends to treat is 3.72m^3/day and that the chosen disinfection system treats a flow rate of 1m^3/hour, a minimum of 4 hours is required, having assumed 7 hours of system operation in case of some reason the system is in operation for a longer period of time. In the year 2016, the cost of energy was 0,1383 €/KWh. Therefore, the annual cost is about 4,00 €.

The monetary amounts spent per year (in water and sanitation) for the civil pavilion with and without the proposed treatment solution are shown in Table 6.

Table 6 - Comparison of costs before and after the installation of the treatment solution

	Cost of water consumed (€/year)	**Cost of sanitation (€/year)**	**Cost of maintenance (€/year)**	**Cost of energy of the UV system (€/year)**	**Total cost (€/year)**
Current system	14 180	12 530	-	-	26 710
System with the proposed treatment solution	11 902	10 302	500	4	22 708

In the following graph, Figure 3, the accumulated costs are presented, considering the investment made to install the treatment solution.

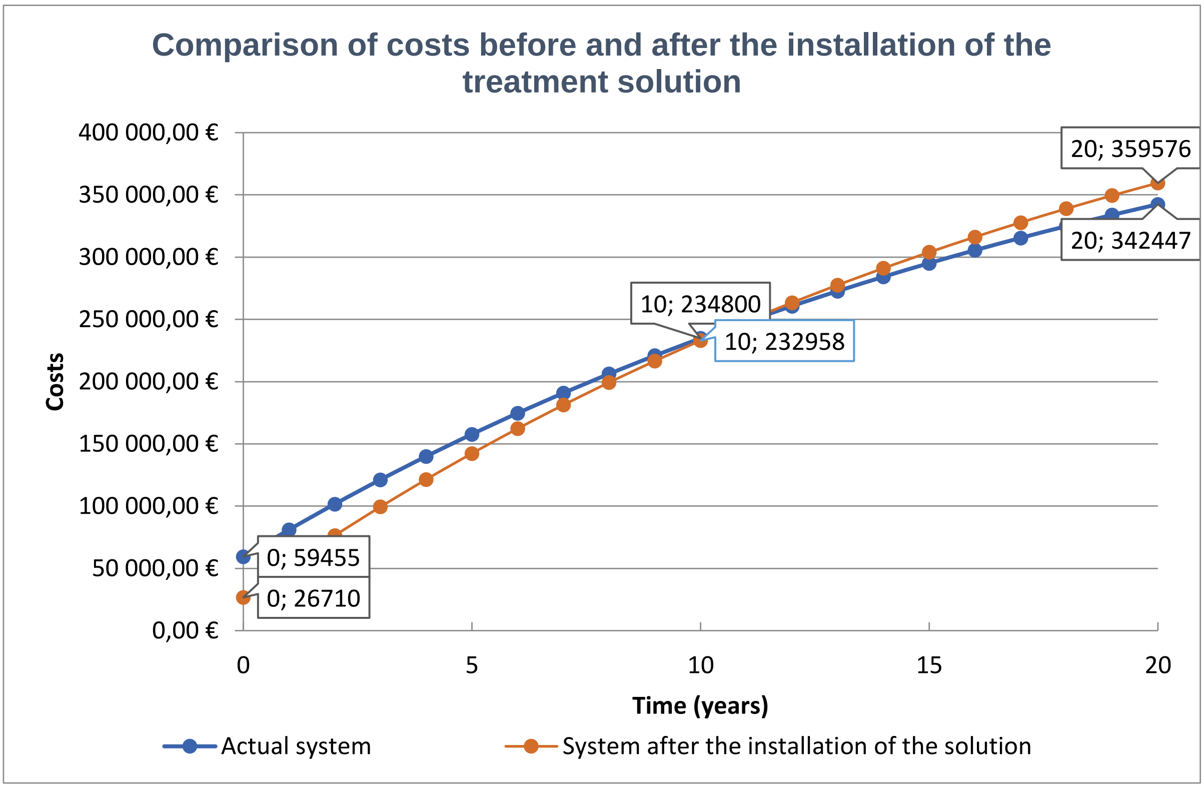

Figure 3 - Comparison of costs before and after the installation of the treatment solution.

As it is possible to observe in Figure 3, the estimated cost for the treatment solution under study was about 37,000 €, so at the end of 11 years, there is a return on the initial investment. This is a viable project, since there is a recovery of invested capital in a period clearly shorter than the estimated lifetime of the treatment solution. Its maintenance costs are low, considering the remaining solutions of wastewater treatment on the market. It should be noted that it has been assumed that the price of water consumption remains constant over the years and has only been updated to the year of implementation of the solution, which may not correspond to the reality given the growing water shortage will increase its price per m^3 over the considered years. However, this hypothesis has the advantage that, consequently, these types of natural solutions with re-use on the spot may become increasingly attractive from an economic and environmental point of view. It should be noted that the consumption of the civil pavilion has been overestimated, which may mean that the green walls are larger than those that would be necessary to treat the grey water produced there. This may allow the initial investment to be lower and the payback period also to decrease, making this treatment solution more attractive.

It is important to say that the consumptions referring to sanitary devices were estimated through information provided by the cleaning team and by bibliography. It is necessary to consider the inherent limitations of this estimate, since only real monthly consumption for the year 2016 was available. Consumption figures would be considerably more reliable if there had been continuous monitoring at the level of each device. However, there were temporal limitations that did not allow this option.

In short, considering the quality and quantity of grey water, it is crucial that they are not treated as waste to be returned to the receiving environment, but rather as a valuable resource after appropriate treatment, which can be reused in floors, for example, as was done in the case study analyzed. The possibility of using treated wastewater as an alternative source, independent from the public supply system, allows the conservation of part of the high-quality water resources that would be used for service purposes.

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