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Persuasive Technologies for Increasing of Pro-Environmental Behaviors

MASTER DISSERTATION

João Alexis Gordinho Faria
MASTER IN INFORMATICS ENGINEERING

UNIVERSIDADE da MADEIRA
A Nossa Universidade
www.uma.pt

February | 2022

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FCEE

Mestrado em Engenharia Informática

Persuasive Technologies for Increasing of Pro-Environmental Behaviors

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6 de maio de 2022

Abstract

With global warming being contested outside the scientific community, the anthropogenic impact is recognized by the overwhelming carbon dioxide production, which causes acidity to the world's oceans. World nations fail to reach a consensus on mitigating climate change. While there are numerous techniques in aspiring pro-environmental behaviors, one of them is using persuasive interactions and persuasive technologies.

This dissertation seeks to use persuasion to provoke sustainable actions in users using interactive technologies. The dissertation expands the well-known Persuasive Systems Design framework and leverages it further with the Peak Shift Effect (PSE) principle as an artistic experience. The experimental validation procedure of such a novel model is built using interactive Projection Mapping (PM) and, in particular, motion capture. Users are asked to toss litter items into the animated, anthropomorphic bin. The dissertation compares the role of an introduced PSE element and the role of design against interactive design in persuading people to be more pro-environmentally oriented.

Keywords: persuasive technology, persuasive system design, interactive projection mapping, behavior change, motion capture, socio-technical system

Resumo

Com o aquecimento global sendo contestado fora da comunidade científica, o impacto antropogénico é reconhecido pela produção avassaladora de dióxido de carbono, que causa acidez nos oceanos do planeta. As nações mundiais não conseguem chegar a um consenso para mitigar as mudanças climáticas. Embora existam inúmeras técnicas para aspirar a comportamentos pró-ambientais, uma delas é o papel de interações persuasivas e tecnologias persuasivas. Esta dissertação busca utilizar a persuasão como meio de provocar ações sustentáveis nos utilizadores, por meio de tecnologias interativas. Esta dissertação expande a conhecida estrutura Persuasive System Design (PSD) e alavanca-a ainda mais com o princípio do Peak Shift Effect (PSE) como experiência artística. O procedimento de validação experimental de tal modelo é construído usando mapeamento de projeção interativa e, em particular, captura de movimento, onde os utilizadores são solicitados a jogar os itens de lixo no caixote do lixo antropomórfico animado. A dissertação compara o papel do elemento PSE introduzido, bem como o papel do design com o design interativo em persuadir as pessoas a serem mais pró-ambientais.

Keywords: tecnologia persuasiva, design de sistemas persuasivos, mapeamento de projeção interativo, mudança de comportamento, captura de movimento, sistema socio-técnico

Acknowledgements

I want to express my deep gratitude to Professor Dr. Marko Radeta, Professor Dr. Filipe Quintal and Professor Dr. Pedro Campos as my research supervisors for their patient guidance, enthusiastic encouragement, and useful critiques of this research work.

To my mom, who raised me, loved me, and sacrificed everything for me. I would not be the person I am or be in this position if it were not for you. You pushed me to be the best version I can be of myself, and you inspired me with your unwavering strength. You are my mom, dad, best friend, and role model.

To my other half, thank you for always supporting me and giving me the best advice. You made me feel at peace when I was stressed, and you made me feel capable when I did not believe in myself. You are both my propeller and my safety net.

To my dog, Tommy, for loving me unconditionally and for forcing me to have school/life balance, for which I am thankful. Thank you for being the gooddest boy. Finally, I wish to thank the rest of my family and friends for their support and encouragement throughout my studies.

This dissertation is part of the following projects: **INTERWHALE** - Advancing Interactive Technology for Responsible Whale-Watching, with grant no. PTDC/CCI-COM/0450/2020 by FCT; **LARGESCALE** - Location-based Augmented Reality Gadgets and Environment-friendly Sightseeing of Cultural Attractions for Locals and Excursionists, with grant no. PTDC/CCI-CIF/32474 /2017 by FCT and Portuguese National Funds (PIDDAC); **INTERTAGUA** - Interfaces Aquáticas Interativas para Deteção e Visualização da Megafauna Marinha Atlântica e Embarcacoes na Macaronésia usando Marcadores Rádio-transmissores, with grant no. MAC2/1.1.a /385 by Programa de Cooperación INTERREG V-A España-Portugal MAC (Madeira-Azores-Canarias) 2014-2020; Project has been conducted with the support of the Wave Labs[1] - interactive technologies for depicting the anthropogenic impact on the marine biosphere.

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[1] `http://wave-labs.org`

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Listings

Acronyms

BCSS Behavior Change Support Systems. 12

CAVE Cave Automatic Virtual Environment. ix, 21

CPU Central Processing Unit. 20, 36

DC Design Constraint. ix–xiii, 20–22, 25, 42–44, 46–49, 56–66

GUI Graphical User Interface. xvi, 38

HCI Human-Computer Interaction. v, 5–7, 11

HDMI High-Definition Multimedia Interface. x, 20, 23, 24

IDE Integrated Development Environment. 23, 38

LED Light-Emitting Diode. 22

MDF Medium-Density Fiberboard. ix, 20, 21

PM Projection Mapping. ii, 20, 42

PSD Persuasive Systems Design. ii, v, viii, 1, 5–8, 11–13, 15, 17, 18, 20, 42–44, 49–51

PSE Peak Shift Effect. ii, iii, xiii, 1, 5, 10, 11, 20, 40, 42, 43, 46, 48–50

QR Code Quick Response Code. ix, 21

ROI Region of Interest. x, xv, 29, 33, 35, 39

UI User Interface. x–xiii, 18, 25, 36, 40–42, 44, 46–50, 63

URL Uniform Resource Locator. 39

USB Universal Serial Bus. ix, x, 20–24

VR Virtual Reality. 11

VS Code Visual Studio Code. 38

1 Introduction

This dissertation proposes the combination of technology, psychological phenomena, and a well-established persuasion design model capable of promoting pro-environmental behaviors (e.g. reduction of marine littering). In the forthcoming section, motivation for using interactive technologies is described, together with the basic overview of the current Persuasive Systems Design (PSD) [10] model and Peak Shift Effect (PSE) [11]. Moreover, various user state changes are described, allowing the reader to enter into the topic.

