# Design of a compact and modular system for bathroom water waste reduction

**Abstract: Water waste in domestic bathrooms remains a challenge in the context of sustainable water resource management. This study aims to present the conceptual development of a solution designed to reduce water waste in bathrooms, based on user needs and sustainable design principles, contributing to environmentally responsible product innovation. A product development process approach was adopted, involving literature review, market analysis, questionnaires, expert interviews, and the application of tools such as quality function deployment, morphological matrix, the Theory of Inventive Problem Solving, and comparative decision matrices. The process included problem identification, requirement definition, concept generation, and selection. As a result, a compact, modular, and sustainable system was designed, integrating water collection, filtration, storage, and redistribution, along with digital monitoring capabilities. The proposed solution demonstrates potential for reducing water consumption without requiring complex structural renovations, offering practical contributions to environmental sustainability and circular economy practices.**

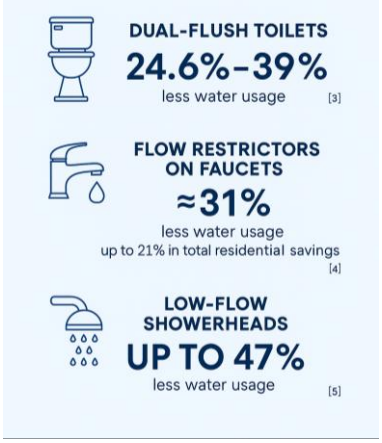
**Keywords: Water efficiency. Water reuse. Product development. Circular economy. Sustainability.**

## 1. Introduction

Water scarcity is one of the major global challenges, driven by population growth, the intensification of productive activities, and unsustainable consumption patterns. In the domestic setting, bathrooms account for a significant portion of water usage, particularly due to the use of toilets and showers, which are responsible for a large share of the daily demand for potable water. In Brazil, residential per capita water consumption ranges from 89 to 209 liters per day, highlighting the urgency of implementing strategies to reduce this usage and promote more efficient utilization of water resources [1,2].

In this context, sanitary technologies aimed at reducing waste are essential. Replacing conventional fixtures with water-saving devices can lead to significant reductions in consumption. Studies have shown that dual-flush toilets can reduce water usage by between 24.6% and 39% [3]; flow restrictors on faucets by approximately 31%, potentially accounting for up to 21% in total residential savings [4]; and low-flow showerheads can achieve up to 47% savings in that category [5], as illustrated in Figure 1.

**Figure 1.** Statistics on water conservation from upgraded fixtures.




This issue is directly aligned with the United Nations Sustainable Development Goal (SDG) 6 — “Ensure availability and sustainable management of water and sanitation for all” —

emphasizing the importance of solutions that promote efficient water use and waste reduction [6,7]. The adoption of efficient technologies in bathrooms contributes both to water conservation and to equitable access to quality water services.

In this regard, the present article aims to present the conceptual development of a solution designed to reduce water waste in bathrooms, based on user needs and sustainable design principles. The study encompasses the initial stages of the product development process, including problem identification, market analysis, requirements definition, and concept generation, with the goal of creating innovative solutions that enhance water use efficiency in sanitary environments.

## 2. Methodology

This research adopted an integrated product development process (PDP). This process start with an exploratory investigation based on scientific literature, patent records, and market solution analysis, with the objective of mapping technological gaps, identifying innovation opportunities, and understanding the challenges related to water consumption and waste. Based on this analysis, the Problem-System was defined, structuring the critical elements of the product's life cycle and their interactions with stakeholders, with a focus on end users (e.g., Figure 2).

**Figure 2.** Methodological Flowchart

**ETAPA 01 - INFORMATIONAL**
- Analyze product life cycle
- Identify project customers
- Identify customer needs
- Define product and project requirements
- Perform analysis of customer needs and project requirements
- Define product specifications

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**ETAPA 02 - CONCEPTUAL**
- Define global function
- Synthesize functional model
- Develop morphological matrix
- Apply inventive problem-solving techniques
- Select concept solution
- Develop preliminary layout

## 3. Results and discussion

The results obtained from the development of the solution for reducing water waste in bathrooms are presented in this section, organized according to the main stages of product design and analysis. These results support the creation of a sustainable, functional, and market-oriented solution.

### 3.1. Problem-System

The analysis of water waste in bathrooms revealed that it results both from users' inappropriate behaviors and the lack of technologies that encourage rational use. It constitutes a complex system, with interconnected flows of inputs, energy, waste, and signaling.

The problem-system illustrates how flows of matter, energy, and information contribute to waste. Inputs include potable water and hygiene products, as well as electricity used by pumps and heaters. Consequently, the system generates wastewater and dissipated energy through the use of showers, faucets, and toilets. The model also highlights the importance of signals — such as flow sensors and educational campaigns — in promoting behavior change. Water efficiency depends on the interaction between users (residential or commercial) and the supply and sanitation systems.

