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Adaptation of a single-family residence in the city of Rio de Janeiro, Brazil, for the implementation of ecological sanitation systems (Ecosan)

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Abstract: The importance of basic sanitation infrastructure services is indisputable for human life. The plots in sector 1 of the former Colônia Juliano Moreira, located in Jacarepaguá (Rio de Janeiro/RJ), were occupied in a disorderly fashion and lack the minimum sanitation infrastructure. The aim of this study was to establish guidelines for the design stages of a single-family residential intervention in low-income areas, with a view to the sustainability of the residence through the dissemination of viable ecological sanitation solutions. Based on the following alternatives: simple filtration for water treatment, constructed wetlands associated with a drain for sewage treatment, rainwater collection and construction of a place to separate solid waste and beds for composting organic waste. Schematic drawings and sketches were made of the systems implemented in the residence. Based on the results achieved, it is believed that this is a model of a single-family house that is sustainable in terms of water and solid waste and can be replicated for homes in the aforementioned community.

Key words: ecological sanitation; EcoSan; building systems; sustainable architecture

1 Introduction

The importance of basic sanitation is indisputable for human life. And the lack of adequate sanitation infrastructure is not exclusive to slums or rural areas. Major urban centers have grown in a haphazard manner and contain areas neglected by the government.

In this context, the universalization of basic sanitation remains one of the greatest structural challenges for human and environmental development in Brazil. This deficiency is not restricted to remote areas, manifesting critically in urban centers that have grown in a disorderly manner and under the neglect of public authorities.

Data from the National Sanitation Information System (SINISA) for 2020 show that in Brazil, more than half of the collected sewage is not treated, more than 70% of the collected solid waste is disposed of in dumps or controlled landfills, and less than 5% of the collected stormwater undergoes any type of post-collection treatment [1].

The health threat to residents of Sector 1 of Colônia Juliano Moreira (CJM), in the western zone of the city of Rio de Janeiro, motivated this research. The population residing in this region, currently administered by Fiocruz, originated from land donations to CJM employees in the early 20th century. Since then, there has been no piped water or sewage system in the region. Furthermore, the waste generated by households is collected by the municipal sanitation company (COMLURB) without separation, with organic and inorganic materials sharing the same final disposal site.

Currently, the population uses water from the waterfall in Pedra Branca State Park, which is dammed and monitored by INEA to ensure its potability; despite this, Fiocruz conducts regular outreach with residents to raise awareness of the importance of disinfecting the water before consumption. Sewage is not collected by the state collection network, so residents dispose of this organic material directly into the ground in rudimentary pits. It is known that if done improperly, sewage disposal can pollute the soil, the region's groundwater (rendering this water source unusable), and even the waterfall itself, which supplies residents through percolation through the soil. All these scenarios harm the environment.

Given this reality, this study aims to establish design guidelines for a single-family residential intervention in a low-income neighborhood, using ecological sanitation (EcoSan) as a viable and sustainable alternative. A case study is conducted on Caminho da Cachoeira Street, in the area of the former Colônia Juliano Moreira, in Jacarepaguá, in the city of Rio de Janeiro, Brazil. The research is based on the implementation of water treatment, sewage, rainwater harvesting, and waste management systems, aiming to provide sanitation autonomy and reduce environmental impacts in the region.

2 Theoretical framework

2.1 Ecological sanitation (EcoSan) alternatives

Each new project, regardless of the area, must research the best alternatives within its specific context. In this study, various possibilities were explored in the literature across the four areas of ecological sanitation: water treatment, wastewater treatment, rainwater harvesting and utilization, and solid waste management. Below is an overview of how the selected techniques will function.

2.1.1 Water treatment

Slow sand filtration (SSF) is a very common practice in Brazilian homes and consists of removing impurities from raw, flocculated, or decanted water using porous granular material—usually sand—as a filter medium [2], which may also include a layer of coarse granules (gravel). This technique is highly effective at removing pathogens and organic matter. It is a very inexpensive and easy-to-operate alternative [3].

Figure 1 shows a basic diagram of slow sand filtration: raw water enters the system from the top and, aided by gravity, passes through the filter layers. As mentioned earlier, a Schmutzdecke film forms, creating the first layer of the system, followed by the sand (fine- grained material), and finally the coarse-grained material or gravel.

