Fostering Sustainability on Campus: Design of an IoT-Enabled Smartbottle for Plastic Reduction in the Academic Environment

João Mendes[1], Ana Curralo[1,2(✉)], António Curado[3], and Sérgio I. Lopes[1,4]

[1] ADiT – Instituto Politécnico de Viana do Castelo, 4900-347 Viana do Castelo, Portugal
jmiguelmendes@ipvc.pt, {anacurralo,sil}@estg.ipvc.pt
[2] ID+ – Instituto de Investigação em Design, Media e Cultura, Aveiro, Portugal
[3] Prometheus – Instituto Politécnico de Viana do Castelo, 4900-347 Viana do Castelo, Portugal
acurado@estg.ipvc.pt
[4] IT – Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

Abstract. Public higher education institutions have a particular moral responsibility in increasing the awareness, knowledge, skills and values required to create a fair and sustainable future. Through sustainable design, the Project Refill_H20 aims to eliminate the use of plastic water bottles in the 6 schools of the Polytechnic Institute of Viana do Castelo (IPVC), respective bars, canteens and halls of residence A survey of the academic community will identify the set of physical, aesthetic and functional features to create the product specifications for the Smartbottle and Water Refill Station. ICT and IoT technologies will encourage autonomy, pedagogically helping users to acknowledge, identify and reduce their environmental footprint. Applying the principles of circular economy, this academic project promotes the reduction of plastic consumption, production and waste. Contributing towards a paradigm shift, sustainable design canvasses conditions to reduce plastic in the oceans, improving the environment and the quality of life on Earth.

Keywords: Sustainable design · Smartbottle · IoT · RFID · Sustainability · Campus

1 Introduction

Sustainable development allows meeting the needs of the present without compromising the ability of future generations to meet their needs. This principle combines sustainable design and technological innovation to promote new models of behaviour while producing ecological awareness, action, and economic results. In the intersection between design, technology and sustainability, the tangible target of the "Refill_H20" project is to eliminate the use of plastic water bottles on the IPVC Campus (Polytechnic Institute of Viana do Castelo), a higher education institution aiming to play a leading role in sustainable development.

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The IPVC is a higher education institution that in addition to investing in innovation, research and knowledge, assumes a proactive role in the sustainable development of the Alto Minho region in the north of Portugal. Although often overlooked, higher education institutions play a key role towards sustainability as a whole and specifically in the reduction of plastic waste. Reducing the consumption of plastic water bottles would constitute a change in the consumption habits of the IPVC academy: students; teachers and employees, favouring the reduction of disposable waste, subsequently reducing the energy consumption and greenhouse gases emission from the recycling process.

This article presents a case study on the development of sustainable products through a project approach oriented towards the search for innovation. The study addresses a multidisciplinary methodological approach based on the intersection of complementary tools. Based on the concept of Participatory Design, the bottle as interactive artifact stems from a previously defined methodology [1], including user participation in the design process. The cooperation between sustainable design and technological innovation in the context of Information and Communications Technologies (ICT) and the Internet of Things (IoT) allows developing an interactive Smartbottle that 'communicates' with a water refill station. This is intended to foster more eco-friendly attitudes from users, students, teachers and employees, contributing to a paradigm shift in plastic consumption and waste. The new habits will favour waste reduction, particularly plastic water bottles, on campus and beyond.

The Smartbottle is equipped with a radio frequency identification (RFID) chip, integrated with the refill station management system, enabling an automatic filling process with no physical contact with the equipment, an estimated average amount of water consumption through a mobile application, an estimated amount of averted plastic waste, energy saving from overall waste reduction, reduction of greenhouse gas (GHG) emissions and information on users' environmental footprint.

The search for innovation through sustainable design and new technologies may be profitable and promote systemic changes in the behaviour of individuals. Also, the mitigation of environmental imbalances on campus will have off-campus impact. Design thus offers answers to protect the environment and improve the quality of life.

2 Sustainable Design and Academic Environment

Etymologically, the term sustainable derives from the Latin *sustinere* (hold up, hold upright; furnish with means of support; bear, undergo, endure). Sustainability is the ability of consumers or companies to remain in a given environment without violent damage to that environment. It requires strategies so that resources may be available in the future.