1.1 Motivation

Problem statement. In 2016, the Ellen MacArthur Foundation and the World Economic Forum, with analytical support from McKinsey & Company, put out a report that estimates that by 2025, for every 3 tonnes of fish, there will be 1 tonne of plastic, or synthetic organic polymers. By 2050, there will be more plastics in the ocean than fish, by weight [12] with an estimated 1200 metric tons of plastic waste in the natural environment, whether in the sea or land [1].

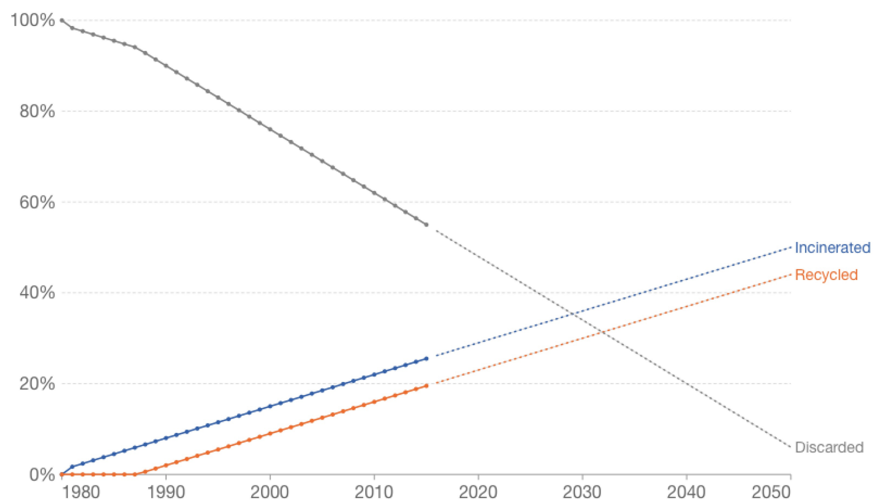

Fig. 1. Estimated global plastic disposal method trends over the last three decades (1980 - 2015) and extrapolation of rates through 2050 [1,2]. Around 2030, incinerated and recycled plastic disposal is estimated to be the same as discarded plastic. Recycling plastic took off at around 1990, where at the same time we see a significant decrease of discarding methods.

The environmental impact of the plastic industry has long outpaced many human-made materials. Up to 2017, the human race produced 8300 million metric tons of virgin plastics [1]. In 2010 alone, 192 coastal countries generated 275 million metric tons of plastic waste, of which 4.8 to 12.7 million tonnes entered the ocean [4]. In Figure 1 we see how much plastic waste has been discarded, recycled, or incinerated since 1980. Plastic recycling and incineration were negligible before 1980, so 100 percent was thrown away. Since 1980, for incineration and 1990 for recycling, there was an average increase of approximately 0.7 percent per year.

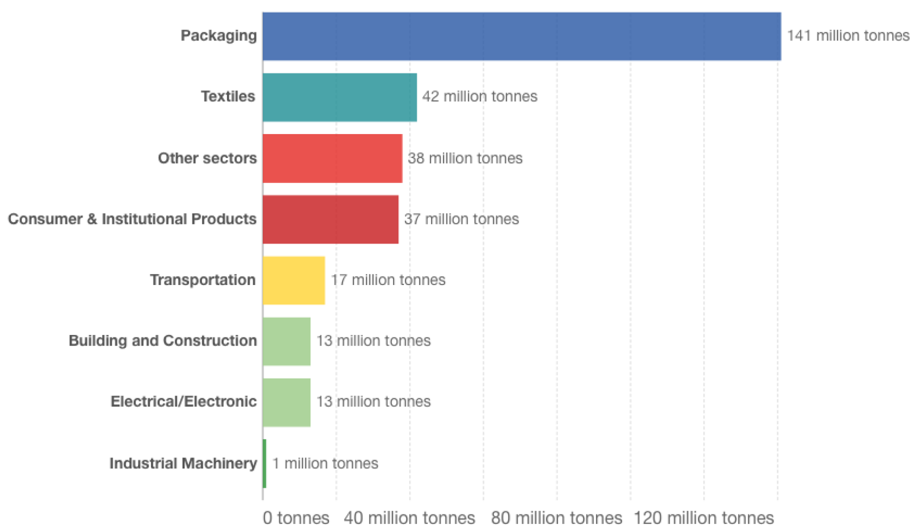

Fig. 2. Tonnes of plastic waste produced worldwide by industry [1,3]. Packaging leads the production of plastic waste, followed by textiles. All other industries combined produce less plastic waste than the packaging industry alone.

In terms of plastic waste generation, it is mainly influenced by the product lifetime of the plastic. For instance, packaging has a short 'in-use lifetime' of around six months or less. Figure 2 shows the various sectors that use primary plastics. In 2015, the primary production of plastics globally reached over 400 million tonnes. Almost half of the global waste was attributed to packaging.

Per capita, plastic waste generation is seen in Figure 3, measured in kilograms per person per day. The analysis shows differences of around an order of magnitude here: the amount of plastic waste generated daily per capita in

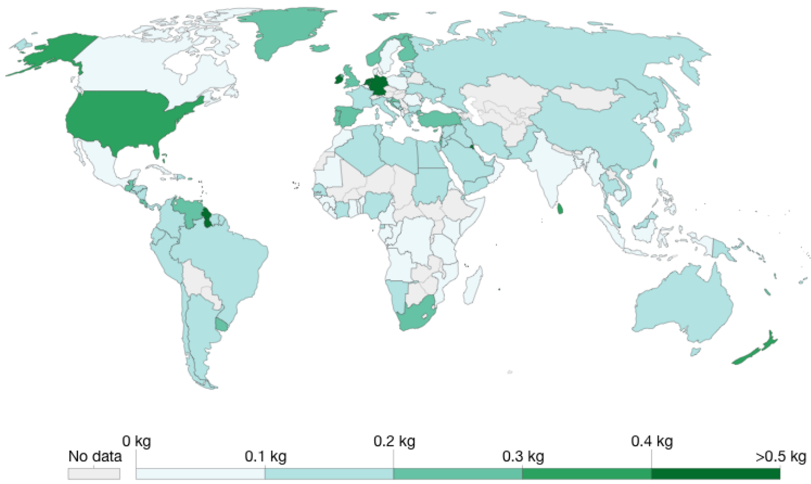

Fig. 3. Daily plastic waste generated per person per day in kilograms, 2010 [4,5]. The predominant plastic waste producers per person reside in the United States of America, Guiana, Ireland, Germany, Kuwait, and New Zealand.