### 3.2. Product Life Cycle

Mapping the product life cycle and identifying key stakeholders at each stage are essential for defining market strategies, managing costs efficiently, and fostering continuous innovation — key elements for ensuring competitiveness and sustainability. This approach also guides strategic decisions and enhances adaptability to market and environmental changes [8] [9].

The product life cycle was comprehensively analyzed, from demand identification to disposal or recycling. This allowed for the mapping of stakeholders involved in each phase and their specific needs, ensuring a solution that is both technically and commercially viable.

The phases were grouped into three macro categories: internal (development, engineering, and production), intermediate (distribution, sales, and installation), and external (use, maintenance, and disposal). Two priority groups were highlighted through field research: end consumers and installation/maintenance professionals, whose contributions were crucial for identifying customer needs, later translated into product requirements.

### 3.3. Similar Products and Patents

Market analysis revealed a range of solutions aimed at saving water in bathrooms, including efficient faucets and showers, low-consumption flush systems, water reuse technologies, and smart devices [10–16]. A search in national and international patent databases identified 12 relevant patents [17–28], 7 of which are directly related to water reuse. Despite the existence of segmented solutions, there remains room for a more comprehensive and accessible product that integrates reuse, control, and monitoring functions in an adaptable way.

### 3.4. Identification of Customer Needs

Following the identification of the product's main customer segments, a field study was conducted via an online questionnaire to gather information on their needs. Among the most frequently mentioned were: the importance of avoiding water waste; ease of installation and use; low acquisition and maintenance costs; easy maintenance; and adaptable application, with a preference for products suited to different types of bathrooms. Participants also emphasized the need for real-time feedback on bathroom water consumption.

### 3.5. Quality Function Deployment (QFD)

The QFD, or House of Quality, aims to align customer expectations with the product's technical requirements through a systematic approach. The process began by converting customer needs, collected through questionnaires, into technical requirements. Their correlations were rated on a scale from 0 (no relation) to 8 (strong).

**Figure 3.** Quality Function Deployment – QFD

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Maintenance Time | | |
| | | | | | | | | | | Acquisition Cost | | 0 |
| | | | | | | | | | | Maintenance Cost | 1 | 2 |
| | | | | | | | | | | Consumption Monitoring | -1 | -1 | -1 |
| | | | | | | | | | | Installation Time | -1 | 1 | 0 | 1 |
| | | | | | | | | | | Installation Cost | 2 | -1 | 1 | 2 | 0 |
| | | | | | | | | | | Operation Steps | 1 | 1 | -1 | 2 | 2 | 2 |
| | | | | | | | | | | Reused Water Rate | -1 | 0 | 0 | 1 | 0 | -1 | 0 |
| | | | | | | | | | | Product Volume | 0 | 1 | 2 | 2 | 0 | 2 | 2 | 2 |
| | | | | | | | | | | er Consumption | 0 | 2 | -1 | 0 | 0 | 2 | 0 | 0 | 0 |
| # | Client Weight | Client Evaluation Score | Water Consumption | Product Volume | Reused Water Rate | Operation Steps | Installation Cost | Installation Time | Consumption Monitoring | Maintenance Cost | Acquisition Cost | Maintenance Time |
| | | | Liters | Cubic Meter | % | # | Reais (BRL) | Hours | # | Reais (BRL) | Hours | Reais (BRL) |
| | | | ⬇ | ⬇ | ⬆ | ⬇ | ⬇ | ⬇ | | ⬇ | ⬇ | ⬇ |
| N1 | 1 | 9 | 8 | 0 | 8 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| N2 | 1 | 6 | 0 | 8 | 0 | 0 | 8 | 8 | 2 | 0 | 4 | 0 |
| N3 | 1 | 6 | 0 | 2 | 0 | 8 | 0 | 0 | 2 | 0 | 0 | 0 |
| N4 | 1 | 3 | 2 | 0 | 8 | 0 | 0 | 0 | 8 | 0 | 2 | 0 |
| N5 | 1 | 3 | 0 | 2 | 0 | 4 | 0 | 4 | 0 | 2 | 0 | 2 |
| N6 | 1 | 3 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 0 | 8 |
| N7 | 1 | 9 | 0 | 4 | 0 | 2 | 8 | 0 | 4 | 0 | 8 | 0 |
| N8 | 1 | 9 | 0 | 8 | 0 | 4 | 0 | 0 | 4 | 8 | 0 | 8 |
| | | | Requirements Importance Ranking | | | | | | | | | |
| | | | 78 | 174 | 96 | 126 | 120 | 60 | 156 | 90 | 102 | 102 |