Human activities do not require disrupting the natural recovery cycles of the planet. Also, they don't require weakening the natural heritage of future generations [2]. Sustainability should reach all levels and areas of knowledge, for global unabridged application in contemporary society [3]. Human well-being is a social construct that takes shape over time, considering different factors. The notion has evolved since the industrial revolution, with successive changes following the evolution of society. Although it constitutes a dynamic and articulate set of perspectives, expectations and evaluation criteria, there

is a persistent characteristic: to combine the perception of well-being with an increasing availability of products and services [4]. Therefore, identifying the unsustainable nature of many of the current practices will allow building a more conscious society, economically viable, socially just and ecologically correct, based on deep and complex sustainable approaches [5].

In fact, the principles of several universes, including the academic world, are delayed regarding what happens in the "real" world. This delay subsequently hinders the development of a lifestyle that is consistent with current issues, considering education an interactive process in which the environment changes the student, and the student changes the environment. As such, it is imperative to foster new relationships outside the comfort zone, learning new ways to participate and guide projects, improving citizens' ability to engage in meaningful dialogues about the environment, promoting new rapports between makers and users.

3 The Smartbottle Ecosystem

The Smartbottle Ecosystem was designed to achieve the main goal of the Refill_H2O, an EEA Grants Portugal environmental project [6], that aims to eliminate the use of plastic water bottles on the IPVC Campus, through the design and development of an interactive Smartbottle that 'communicates' with a Smart Water Refill Station to foster more eco-friendly attitudes among local users such as students, teachers and employees, thus contributing to the reduction of plastic consumption in bars, canteens and halls of residence in the IPVC campus. Figure 1 depicts the overall Smartbottle ecosystem, presenting two examples of use of the Smart Water Refill Station.

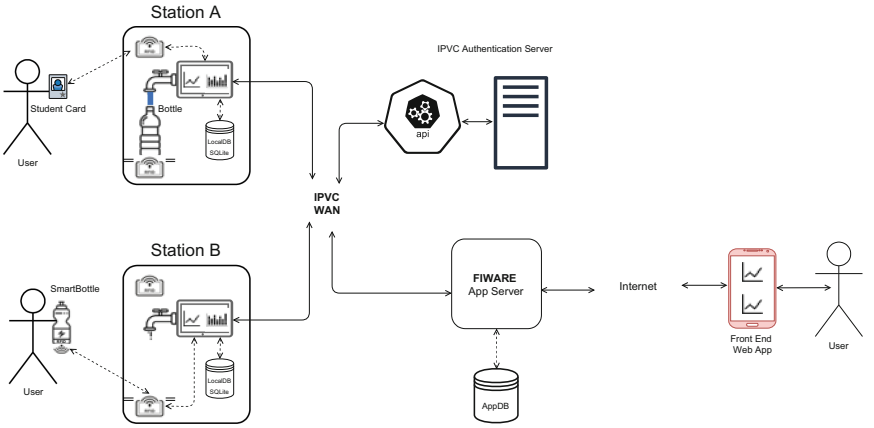

Fig. 1. Smartbottle ecosystem with two smart water refill stations, and core blocks of the ICT infrastructure.

The proposed ecosystem includes five main components: 1) the Smartbottle (interactive artifact); 2) the deployed IoT Edge Devices (Smart Water Refill Station) that communicates with the Smartbottle using RFID technology and the Student ID Card

for user authentication; 3) the IPVC Wide Area Network, i.e. the ICT infrastructure that will perform backhaul communications; 4) the IPVC Authentication Server (that can be accessed in a "as-a-service" approach); 5) the FIWARE Application Server handles all communication between the IoT edge devices, data storage, and the client app through a context broker [7], whose architecture is described in detail in [8].

The Smartbottle is equipped with a radio frequency identification (RFID) chip, that integrates with the Smart Water Refill Station, enabling the following features:

- automatic filling process (no physical contact with the equipment);
- estimated average amount of water consumption through a mobile application (number of refills per time period);
- estimated amount of averted plastic waste (considering different metrics: temporal, cumulative, individual or referring to colleges, classes, etc.);
- energy saving from overall waste reduction and reduction of greenhouse gas (GHG) emissions;
- information on users' environmental footprint.