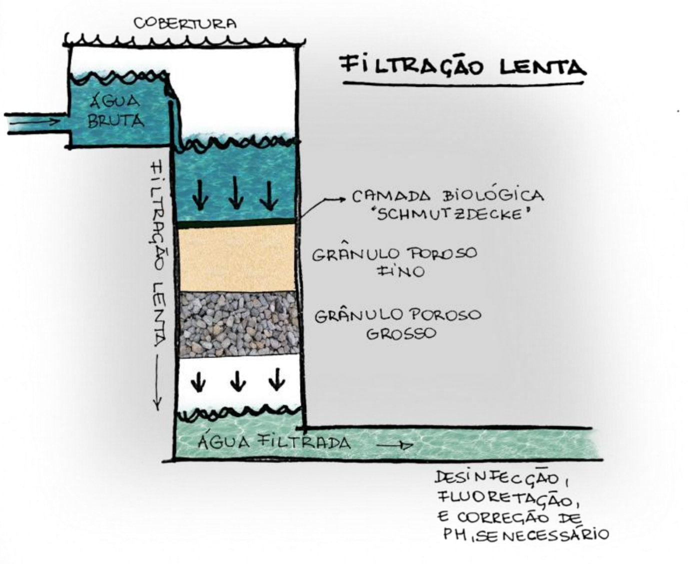

Figure 1. Schematic cross-section of a slow sand filter. Source: the authors, based on SCALIZE, 2020 [4]

2.1.2 Sanitary sewage treatment

The wetlands system consists of ponds, tanks, or shallow, impermeable channels filled with a substrate of gravel and sand and planted with vegetation adapted to regions with saturated soil, known as aquatic macrophytes [5]. The low water level increases the concentration of organic matter, so the vegetation must be resistant to high levels of BOD, nitrogen, phosphorus, and other substances. Macrophytes are capable of adsorbing the organic matter contained in the effluent while simultaneously absorbing these nutrients, as they require abundant mineral salts, phosphorus, and nitrogen from this system [6].

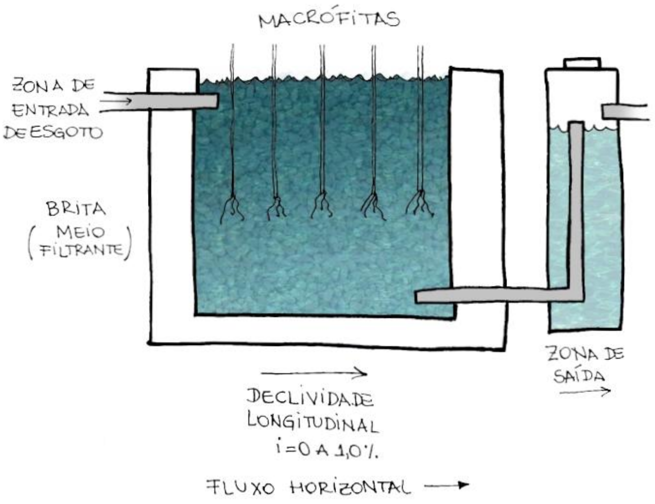

Figure 2. Schematic of constructed horizontal-flow wetlands. Source: the authors (2026)

Horizontal flow structures (Figure 2) consist of a pipe with continuous effluent distribution and an outlet drain to control the water level. Treatment occurs via the biofilm of microorganisms formed on the substrate surface, in the voids, on the roots, and on the rhizomes. There is an 80% to 95% efficiency in BOD removal, in addition to the reduction of nutrients and pathogens [5].

Constructed wetlands have low maintenance costs, low energy consumption, and no mechanical or chemical operations, in addition to being a sustainable and ecological technology, which makes them well-suited for implementation in low-income areas. Brazil's warm subtropical climate also contributes to the productivity and biological activity of macrophytes, enhancing their performance [7].

2.1.3 Solid waste treatment

Recycling is linked to the early days of solid waste management in Brazil, specifically in the late 19th century, when waste pickers were instructed to send bottles, scrap metal, paper, and other materials to factories and facilities where they would be reused [1].

