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# A MANUAL SUCTION TOILET FOR SEWAGE REDUCTION

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In Ecuador, 46.4% of households lack access to a sewerage system, where as a result much wastewater is discharged from sewerage into the environment untreated. This paper presents the results of a research project aimed at the development of prototypes that retrofit existing toilets into a manual suction ultra-low flush toilet. These prototypes use around one liter of water, and therefore the amount of sewage produced is substantially reduced. The strategy covered two areas. First, the prototype design is developed with the active participation from users using sociological study tools such as workshops, focus groups and interviews, which enabled to polish or re-define design aspects aimed at improving levels of end-user acceptance. Second, dissemination of results and designed products is implemented through web platforms to enable replicability, allowing potential participation from external collaborators. The main approach of this research is to act at a small scale (houses, departments, buildings) in order to amend the amount of metric tons of wastewater within a larger urban scale.

*Keywords*: Water, Wastewater, Sewer, Prototype, DIY, Microcontroller.

## 1 INTRODUCTION

Only 53 Municipalities (from 221 in Ecuador) discard wastewater after a partial treatment as reported by the National Institute of Statistics and Census (INEC 2016). In 2017, Quito city inaugurated its first wastewater treatment plant for the Machangara River. The plant was announced to process the wastewater produced by 75 000 people (IAGUA 2017). Although this treatment plant represents a first step towards a more complex plan for the city rivers recovery, the amount of beneficiaries represents 2.8% of the city population, which reveals the existing facilities as insufficient. In addition to the lack of infrastructure the individual water consumption levels widely exceed the average within the region: while 169 liters are daily consumed per capita, Ecuadorians can use up to 220 liter a day (EPMAPS 2015).

Existing water saving toilets available in the Ecuadorian market tend to be dual flush, using 4.1 liters of water for urine and 6 for solids. There are other existing references on national and international markets that can be implemented as a potential solution: approaches based on incineration, chemical treatments, prototypes based complex vacuum platforms or dry toilets. However, this research recommends a solution that can be implemented on the existing toilets. has an open license and can be replicated and implemented in many other areas. Therefore, the developed prototype will be focused on the user acceptance, accessibility and replicability.

## 2 METHODOLOGY

Methodology is based on iterative prototyping accompanied by sociological tools within each iteration: the project started in May 2014 by establishing basic requirements through focus groups with potential users el Proyecto (Sáez *et al.* 2016). Subsequently, a solution is materialized through a prototype that was proved by potential users. After being evaluated, new information can be gathered to settle further inputs to improve the development of future prototypes. First functional prototypes were delivered by 2016. Prototyping was is particularly useful for concept generation, evaluation, refinement and production as the process can enrich the feedback from clients and users, who can provide a response based on aesthetics, form, interaction, and usability (Martin and Hanington 2012). From 2016, this research has produced 6 prototypes. It is important to mention that through the cyclical process of generating, evaluating them and redesigning prototypes, this research has also produced: eight site visits at houses with dry toilets installed near Quito, twenty-eight semi-structured interviews with potential users of the proposed system, twelve focus groups with end users with earlier versions of the product (Sáez *et al.* 2016). Each iteration for a new prototype was accompanied by a participatory design approach, as the user feedback was fundamental in different stages of research development, in order to define the design aspects towards the needs and the acceptance from users.

## 3 REQUIREMENTS

The analysis of the mentioned research tools used during the iterations has allowed to define three elementary requirements to determine the design of the toilet prototype.

### 3.1 User Acceptance

Analysis of the data collected with potential users suggested to maintain standards of comfort established by the existing bathrooms. Any alternative that involves more effort and less comfort results in lower levels of user acceptance. Interviews showed an almost universal aversion to any interaction with feces and urine deposited in the toilet. Interviews also showed a lack of interest in knowing the final destination of the sewage. In response, the purpose of the project was to work on the existing toilets: the prototype was developed through an intervention of the traditional toilet, which aims to simplify the usage and maintenance avoiding a complex intervention from users with their waste.