Kuwait, Guyana, Germany, the Netherlands, Ireland, and the United States is more than ten times higher than in many countries, including Kenya, Tanzania, Mozambique, and Bangladesh. Figure 3 provides a total picture of plastic waste production and does not take into account the differences in waste management, recycling, and incineration. Thus, these data do not represent the quantity of plastic that is in danger of entering the ocean or other bodies of water.

However, despite the fact that high-income countries tend to have good waste management infrastructure and so very little waste is improperly disposed of, they can contribute to plastic pollution by littering. Approximately 2 percent of the total plastic waste generated worldwide is littered [4].

It is estimated that about 80 percent of sea plastic comes from land-based sources, while the remaining 20 percent is made up of marine sources [13]. About half of the 20 percent originating from the sea comes from fishing fleets (such as nets, lines, and abandoned vessels), which account for around ten percentage points [14]. In other estimates, marine sources are credited with a slightly higher proportion of ocean plastics, 28 percent [15]. Though the exact amount remains uncertain, marine sources likely contribute between 20 and 30 percent, while land-based sources dominate 70 to 80 percent.

Numerous cases of wildfire and ecosystem damage caused by plastics have been documented since the 1980s. Debris from plastics can negatively impact wildlife through three main pathways [16]:

– Entanglement - Plastic rope, netting [17], and abandoned fishing gear [18] are the most common causes of entanglement. However, entanglement with other plastics such as packaging has also been recorded.

– Ingestion - Ingested plastic can occur unintentionally, deliberately, or indirectly by eating species that also ingested plastic. Ultimately, the amount of ingested material is determined by the organism's size. Fish species larger than a few centimeters in length have been found with plastic films, cigarettes, and food packaging in their digestive system. Sperm whales have been documented to have swallowed large amounts of plastic debris, including nine meters of rope, 4.5 meters of hose, and large amounts of plastic sheeting [19]. When consuming large volumes of debris, stomach capacity is greatly diminished, leading to a lack of appetite and a false sense of satiation [20]. A major concern with microplastics is ingestion.

– Interaction - Abrasion, collision, obstruction, or use as a substrate are harmful interactions with wildlife. Fishing gear, for instance, has been shown to cause coral reef ecosystems to abrade and be damaged when colliding with them. Plastics can also impact the structure of ecosystems upon the interaction between substrate and plastics (impacting light penetration, organic matter availability, and oxygen exchange).

For the health of humans, it is the smallest particles - micro- and nano-sized particles that can be consumed - that are the greatest threat. Particles of plastic can be ingested through water, ingested through marine products containing microplastics, ingested through the skin via cosmetics, or even inhaled as they pass through the air [21].

Technology for aspiring pro-environmental actions. While there are efforts to clean the oceans, such remains with expensive and slow means. In contrast, a potential solution may be to use interactive technologies in education and aspiring pro-environmental behavior. Throughout the forthcoming literature review, it will be asserted that interactive technologies are widely used for numerous kinds of purposes. However, they lack in persuading people to become more environmentally friendly, i.e., avoid littering. While several taxonomies are

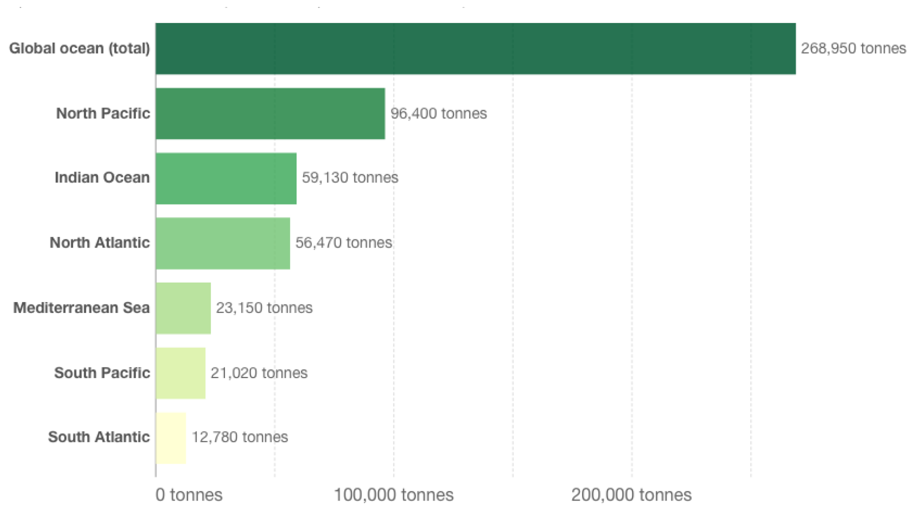

Fig. 4. The amount of plastic waste floating at the surface of the oceans, 2013 [6,7]. The north Pacific ocean is the bigger container for floating plastic waste, followed by the Indian Ocean and the North Atlantic ocean. The southern oceans have the least floating plastic waste at the surface.

proposed for persuasive systems, such as the 40 strategies of Fogg [22], Cialdini's six principles of persuasion [23] and the PSD model [10], the proposed dissertation focuses on the latter most. PSD was envisioned by Oinas-Kukkonen & Harjumaa in 2009 as the adequate computer-mediated persuasion, which will be challenged throughout the dissertation as a base model for interactive computer-mediated persuasion, expanded to pro-environmental engagement.

1.2 Objectives

The five core objectives of this dissertation are:

1. Analysis and critical interpretation of existing PSD model
2. Literature review of PSD applied in HCI
3. Proposed design of a novel model with PSE
4. Verification of the proposed model in the experiment
5. Further discussion on obtained results and report findings

1.3 Research Questions

More specifically, this dissertation will perform an experiment to test and validate the proposed model built on PSD. Research questions will assess:

- **[RQ1].** How can a current widely adopted PSD model create persuasive actions for the greater audience to produce less litter?
- **[RQ2].** What is the role of technology against traditional design when persuading the audience to produce less litter?

In this study, the proposed technology will be based on projection mapping. The audience participates in an augmented litter-bin experiment in which the bin reacts accordingly to whether the user litters or correctly puts the litter inside the bin.