All materials follow similar steps, beginning with the separation and classification of different types of materials (glass, paper, plastic, metals), followed by processing to obtain smaller fractions (shredded materials, for example), and then the sale of these condensed materials obtained from recycling processes so they can ultimately be used and utilized in industrial processes [5]. Process illustrated in Figure 3.

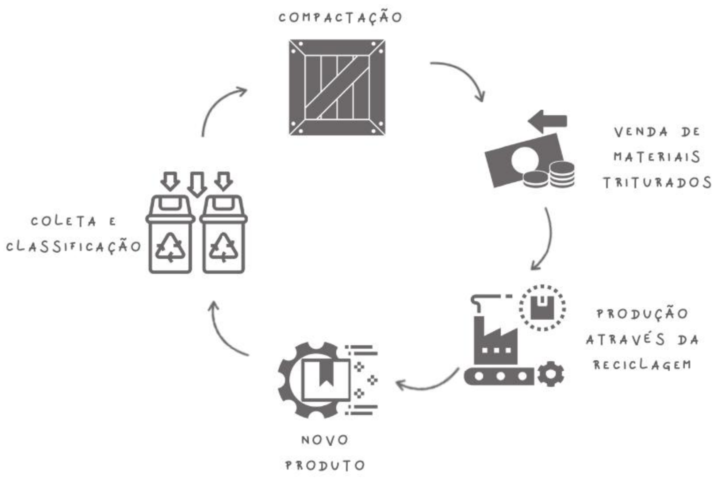

Figure 3. Diagram of the reverse logistics policy for recycling. Source: the authors (2026)

Composting is another waste treatment technique; unlike recycling, it is intended for organic materials and is believed to be the oldest biological system used by humans. However, due to a lack of control, the time required for compost stabilization was longer than necessary. It was not until 1920 that scientific research on the subject began [5].

The process consists of the degradation of organic matter by microorganisms in an aerobic environment (in the presence of oxygen). It is necessary to provide a controlled and favorable environment so that microorganisms can degrade the organic matter and produce a material called organic compost, while also releasing carbon dioxide, water vapor, and heat. It is necessary to measure oxygen, moisture, nutrients, and temperature, as all these parameters can accelerate or slow down the treatment of the waste [1].

2.1.4 Stormwater drainage

Rainwater that runs off lots and roofs is exposed to various contaminants present in the city. Therefore, this water must undergo treatment before being discharged into waterways [1]. In the case of reuse for watering plants and washing floors and cars, high-efficiency treatment is not necessary; filtration of particulate matter alone is sufficient [8].

Water collection from roofs is done via gutters, which channel the water through downspouts to the storage tank. Ideally, the first rainwater should be discarded, as there is a possibility of impurities being retained on the roof. Periodic cleaning is also necessary to remove debris from inside the storage tank [8].

The dimensions of a drainage system are determined based on the volume of water the environment can collect, depending on the intensity of rainfall in the region, and may vary over time due to the accumulation of trash and sediment carried by the rainwater runoff [1]. To trap larger debris such as leaves and branches, screens are placed over the gutter or grates are installed in the downspout; however, this system requires constant maintenance [8].

3 Case study

Located in the Jacarepaguá neighborhood, in the western part of the city of Rio de Janeiro, Brazil, the Colônia Juliano Moreira (CJM), or simply "Colônia," shared similar characteristics with the Jacarepaguá lowlands in terms of its settlement. This entire region was occupied starting in the 16th century by sugarcane and coffee plantations during the colonial period [9].

Currently, the Colônia is divided into sectors with independent administrations. This was the result of an agreement reached between the Federal Heritage Secretariat and the Ministry of Health in December 2000 regarding the division of the Colônia [10].

The Fiocruz Atlantic Forest Campus (CFMA) was established in the Colony in 2003, but since the late 1990s, Fiocruz had already been conducting activities in the region, including research on the production of herbal medicines [11].