### 3.2 Accessibility

An additional objective is to minimize the economic impact of changing the toilet system and, as such, to allow an easy access. In this sense, it was of great importance to take advantage of the existing infrastructure of conventional sanitary facilities. The prototypes were developed under the premise of using inexpensive and easily accessible components in local shops, which could be installed by the end user, or if necessary, with the help of a trained installer.

### 3.3 Replicability

In order to facilitate the transition in the toilet model, the design intends to be replicated and also improved through the direct intervention of users and other enthusiasts interested. Two main approaches were used for dissemination of results and further collaboration to modify those results. First, open participative workshops were offered through which collaborators from different disciplines were brought together. The workshops ended with the construction and implementation of prototypes in four households who had volunteered to have the toilet installed.

Second, the data generated by these workshops gave feedback that facilitated work on web platforms to disseminate the information needed for building and implementing the prototype. At the time of writing of this paper, the research team is editing the construction guides, video tutorials and the code needed to operate the prototype. All the material is developed for a target of "makers". For this reason, the current prototype is registered under a Creative Commons license. Overall, this research will evaluate not only the reproducibility of the project, but also the interventions in the design by enthusiasts involved.

## 4 RESULTS

### 4.1 Prototypes Accessibility

The prototypes were generated in different phases. The first one was focused on the mechanism: A design that generates vacuum through a manual movement was developed. This mechanism replaces the traditional logic of existing toilets where an amount of discharged water must overcome the resistance presented by the water contained in the basin and the siphon with help from gravity and water volume. Instead, vacuum was used to overcome that resistance. The prototypes are built with elements commonly available in general hardware stores: PVC pipes, rubber bands, plastic tubes. The established height of the piston guarantees the necessary suction to drag liquid and solid waste (Figure 1).

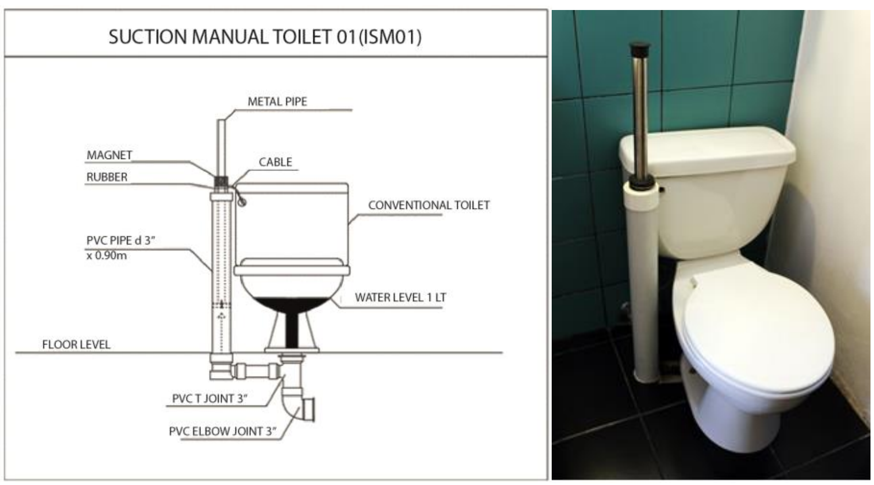


Figure 1. Manual suction toilet prototype. (a) Blueprint, (b) Implementation.

In the second phase of the prototype iteration, the refilling of the needed amount of water for the siphon is solved mechanically. This mechanism allows to the movement of the piston to lift the internal valve of the tank and discharge approximately one liter of water (250 ml for dragging and cleaning and 750 ml for filling the siphon and preventing air leakage). Easily accessible materials were also used. The design was tested in two different buildings, a domestic and a public one. In both scenarios, surveys on users suggest a positive result on acceptance levels, where extremely low water usage was highlighted as one of the most important factors. All interviewed users specified that a prior explanation of the operation of the toilet was necessary, whether it is a verbal indication or through instructions with images, arrows, etc. Despite this, once the user understood how to pull the manual suction flush, they expressed that operation of the piston was very easy to use. However, in particular cases of manipulation there was a blockage at the elevation of the valve of the tank, which produces loss of water. In addition, the implementation of the prototype revealed a potential malfunction due to a possible interaction with steam whenever the toilet was located near showers. In this scenario, the steam produced enough oxidation in some parts of the mechanism that would affect its performance. Therefore, the next iteration of the prototype would have to consider how to overcome the oxidation problem in both private and public scenarios.