1.4 Document Structure

The introduction (Section 1) raised the issue of anthropogenic pollution, suggesting a need for more means to address it and proposing the usage of interactive technologies. Related work (Section 2) further will depict the current usage of PSD model in HCI, capable in aspiring pro-environmental actions. Section 3 will propose a novel system based on gestural interaction and projection mapping, including a validation method for quantifying pro-environmental actions. Section 4 depicts the obtained results for in-between group experiments, using the pro-environmental installation, discussing the findings. Section 5 provides the conclusions and overall dissertation contribution. The remainder of the dissertation (Section 6) also showcases the obtained individual results from a carried out pilot study with 20 participants.

2 Related Work

This section reports on the general usage of PSD in HCI while outlining some of the current state-of-the-art interfaces available on the market.

2.1 On Persuasive System Design

Below are presented the terms of persuasion, PSD, persuasive changes, and their usage in the HCI literature.

2.1.1 Persuasion

Persuasion can be understood as influencing a person's free will to achieve a target behavior or attitude without being coercive or deceptive [10]. According to Simons, persuasion is:

> "Human communication designed to influence the independent judgments and actions of others. Persuasion is a form of attempted influence because it seeks to alter the way others think, feel, or act, but it differs from other forms of influence. It is not the iron hand of torture, the stick-up, or other such forms of coercion. Nor, in its purest sense, is it the exchange of money or other such material inducements for actions performed by the person being influenced. Nor is it pressure to conform to the group or the authority of the powerful" [24].

Although computers do not have their own intentions, it is possible to perform computer-human persuasion, which may persuade the user on the creator's behalf.

2.1.2 Why Persuasive System Design?

Our choice in the PSD model is based on the fact that other models, such as Cialdini's six principles of persuasion and Fogg's 40 strategies, seem to be more directed at human-to-human persuasion. At the same time, PSD was created to be a solution for computer-to-human persuasion.

2.1.3 Types of Change

One of the most critical goals to define for a persuasive system is the type of change, in particular, whether we want to change the user's attitude, behavior, or both. Attitude change occurs when a person changes its evaluation from one value to another [10]. The cognitive consistency theory suggests that behavior change should come first, then hopefully, attitude change. Also, it is easier to study behavioral change than attitude change because the latter happens in the long term.

This particular PSD model has been widely used in the literature, and it provides a phased analysis of the development of persuasive systems. Their twenty-eight design principles for persuasive systems are organized into four categories: primary task, dialogue, system credibility, and social support. Hereinafter, main categories and strategies are depicted, bridging the reader more into the topic.

2.1.3.1 Primary task

These task design principles are reduction, tunneling, tailoring, personalization, self-monitoring, simulation, and rehearsal. The *reduction* principle states that the system should reduce complex behavior into more straightforward tasks. *Tunneling* is using the system to guide the user's experience through the process. *Tailoring* means providing information that is tailored to the users' circumstances, needs, interests, etc. *Personalization* is offering a system in which its content or services are personalized. *Self-monitoring* is keeping track of the users' performance or status. *Simulation* is essential for providing feedback on the users' actions, enabling them to establish the link between cause and effect. *Rehearsal* allows users to rehearse a target behavior [10].

2.1.3.2 Dialogue

This category provides a degree of feedback that helps users perform their tasks. The design principles are praise, rewards, reminders, suggestion, similarity, linking, and social role. The *praise* strategy provides recognition to provide feedback based on the users' behaviors. The system should also offer *rewards* to the users that perform the target behavior. During the experience, the system should *remind* the user of their target behavior. *Suggestions* that are appropriate to the target behavior will be more persuasive. *Similarity* is essential for persuasive technologies because it reminds the users of themselves. Likewise, *liking* is building a visually attractive system. Finally, a persuasive system should adopt a *social role* [10].

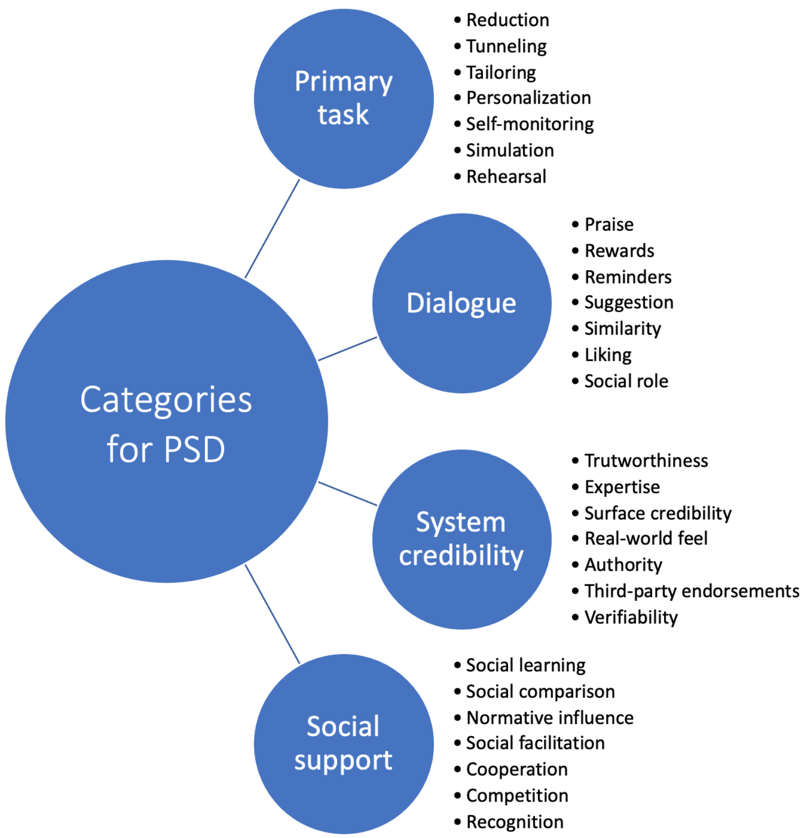

Fig. 5. Categories for Persuasive System Principles: Primary task, dialogue, system credibility, and social support. Each category comprises several design principles describing the best techniques to improve persuasion.

2.1.3.3 System credibility

Conversely, the design principles that help design a more credible and persuasive system are trustworthiness, expertise, surface credibility, real-world feel, authority, third-party endorsements, and verifiability. *Trustworthiness* is providing trustworthy information. *Expertise* is having information that incorporates competence and experience. *Surface credibility* provides a look and feel that transmits credibility on a firsthand inspection. *Real-world feel* means presenting information about the organization and/or people responsible for the system. The *Authority* strategy refers to people who hold roles of authority in the field of the scope of action of the system. Similarly, *Third-party endorsements* from respected sources bring the perception of credibility to the system. *Verifiability* is essential to verify the content accuracy and confirm the perception of the credibility of the system [10].