Setores	Fonte
01	FIOCRUZ - Sede do Campus Mata Atlântica e Área de Preservação Ambiental
02	Prefeitura da cidade do Rio de Janeiro - Unidades Hospitalares, área para reassentamento e extra hospitalar
03, 3A e 3B	Prefeitura da cidade do Rio de Janeiro - Áreas Habitacionais - Favelas
04 e 4A	Exército Brasileiro
05	FUNASA - Fundação Nacional de Saúde - Hospital Hélio Fraga
06	Hospital Hélio Fraga - Fundação Nacional de Saúde

Figure 4. Map of sectorization of the Juliano Moreira Colony. Source: adapted by the authors from Nascimento, 2018

On the border between sectors 1 and 2, there is a concentration of colonial-style houses and the aqueduct listed by IPHAN. Unfortunately, few of these buildings are in good condition, despite being part of the neighborhood's history. Sector 1 encompasses the largest area of the colony and a significant concentration of native Atlantic Forest flora, housing approximately 220 families and covering an area of about 500 hectares. In 2012, the area was undergoing a regularization process [12].

Currently, the population's water supply comes predominantly from artesian wells and the waterfall at Pedra Branca State Park, which is monitored by Fiocruz and Inea. As such, the area is not connected to the municipal urban water supply network or the sewage treatment network. Residents dispose of their wastewater in sumps without any prior treatment. Solid waste is collected by the Municipal Urban Cleaning Company (COMLURB) without being sorted by category; thus, organic and inorganic waste share the same final disposal site.

To contextualize the site, a site survey was conducted. The creation of an illustrative map (Figure 4) was essential for identifying topographical features, key landmarks (such as the Fiocruz Atlantic Forest research center, colonial buildings, and the study site), and watercourses relevant to this study.

Figure 5. Map with photographs taken in the field. Source: the authors (2026)

4 Methodology

The first stage of the work consisted of assessing the feasibility of implementing ecological sanitation principles in a residence in Sector 1 of Colônia Juliano Moreira (CJM), in the western zone of the city of Rio de Janeiro, Brazil. Field research and a survey of the region were conducted.

Subsequently, a literature review was conducted on possible ecological sanitation practices in the four study areas: water and wastewater treatment, stormwater harvesting, and solid waste disposal, with a focus on the case study of this work. The aspects to be considered were the implementation and maintenance costs of each technique so that the resident family could afford them.

Finally, an in-depth site study was conducted to subsequently develop a proposal for intervention in the residence within the aforementioned low-income neighborhood for the implementation of ecological sanitation practices. In this stage, a design was created using AUTOCAD software and preliminary sizing was performed, following current standards where available or based on the literature.

Figura 6. Flowchart of the study methodology. Source: the authors (2026)

5 Results and discussion

First, to begin a project, one must define its subject of study, its characteristics, existing conditions, and the demand. This allows for an evaluation of the most common alternatives for the subject.

On the study site, a family of four resides on Caminho da Cachoeira Street; currently, this residence receives water from the Cachoeira stream, which is preserved by Fiocruz, and sewage is directed to a simple septic tank. Solid waste is collected directly by COMLURB (door-to-door) without distinguishing between dry and wet waste (undifferentiated). The site already has a cistern at the northern end, currently deactivated, and a drain at the lowest elevation near the site entrance.

To the north and northeast of the property, there is dense forest and higher terrain. To the northeast and east, there is a denser concentration of residences. There are no buildings on the lot immediately to the west. The study site covers 630 m², with the residence occupying approximately 150 m², resulting in an undeveloped open area of 481 m². The site has no large impervious areas, only the slab foundation (0.60 m) surrounding the residence, and the outdoor space was utilized for the implementation of ecological sanitation systems.

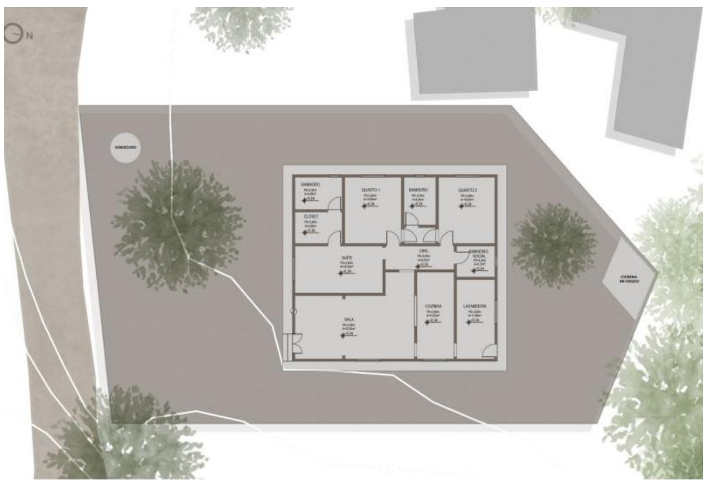

Figure 7. Survey of the existing conditions. Source: the authors (2026)

It is necessary to examine the alternatives available on the market or in the literature to best suit each project. In this case, to prioritize low-cost treatment—as previously recommended by FIOCRUZ—filtration with chlorination disinfection is proposed.