To use the refill station, the user must provide valid authentication by placing the Smartbottle [1] in the refill station or by placing an ID Card with native RFID technology and placing a conventional water bottle in the refill station.

The client application is based on responsive web technologies with visual analytics tools and dashboard-based technologies such as Grafana, towards a powerful interface to display useful information in a clear, user friendly way. The user interface includes three main functional areas: i) a dashboard that will display relevant metrics (number of refills per time period, estimated average amount of water consumption, estimated amount of averted plastic waste, energy saving from overall waste reduction and reduction of greenhouse gas (GHG) emissions); ii) specific key performance indicators (KPI's) and information on users' environmental footprint; An Authentication Area enables user authentication, allowing the application to change accordingly to the user; and iii) a user and system administration area to support backoffice operations regarding user management and system administration tasks.

This will allow the use of the refill station without a Smartbottle. When using a Smartbottle, the refill station dispenses water until the maximum capacity of the bottle or until the ID Card disconnects from the RFID reader. After disconnection, the station will trigger an event that will store data on a local self-contained transactional light-weight database engine, serverless and featuring zero-configuration, with no setup or administration requirements.

The Smart Water Refill Station features an application for user interface, for real-time display of different metrics and indicators concerning the contribution towards waste reduction, reduction of greenhouse gas (GHG) emissions and other relevant information. Gamification is used to promote user motivation and engagement [9], applying game features to a non-game context. This will allow open competition, selecting who contributes more towards the reduction of the GHG, or who shows healthier behaviours concerning water drinking, and the subsequent advantage is to promote a cleaner and more sustainable campus.

4 Prototype Candidates Design

From a methodological point of view, the Refill_H2O project involved an exhaustive survey at the scale of the IPVC (schools, bars, canteens and halls of residence), to identify the consumption habits of the resident population (students, teachers and staff) concerning plastic water bottles. This early survey is a determining factor in the entire follow-up of the project as it assesses and provides answers for the research questions that arise during the design process, informing and enriching the research conclusion.

In the survey, the resident population was invited to identify a set of physical, aesthetic and functional requirements to allow the identification of design specifications for a new environment-friendly water bottle. The appropriate materials, automatic opening and closing, easy to fill, adequate volume, durability and aesthetic appearance. Subdivided in three stages, the Consumer, the Bottle and the Service, the survey collected data to be used as input for the Smartbottle design and the quality of the future service.

In the first stage, the questions focused directly on the daily water intake of the IPVC population, the preferred locations for regular water collection and the number of bottles purchased weekly at the institution. Subsequently, the survey inquired on the opinion about the bottle, to define essential characteristics for the development of the future product. The questions assessed the bottle volume, factors to take into account in the development of the sustainable bottle, the material and relevant characteristics of the product. Service-oriented questions focused on understanding if the technological factor associated to the bottle and the refill station was appealing to the user, if it should be interconnected with an application and what data to present the user, the price the user would be willing to pay, the payment methods, the type of water, if the product was regarded as useful to reduce plastic in the planet, and if the user would actually be willing to use it.

Through the participation of 536 consumers, it was possible to identify the gender, age group, education level and occupation, predominantly (80%) students. Although a similar percentage of respondents drink water frequently, more than 90% agree it is useful to monitor the daily water intake. Concerning reusable bottles only 412 users declare to have one, corresponding to 10% of the total users. This project targets 5000 consumers. It was also identified that 96.1% of the respondents prefer a reusable bottle instead of a disposable plastic bottle. Concerning size, the preferred capacity was between 0.50 cl and 0.75 cl.

Aspects such as Functionality, Materials and Cost were considered the most significant for the sustainable bottle. Among a variety of environmentally friendly materials, the preferred were Stainless Steel, Recyclable Plastic, Bamboo and Glass. Other selected aspects were easy washing, absence of smell or taste in the water, easy to carry and thermal insulation.

With regard to service, that is, the relationship between the Smartbottle and the filling station, it was possible to understand (Table 1) that users are interested in a system with communication between the machine, the bottle and an application (app), displaying information such as volume of water intake, contribution to overall ecological footprint, and cost comparison.