Figure 2. (a) Model with micro controller, (b) Servomotor.

For the next phase, the internal valve of the tank was mechanically detached from the piston in order to be controlled by a small servo motor. The aim of this change is to avoid water loss when improper manipulation from the user occurs, as well as recording of data usage (liters of water consumed, number of times the piston is activated and frequency of use). The latest version of the developed prototype includes a micro controller board, which is designed to be used as open hardware (Figure 2a). This micro controller allows a very precise regulation of the entire system and makes the prototype adaptable to diverse range of toilet models. The latest prototype also includes a switch that is activated with the piston movement; also, a small servo that accurately and safely lifts the inner valve of the tank (Figure 2b). Furthermore, a potentiometer allows the user to precisely regulate the amount of water required per discharge (Figure 3a).

A second variation allows the water tank to be replaced by a solenoid valve using the water pressure directly from the pipe system (Figure 3b).

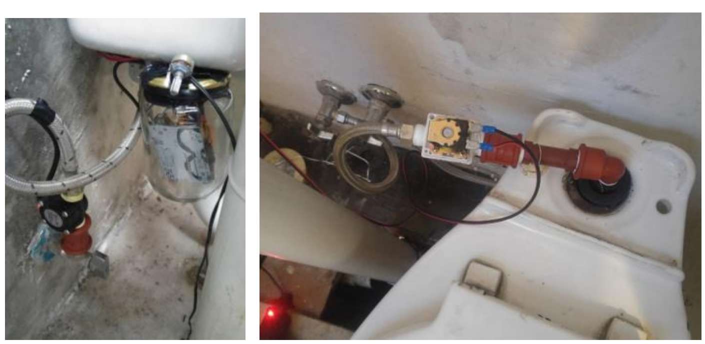

Figure 3. (a) Potentiometer incorporated, (b) Prototype with solenoid valve and no tank.

Regarding replicability, all the electronic elements that are used in the toilet are easy to find in local markets, with elements that are low cost and relatively simple to program. A user without any knowledge about the board would use the micro-controller already programmed to be installed. However, anyone with basic programming knowledge would be able to follow a tutorial for programming the controller. Prototypes with microprocessors are currently being tested with users (Figure 4).

Figure 4. (a) Prototype ISMa.02.4, (b) Prototype ISMa.03.2.

### 4.2 Diffusion

Since a Creative Commons license has been generated (Figure 5), any contributor is legally able to build and modify the existing device and share the new incomes and results from those modifications. The project currently works on the web-based tools that will help to replicate the prototype under the dynamic of “Do It Yourself”, without the need of having a member of this research team.


Figure 5. Creative Commons License segment.

Two videos have been made that are currently available on YouTube. The presented tutorials explain how to assemble the device and also how it works.

## 5 CONCLUSIONS

This research shows that the prototype is capable of reducing domestic sewage drastically. The prototype has shown to save up to 92% of water in the consumption per flush. Consequentially, there could be a responding reduction of the overall produced sewage if the prototype is implemented in different households. Participatory design was used to ensure the acceptance by end users. The prototypes developed so far have demonstrated the possibility of transforming conventional toilets at a low cost and with accessible technologies. The designs use components that are easy to find, including the electronic version, which uses free hardware and software to facilitate its replicability by potential users and other enthusiast willing to collaborate. The Creative Commons license and the publication of manuals and tutorials in digital media allow any user to use the prototypes, as well as the possibility of contributing improvements in the design that give continuity to the iterative process of prototyping.

## 6 RECOMMENDATIONS

The following recommendations are made for the prototype improvement: a) It is recommended to evaluate the durability and maintenance requirements for materials, especially within public contexts, where vandalism must be contemplated; b) there is a need for a graphic system to easily understand how to use the device.

Finally, the following recommendations are made for the system improvement. As the reduction of water usage opens up possibilities in the future to: a) Use rainwater for toilet use; and b) add a domestic micro-bio digester for the treatment of wastewater before its discharge to public sewage systems. This can be a step forward work towards the elimination of domestic wastewater production.

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