After being transformed into effluent, this waste flows into a septic tank for pretreatment, then to the horizontal-flow constructed wetlands, and finally to the existing soakaway. It is recommended that, prior to the construction phase, an investigation be conducted to verify whether this pre-existing equipment is correctly installed and fully operational.

Sewage treatment consists of a combination of Constructed Wetlands and a soakaway; the first system is responsible for treating the sewage, and the second will discharge the treated effluent into the soil to minimize its impact. Since constructed wetlands consist of a water body with vegetation (macrophytes), they can be integrated with a garden to create a harmonious environment and a beautiful landscape.

For the solid waste management solution, it was proposed to separate waste into inert and organic categories, where organic waste will be sent for composting to generate nutrient-rich soil, and dry waste will be sent to a voluntary collection point.

As for drainage and stormwater management, the solution will involve gutters and downspouts that collect water into the existing cistern; residents can then use this water for garden irrigation, car washing, and cleaning outdoor areas. We also suggest creating a vegetable garden that can be watered with drainage water and fertilized with compost.

Since the site is on a slope, we chose to install the filter (water treatment system) at the northernmost end of the property, adjacent to the existing water inlet. The sewage treatment system, meanwhile, was positioned at the lowest point of the property, near the front boundary and the existing drain.

At this stage, limiting parameters were established based on an understanding of the family's daily routine and their accounts. These conditions assist in the development of the layouts of the next step. They were:

a. Respect for existing structures (cistern and drain);

b. Unobstructed access from the main gate;

c. It would not be possible to carry out internal work in the residence (therefore, no in-depth survey of the internal piping route was conducted).

Several layout studies were conducted, in which the first two proposals featured completely separate sewage and water systems, whereas the latter ones did not. This lack of connection impairs the open spaces within the residence, as it disrupts the spatial logic. Layout 4 was chosen as the starting point for the preliminary study.

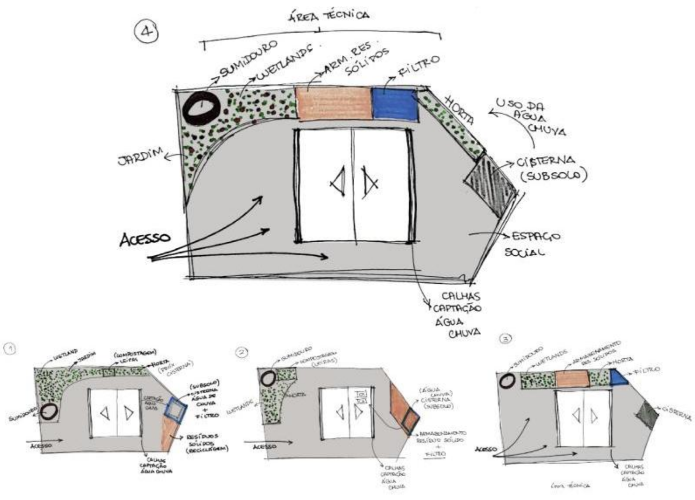

Figure 8. Layout tests. The authors (2026).

Finally, a preliminary positioning of the piping was obtained, respecting the distances and dimensions required by standards. This can be observed in the following floor plans. To implement the subsequent study, it is necessary to assess local conditions during installation, as changes may be required after final sizing.

Based on the preliminary sizing presented in Table 1, all calculations were performed following the references indicated in the same table.