2.1.3.4 Social support

The design principles that leverage social influence and motivate users are social learning, social comparison, normative influence, social facilitation, cooperation, competition, and recognition. *Social learning* encourages users to achieve the target behavior by observing others do the same. *Social comparison* allows users to compare their performance with the performance of others. *Normative influence* leverages peer pressure to influence the user to adopt the target behavior. *Social facilitation* lets the user know via the system that others are performing the same task along with them. The *Cooperation* and *Competition* design strategies leverage the innate drive of humans to cooperate and compete, motivating them to achieve the target behavior. *Recognition*, in particular public recognition, increases the odds of the user performing the target behavior [10].

This model could be further enhanced by applying the PSE proposed by Ramachandran and Hirstein [11]. The PSE is a psychological phenomenon where the exaggeration of particular visual elements is perceived as more stimulating than its standard form. By giving them treats, rats were trained to think that rectangles are better than squares, and eventually, they learned to choose the rectangle. When the shape of the rectangle was exaggerated, making it taller and narrower, the rats chose it more frequently, suggesting that they learned *'rectangularity'* instead of learning the first prototype itself. When a cartoonist produces a face caricature, they will start with the common features and exaggerate the differences to characterize the face in the same way that a taller and narrower rectangle is an exaggeration of the original prototype. Similarly, such accentuation can be found in many sculptures of female bodies that stress curves. This relates to our pattern recognition and aesthetic inclination. This dissertation aims to apply PSE to the PSD model to determine if it increases persuasiveness.

2.2 Usage of PSD in HCI for Pro-Environmental Behaviors

Persuasive technology is used throughout HCI, but in this section, we will focus on persuasive technology for sustainability, particularly those who take advantage of the PSD model.

Suruliraj *et al.* (2020) provided a methodical review of 125 apps designed for waste management to find the persuasive strategies employed, how they operationalize and test if there is a correlation between the number of persuasive strategies and the effectiveness to persuade users to achieve the desired target behavior. They found that *reduction, personalization, tailoring, self-monitoring*, and *rehearsal*, in decreasing order, were the most common strategies found. However, the authors did not find a correlation between the number of strategies and the apps' effectiveness [25].

Similarly, using the PSD model, Samarasinghe *et al.* (2020) sought to promote residential earth buildings in New Zealand, where they are not common, using VR as persuasive technology. This allowed the users to make a model of a sustainable earth building with earth walls, dry toilet, solar panels, rainwater harvesting tank, etc. and showcased it at Auckland Build Expo in 2018 [26].

Mustaquim & Nyström (2014) proposed design principles specifically for PSD for sustainability and a cognitive dissonance model that shows how those principles can persuade. The authors showed how PSD could achieve sustainability by reducing individual dissonance towards changing the target behavior [27]. In another study, the authors proposed a personalized system development lifecycle (SDLC) for persuasive design toward sustainability [28].

Nkwo *et al.* (2018) took advantage of only three strategies from PSD, social learning, social comparison, and recognition, to encourage university students living in dormitories to change their behavior and adopt a more pro-environmental behavior [29]. In 2019, Nkwo sought to learn what social strategies can be used in developing African nations to promote such behavior, being provisions of separate waste bags, waste bins at strategic locations, public recognition to citizens that achieve the target behavior, etc. The author then mapped these social strategies to their matching techniques in PSD that can be translated into a mobile PT for waste management [30].

Nyström (2017) argues that persuasive technology can be gamified to promote sustainability and warns us about the Jevons paradox that stipulates that when people adopt more resource-efficient technologies, the same individuals can, in the long term, end up consuming more resources [31].

Sunio & Schmöcker (2016) wrote about using PT to promote sustainable travel behavior. Evaluating current Behavior Change Support Systems, the authors found missing several crucial features for travel behavior change, such as tunneling, rehearsal, cooperation, and social facilitation [32].

In 2016, Cingolani *et al.* evaluated the success of persuasive messages and demonstrative messages in reducing littering on river beaches in Argentina. They found that the combination of a personalized request with the example of picking up litter effectively reduced littering, reducing an average of 35% [33].

Karpinska-Krakowiak *et al.* (2020) discovered that negatively framed messages have more persuasive power in prompting pro-environmental intentions such as waste reduction, but only when coupled with anthropomorphic cues [34].

Shevchuk & Oinas-Kukkonen (2020) studied how the PSD model could contribute to Green information systems (IS). The authors found that the PSD model has a high potential for becoming a tool for Green IS improvement from reviewed studies [35].

Tam (2014) studied the effectiveness of anthropomorphic persuasive appeals. The author found that anthropomorphic messages, relative to non-anthropomorphic ones, motivate more conservation behavior and elicit more favorable responses among recipients who have a strong need for effecting or social connection [36]. Similarly, using a persuasive human-like conversational agent, in a 2x2 experiment with 225 participants, Diederich *et al.* (2019) discovered empirical support for the influence of persuasive design elements on individual environmental beliefs. They found that anthropomorphic design can contribute to expanding the persuasiveness of artifacts [37].

Most of the literature remains limited to user interfaces that aspire to pro-environmental changes. The dissertation contributes by expanding further practical and low-cost system, allowing scholars to measure the effect of the UI elements on the pro-environmental actions.

2.3 Current Persuasive interfaces

In the upcoming subsection, some existing interfaces are depicted as part of a wider literature review, which tackles pro-environmental actions and are used as persuasive technologies.

2.3.1 Apple Watch Activity app

Although more related to health, the activity app on the Apple Watch can be considered an interface that aspires to pro-environmental actions. As depicted in Figure 6, it is composed of three rings: Move, exercise, and stand. The goal is to close all rings by the end of the day.

Fig. 6. Apple Watch Activity app is an excellent example of a persuasive system, in particular, to achieve a healthier lifestyle by increasing daily activity such as steps and fitness with complete workouts.

It sends smart notifications encouraging the users to stand at least 1 minute each hour or move or exercise with positive, cheerful messages such as "there is still time to close your rings today. You can do it!". It uses many principles from PSD such as:

– **Primary task**

- **Reduction**: The app reduces effort in all capacities, such as showing a list of common exercises;
- **Self-monitoring**: The user can keep track of their performance such as distance walked, calories lost, heart rate, minutes of exercise, hours standing, number of steps, number of flights of stairs climbed, etc.;

  - **Tailoring** The app lets the user choose their goals.