More than 97% of the respondents consider the refill station & the reusable bottle are an adequate strategy to prevent plastic use in the IPVC community. However, according

Table 1. Important information to be provided by the application (Source: Authors).

1	Amount of water intake	436 (81,3%)
2	Contribution for ecological footprint	335 (62,5%)
3	Comparison of average weekly expense	261 (48,7%)
4	Number of daily refills	258 (48,1%)

to Table 2 below, approximately 85% of the respondents declared they would prefer the new system instead of purchasing disposable bottles provided the school provided a refill source at a low cost. About 90% of the respondents declared they would use the local filling station provided a good drinking water quality.

Table 2. Answers concerning the use of the refill station (Source: Authors).

Questions:	Answers:	Percentage:
If there was a low-cost refill source at school, would you prefer it to purchasing new disposable bottles?	Yes	84.70%
	No	15.30%
Would you use the refill station?	Yes, but only with the guarantee of high-quality water	46.80%
	Yes, however, I want high quality water at a low cost	47.60%
	No. Tap water or bottled water is good enough for me	5.6%

The participation of target users in the process of developing a product that aims to reduce plastic in the oceans allows the designer to understand and assimilate what target consumers think. This is useful to align the constituting features and create a product that will fulfil its function and purpose.

5 Results - Prototypes

The following stage was bottle drawing. To innovate and create an attractive bottle that would simultaneously raise awareness towards endangered marine species, a specific shape of a marine mammal was considered. Although all marine life is in decline due to ocean pollution, in the next 30 to 50 years the Orca may lose more than half of its population due to hazardous substances on seawater. Toxic chemicals weaken the Orca's immune system, affecting its reproductive capacity. Parents may also eventually transmit the pollutants during birth or during the breastfeeding period, causing the species to gradually reduce. Hence, the shape of the bottle was based on the physical and morphological traits of the Orca.

Fig. 2. Prototype A, B and C (Source: Authors).

The cylindrical, aerodynamic body of prototypes A, B and C, inspired by the shape of an Orca, as portrayed in Fig. 2, present curves that constitute an ergonomic handle, facilitating bottle use and transportation. Different raw materials were proposed to meet the survey results. The material for prototype A was recyclable plastic, highlighting the contrasting colours of the Orcas. The stopper of prototype B is made of recyclable plastic and the body of the bottle is in aluminium, and prototype C is entirely in aluminium.

The reliefs in prototypes B and C add friction to the bottle curves. The first relief was inspired by the white spots of the Orca, the second is based on the new brand image of the IPVC campus. The projection at the base is intended to add stability to the bottle when placed on a surface. That will be the place of the technological chip that will communicate with the filling station. All prototypes were designed to include an RFID tag in the bottom for easy interface with the Smart Water Refill Station.

6 Conclusion

The Smartbottle is intended to improve the environmental status of marine waters and coastal areas, by helping to reduce the use of plastics and plastic waste. The Smartbottle & Refill Station system constitutes an awareness raising initiative targeting students, teachers and workers of the IPVC campus. The system design is intended to raise awareness of the negative impact of plastic production on life on the planet.

A hybrid methodology allows designers to prioritize the development stages, focusing on the needs of target users. The inclusion of ICT and IoT technologies enables the creation of an interactive Smartbottle that 'communicates' with a Smart Water Refill Station. A survey of the academic community identified a set of physical, aesthetic and functional features to create the product specifications. Innovation through sustainable design and new technologies may be profitable and promote systemic changes in the behaviour of individuals and their communities. Hence, the mitigation of environmental imbalances on campus is expected to produce off-campus results.

The prototypes will be subject to a usability test performed near the target users, to identify and solve problems, improving product usability. This test will assess the different tasks involved in the Smartbottle use, such as grabbing, drinking, carrying and refilling. Through prototyping and usability testing it is possible to understand the users' performance and relationship with the Smartbottle and Refill Station.

Design projects are able to change the way of life of consumers. As key transformer of society, design is able to develop new social propositions and influence attitudes.

Allied with the axiom that human needs do not include environment degradation, the power to increase social awareness allows designers to improve the world.

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