**Figure 4.** Quality Function Deployment – QFD (Benchmarking)

| # | Efficient Faucet - Lorenzetti | Efficient Showerhead - Exatron | Economic Flush System - Deca | Gray Water Reuse System | QuickStream - Rainwater Harvesting System (Amanco) | Youpin XiaoDa MUJA - Motion Sensor for Existing Faucets | TUYA TECHMON - Water Leak Detector |
|---|---|---|---|---|---|---|---|
| N1 | 4 | 4 | 4 | 4 | 3 | 3 | 4 |
| N2 | 5 | 4 | 4 | 0 | 2 | 5 | 5 |
| N3 | 5 | 5 | 5 | 5 | 3 | 5 | 3 |
| N4 | 0 | 5 | 0 | 0 | 0 | 0 | 0 |
| N5 | 0 | 3 | 2 | 0 | 3 | 5 | 5 |
| N6 | 4 | 4 | 4 | 1 | 2 | 5 | 5 |
| N7 | 3 | 3 | 2 | 0 | 4 | 5 | 5 |
| N8 | 5 | 4 | 2 | 1 | 4 | 5 | 5 |
| | Competitor Ranking | | | | | | |
| | 180 | 189 | 144 | 78 | 144 | 207 | 204 |

The interdependence among the requirements was analyzed in the "roof" of the QFD using a scale from -2 (highly negative) to 2 (highly positive). The development of the matrix was collaborative, involving technical and well-founded discussions to resolve divergences. Figure 3 and Figure 4 present the final structure of the matrix, where N1 corresponds to the need "to avoid water waste," N2 "to be easy to install," N3 "to be easy to use," N4 "to provide consumption feedback," N5 "to be adaptable," N6 "to be easy to maintain," N7 "to have a low acquisition cost," and N8 "to have low maintenance cost." As a result, the ranking of the project requirements was established, with product volume, consumption monitoring, and installation cost standing out as priorities.

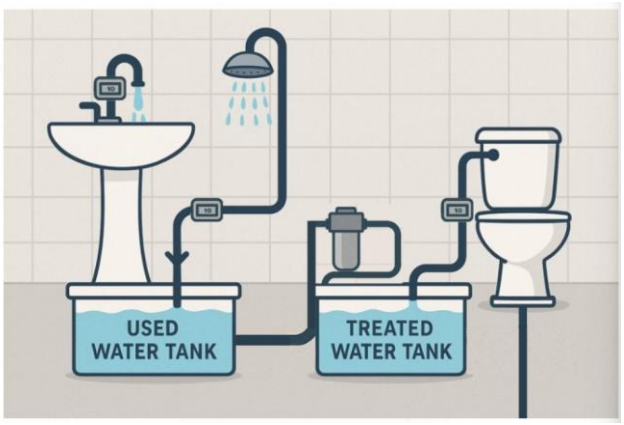
### 3.6. Morphological Matrix and Concept Selection and Detailing

Based on the requirement ranking established through the QFD matrix, a morphological matrix was developed — a tool that enables the systematic combination of different technical solutions for the product's functions. This approach broadens the range of design alternatives and fosters innovation by exploring multiple possibilities for each function.

Using the matrix, six solution proposals were developed, aligned with the guidelines established in the previous stages. Creativity was emphasized to meet technical, functional, and market requirements, as well as user expectations, while also considering operational and economic constraints. The alternatives were evaluated based on criteria such as technical feasibility, cost, functionality, and user adherence, allowing for the selection of the most appropriate option. The final selection resulted from an analytical and collaborative process, culminating in the proposal with the greatest potential for success.

The proposed solution is compact, modular, and sustainable, promoting water reuse in bathrooms with a focus on reducing waste and avoiding structural renovations. The structure comprises four modules — collection, filtration, storage, and redistribution — integrated into the existing hydraulic infrastructure, as illustrated in Figure 5.

**Figure 5.** Conceived solution




Water is collected from the sink and shower, both operated manually using flow-reducing valves. After use, it is directed to an embedded tank equipped with an overflow siphon to prevent spillage. Treatment occurs via a chlorine dosing system, and the treated water is stored in a second reservoir, which supplies the toilet flush tank with automatic level control. The flush mechanism itself remains conventional.

The system includes digital monitoring with flow sensors installed at the sink, shower, and toilet, enabling data logging and remote transmission via wireless network. This functionality facilitates consumption tracking and encourages conscious water use. The proposed solution features easy installation, affordable cost, and strong environmental appeal. It is suitable for both new construction and retrofitting of existing buildings, offering environmental benefits and water savings.

## 4. Conclusion

This study presented the conceptual development of an innovative, compact, and

modular solution aimed at reducing water waste in bathrooms by promoting water reuse and sustainable practices. Through the application of methodologies such as QFD, the morphological matrix, TRIZ, and the Pugh matrix, a decision-making process was structured based on user needs, market demands, and technical constraints.

The proposed solution stands out for its technical feasibility, ease of installation, and potential to enhance water efficiency without requiring complex structural renovations. The combination of functionality, modularity, and smart monitoring represents a valuable contribution to sustainable design, contributing to the mitigation of excessive water consumption impacts.

The results underscore the importance of systematic approaches focused on innovation in the development of sustainable products. For future stages, it is recommended to proceed with prototyping, testing, and field validation to confirm the solution's effectiveness and expand its applicability.

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