- **Dialogue**

  - **Praise**: Whenever a ring is closed, the app shows a satisfying animation of celebration;

  - **Rewards**: The app gifts digital awards whenever the user achieves a goal;

  - **Reminders**: Along the day, the app reminds the user to stand or that it is still possible to close the rings;

  - **Suggestion**: Appropriate suggestions are provided, such as walking and running more at a higher pace to increase cardio-fitness;

  - **Liking**: The app is visually attractive with a dark background and bright colors.

- **System credibility**

  - **Trustworthiness**: The app provides unbiased and trustworthy information;

  - **Expertise**: The iPhone app is equipped with helpful information about several health aspects such as cardio fitness, benefits of sleep, and others;

  - **Surface credibility**: At a glance, it is possible to understand that the system is credible. It is free, and there are no ads.

  - **Authority**: Apple in itself is a source of authority.

- **Social support**

  - **Social learning**: Users can see their friends daily activity such as calories burnt, number of steps, distance walked, among others;

  - **Social comparison**: Using their friends' daily activity, users can compare their own activity with theirs; Normative influence: Users can check their friends' goals and progress in real-time;

  - **Cooperation**: When a friend achieves a goal, the user is invited to send a congratulatory message.

  - **Competition**: User can invite their friends to a 7-day competition.

2.3.2 Opower

Opower, seen in Figure 7, takes advantage of persuasive technology to increase energy efficiency in households worldwide.

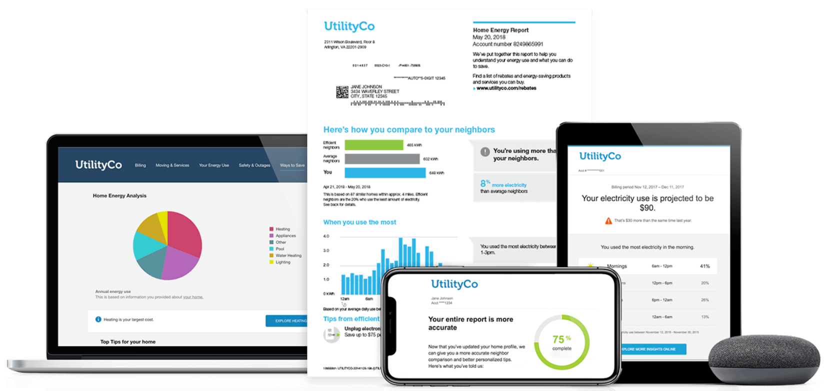

Fig. 7. Opower energy report card takes advantage of several design principles from PSD to persuade users to reduce their energy consumption at home. This is also a technology for increasing pro-environmental behaviors.

Collecting energy consumption data, opower presents the user with usage data and compares it with their neighbors. Used PSD principles in this case are:

– **Primary task**

- **Reduction**: What otherwise would be nearly impossible to achieve, Opower provides easy-to-read graphics of home energy consumption.
- **Tunneling**: Each month, Opower provides tips on how to be more energy efficient
- **Tailoring**: The users are asked to fill a home profile in order for Opower to give them a more accurate neighbor comparison and personalized tips;
- **Personalization**: The system chooses which tips are more relevant for the user;
- **Self-monitoring**: The user can monitor their energy usage;
- **Simulation**: Opower provides tips to reduce energy consumption and estimate the resulting savings;

– **Dialogue**

- **Praise**: The system praises users by showing messages of encouragement such as "Great job! You spent €6 less on electricity during peak hours this week";
- **Reminders**: "Rate Coach" is a weekly email sent by the system to help save money by avoiding high-cost times;
- **Suggestion**: As stated before, the system provides tips to save money and energy;
- **Liking**: The system has adequate icons and interfaces for the purpose;

– **System credibility**

- **Trustworthiness**: The system offers truthful energy usage information;
- **Expertise**: The company website, emails, and bills provide further details about their knowledge;
- **Surface credibility**: First meeting the system, it is possible to establish that it looks credible;
- **Real-world feel**: Materials from the system always include ways to contact people for questions or feedback;
- **Third-party endorsements**: The website contains endorsements from third parties such as "Evergy" and "Baltimore Gas and Electric";
- **Verifiability**: There are links on the website that lead to other websites that support the claims. Opower also clearly informs the user how they define similar homes to make comparisons;

– **Social support**

- **Social comparison**: This is the core principle of this system, where the users share and compare their energy usage information;
- **Normative influence**: Naturally, every user that solicits this system has the goal to reduce energy consumption and save money. Showing the energy usage of their neighbors, users are under peer pressure to adopt a more energy-efficient behavior;

- **Social facilitation**: The system allows the user to know how many similar homes are using the system for the same purpose;
- **Cooperation**: By using this system, users are also allowing Opower to share their energy usage with their neighbors;
- **Competition**: Knowing their neighbors' energy usage, users could feel a need to compete to have the lowest consumption in the neighborhood;

2.3.3 Milano Piano Stairs

When leaving the metro station of Duomo in Milan, there is a public installation in the form of piano keys on the stairs (Fig. 8). A piano note is played as if the stairs are a piano keyboard when commuters step each stair. Close to these augmented stairs are escalators. This setup takes advantage of persuasion to reduce the number of commuters taking the escalators resulting in a reduction of energy consumption and promoting a healthier lifestyle. Analyzing this system through the PSD principles are:

– **Primary task**

- **Tailoring**: The system is placed strategically close to the escalators to force commuters to decide between the two;
- **Self-monitoring**: Commuters can track their performance by noticing how much they climbed the stairs;
- **Rehearsal**: Rehearsing a song is possible since the piano is anatomically correct;

– **Dialogue**

- **Liking**: The system is visually appealing and fun-looking;
- **Social role**: The system has a social role of promoting healthier and more ecological lifestyles;

– **System credibility**

- **Surface credibility**: First meeting the system, it is possible to establish that it looks credible;

– **Social support**

Fig. 8. "Piano Stairs" public installation in Milano, Italia @ Piazza del Duomo. Picture taken by Lieven Soete [8]. Commuters leaving the subway create piano melodies with their feet by climbing the stairs. This public installation takes advantage of persuasion to reduce the number of commuters taking the escalator and therefore reduce energy consumption in an effort to avoid a negative impact on the environment, while also promoting healthier habits.