Table 1: Summary of calculation results. Source: the authors (2026)

System	Calculated Dimension	Actual Value Adopted	Bibliographic Reference
Slow Filter	0.58 m²	0.80 m²	[5]
Chlorinator	-	Ø 25mm - 13 cm height	[13]
Grease trap	Small	Small = Ø 30 cm	[14]
Inspection chamber	0.6 x 0.6 x 0.6 m	0.6 x 0.6 x 0.6 m	[14]
Septic tank	2.22 m³	2.40 m³	[15]
Constructed wetlands	-	2.38 x 1.38 m =3.28 m²	[16]
Soakaway	-	Ø 1.50 x 2.00 m	[17]
Cistern	14.89 m³	16.12 m³	[5]
Sand box	0.6 x 0.6 x 0.6 m	0.6 x 0.6 x 0.6 m	[18]
Gutters	100 mm	100 mm	[19]
Vertical conductors	100 mm	100 mm	[19]

In Figures 9, the floor plan shows the proposed interventions in the residence with ecological sanitation alternatives.

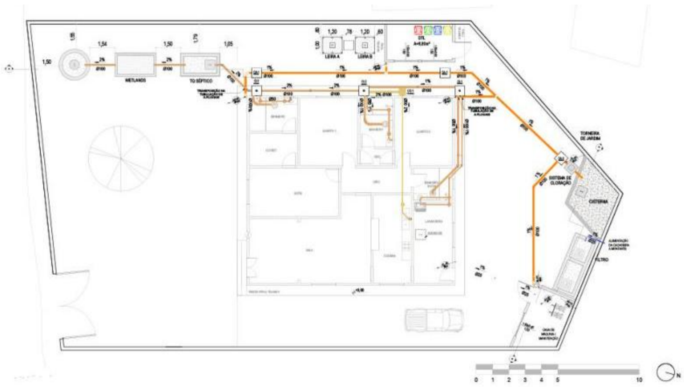

Figure 9. Ground floor plan.Source: the authors (2026)

For water treatment, a slow sand and gravel filter was used to remove coarse particulate matter, combined with chlorination and a household activated carbon filter. This water is pumped to an elevated tank and distributed to the residence for consumption. After use, the effluent proceeds to the domestic sewage treatment system. At the residence's outlet, the sewage is directed to an inspection chamber containing effluent from the bathrooms and laundry room, as well as a grease trap from the kitchen. Both are conveyed through Ø = 100 mm piping to a septic tank for the removal of settleable solid material and to help buffer fluctuations in sewage flow; it then proceeds to the constructed wetland, which aims to remove organic matter from the system. At the end of this stage, the material proceeds to a soakaway.

As for the management of household solid waste, it was proposed to separate inert and non-inert materials, with the former to be stored in a temporary waste storage area (DTL) located outside the residence, equipped with appropriate bins for sorting this material. On the other hand, non-inert waste should be stored in bins and directed to compost piles, which are also located outside. The compost piles produce compost and leachate, both of which can be sold by the residents.

Finally, stormwater drainage will be collected via gutters and collectors, properly sized and routed to sand traps for removal of suspended solids, and subsequently conveyed to the existing cistern. This water can be used by residents for watering plants, cleaning floors and sidewalks, washing vehicles, and other purposes.

6 Conclusion

The research conducted demonstrates that the implementation of decentralized, low-cost systems is a technically and socially viable solution to mitigate the sanitation deficit in low-income areas. Through the established guidelines, it was possible to propose a model for an autonomous residence that integrates slow sand filtration for water treatment, the use of constructed wetlands for domestic effluent, rainwater harvesting, and integrated solid waste management.

The results indicate that the combination of technologies such as septic tanks and horizontal flow wetlands is highly efficient in removing organic matter, adapting to the physical and economic constraints of the case study in Colônia Juliano Moreira. Furthermore, waste management through composting and recycling transforms environmental liabilities into resources (compost and nutrient-rich soil), fostering the circular economy at the household level.

Therefore, it is concluded that the proposed model not only fulfills the objective of establishing design guidelines but also serves as a replicable prototype for other homes in the community, aligning with practices already promoted by Fiocruz Mata Atlântica. For future studies, we recommend continuous monitoring of the biological efficiency of the systems after installation, an assessment of the socioeconomic impact of the water and sanitation autonomy generated for the resident family, as well as studies on economically viable alternatives for implementing the technologies studied.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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