- **Social learning**: Commuters can see others taking the stairs and producing piano sounds with each stair;
- **Social comparison**: Commuters can compare their performance of creating or playing a song to others;
- **Normative influence**: There is social pressure not to look lazy and take the stairs.
- **Social facilitation**: The system allows multiple commuters to perform the same task of climbing the stairs;
- **Cooperation**: Commuters can cooperate to play harmonies;

This system has a decisive social role which reflects the number of design principles in each PSD category. The primary task is simple and straightforward, making it hard to apply any principle. The system has minimal dialogue, and it is challenging to establish system credibility due to the straightforward User Interface.

The aforementioned interfaces provide practical applications where persuasive technologies may affect the health, well-being, and more sustainable actions of end-users. Still, not many interfaces explored the possibility of reducing anthropogenic pressures, which is at the core of this dissertation. Next, an apparatus of such interface is described.

3 Implementation and Methodology

This dissertation further enhances the state-of-the-art in PSD, proposing PSE usage and an experimental setup for validation. The forthcoming evaluation method, system architecture, and carried out experimental conditions are described, providing the public interface for aspiring pro-environmental actions.

3.1 Pro-environmental Installation Setup

Next, our approach to designing a system architecture that enables the study in detail of our hypothesis is justified, based on the pro-environmental installation (Fig. 9).

The study setup comprises a DC on the floor made of MDF, a *Microsoft Kinect* perpendicular to the floor, and a bin. We placed the *Kinect* far from the ceiling, aided with a wooden stick to add stability, to have more precise readings from the infrared sensor. The bin we used is made of wood and recycled from another project and was covered in a white cloth for the PM. The wall in the lab is gray, but we covered it with several A4 sheets of paper to make it white to maintain the projector's color fidelity. The wire from the Kinect, which comprises a wire for power and another for data transfer, is stuck to the ceiling with adhesive putty. The wire for data is connected to a USB 2.0 extension, which is then connected to the computer through a USB 2.0 to USB-C adapter. The projector is on top of a cabinet, close to the ceiling, and all windows are covered with black cardboard to allow the projector to produce brighter colors.

3.1.1 Hardware

In the forthcoming, devices used in this study are described. Essential to the execution of this project is the *Microsoft Kinect* and a projector. Due to the projector being far from the computer, an HDMI extension could be used, but we opted for connecting an *Apple TV* to the projector to mirror the front-end via *AirPlay*.

3.1.1.1 *Microsoft Kinect*

The *Microsoft Kinect* version 1 (Fig. 11) is a motion sensor composed of a camera, a depth sensor using infrared light, a microphone, and its processing unit (CPU). This device is mounted 90º relative to the ground to capture the

Fig. 9. Study setup with the Design Constraint, *Kinect* at 90º relative to the floor, and a bin in a CAVE environment. A wooden stick supports the *Kinect* to provide stability since it is positioned far from the ceiling. The bin is hexagonal and made of Medium-Density Fiberboard (MDF) because it is easier and cheaper to replicate and is covered in a white cloth to optimize the projection from the projector. The wall is covered in several white A4 pieces of paper because it is painted gray, which could misrepresent the colors of the projection. Running along with the ceiling with adhesive putty from the *Kinect* to the computer is a single wire that later divides into 2 - one for power and another for data. The data wire from the *Kinect* is connected to an USB extension. This extension is then connected to a USB 2.0 to USB-C adapter and then to the computer. The DC on the floor is made of MDF with the feet pictogram, and it was recycled from another project, therefore the QR Code, which is irrelevant for this setup. The projector is behind the DC on its right, close to the ceiling on top of a cabinet. To increase visibility and produce brighter colors, we tapped every lab window with black cardboard.

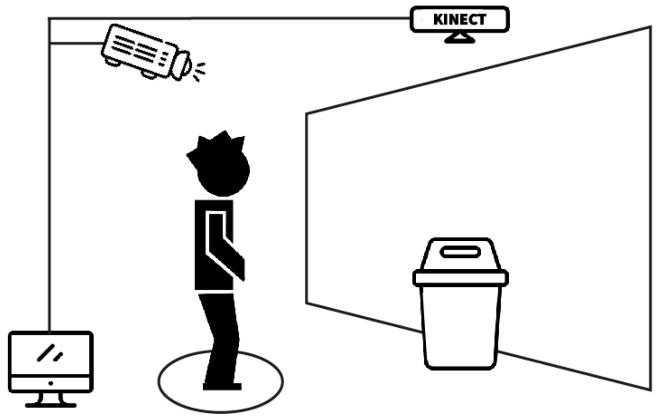

Fig. 10. System diagram of the planned experiment. The user starts the experiment on top of the DC and faces the bin. The *Kinect* is mounted perpendicular to the floor. The computer connects the projector to the *Kinect* and processes all the data. The projector is set behind and above the user to avoid casting shadows on the bin and wall.

floor and detect objects thrown outside the bin. It connects to the computer via USB and has its own power source.

Fig. 11. The Microsoft Kinect v.1 [9] is equipped with an infrared sensor that can perceive depth. Since the floor is flat, if the litter is thrown to the ground, the infrared will detect a difference in depth and tell the computer to draw it on the depth image.

3.1.1.2 Projector

For projecting the animations onto the wall and bin, we used a small affordable *Optoma* LED projector placed high above the users to reduce the possibility of occlusion in the eventuality of them getting closer to the wall. To further increase the visibility of the animations, we covered in black all windows and turned off all screens and lights. The light provided by the projector is enough to be still able to see around and navigate the setup. We have reason to believe that with a more powerful projector, immersiveness would increase, and new setups would become possible, for example, projecting to the floor as well. This would allow us to add other features and elements, such as waves hitting the shore or circling the trash left on the floor, to increase awareness of littering.

3.1.1.3 *Apple TV*

The computer connects the projector to the *Kinect*, but the projector has to necessarily be far away from the *Kinect* to project a bigger image. We tried connecting the projector with an HDMI cable and the *Kinect* with a USB extension of 5 meters, but this caused lag due to the electrical signals getting lost along the cable length. Because it is impossible to use an extension to the *Kinect*, and we did not have a long enough HDMI cable, we decided to connect the computer to the *Kinect* through an USB cable combined with an extension and a USB 2.0 to USB-C adapter, and an *Apple TV* to the projector with an HDMI cable. We wirelessly mirrored the computer screen to the *Apple TV* via *AirPlay* - which uses technologies such as *Bluetooth* and requires both devices to be connected to the same network - to connect the computer to the projector (Fig. 12).

3.1.2 Software

Processing is an open-source, free-to-use, digital sketchbook IDE that allows to code visual elements using the many libraries it disposes of. In this project, we used the following libraries:

- **Keystone** by David Bouchard[2]: Used for projection mapping, allows us to wrap our sketch into flat surfaces;

- **Open *Kinect* for Processing** by Daniel Shiffman and Thomas Sanchez[3]: A macOS *Kinect* implementation using open-source drivers such as *libfreenect* that allows manipulating data from *Kinect*.

[2] fh-potsdam.github.io/doing-projection-mapping/processing-keystone
[3] shiffman.net/p5/kinect/

– **Video** by The Processing Foundation[4]: Allows to play video files and capture data from a camera. It is based on the *GStreamer*[5] multimedia framework using the *gstreamer-java*[6] bindings to interface *GStreamer* from *Java*.

– **Sound** by The Processing Foundation[7]: A sound library for *Processing 3* that provides a way to play and manipulate sound files.

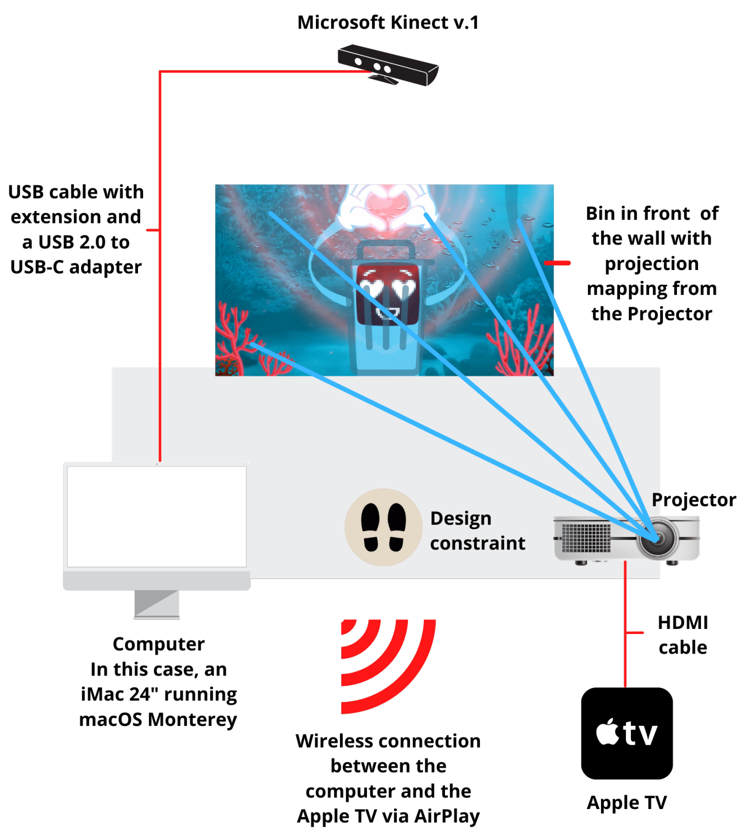

Fig. 12. System Architecture is comprised of a *Microsoft Kinect* and a projector connected to a computer, via USB with an extension and an HDMI cable, respectively. In this case, the projector is connected to the computer via *AirPlay* through an *Apple TV* as an intermediary to reduce long wires through the setup.

[4] processing.org/reference/libraries/video/index.html
[5] gstreamer.freedesktop.org
[6] github.com/gstreamer-java/gstreamer-java
[7] https://processing.org/reference/libraries/sound/index.html

3.1.3 Technology Choice Rationale

This dissertation strives to achieve an affordable, fast, and easily adaptable system architecture that is replicable in various scenarios. We chose Processing because it is free and open-source. The *Microsoft Kinect* is affordable, especially the version 1 that we used. Our lab setup and the bin are probably not easily replicable, but it is possible to adapt the image to any surface, scenario, and bin using this architecture thanks to the Keystone library.

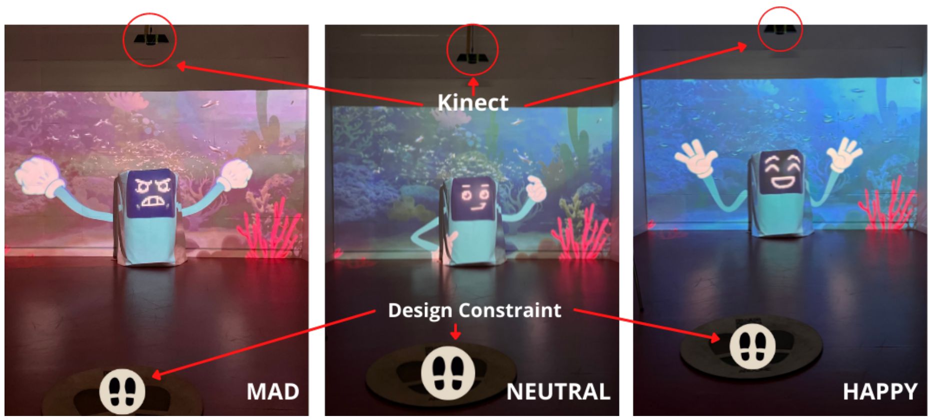

Fig. 13. Setup with projection mapping depicting the three possible reactions of the bin, the *Kinect*, and the DC present. Notice the red/brown water that looks dirty when the user litters and triggers a negative reaction, and blue water when the user correctly places the litter inside the bin triggering a positive reaction. UI and size are normal.

The *Processing* sketch takes the *Kinect* depth data to detect any depth change on the floor and inside the bin, meaning the user littered the floor or picked up the litter, respectively. This is possible by counting the number of blobs lit up on the depth image in green. According to Listing 1, if there is an increase of blobs, the system considers that the user littered the floor, triggering a negative reaction. Similarly, if there is a decrease of blobs, the system considers that the user picked the litter from the floor, triggering a positive reaction. After reacting to the users' actions, the bin returns to a neutral state (Fig. 13).

In Listing 1, `_blobSize` is a temporary variable initialized at the launch of the app with zero blobs and saves the previous amount of detected blobs.

The `checkLitter()` method attributes the new emotion to the bin, setting the state of the movies with `true` for the current emotion and `false` to everything else, and stops all movies except the one that corresponds to the new emotion. This method also starts the fader for the movie transition and plays the appropriate sound effect.

```
public void getCurrentEmotion(int blobSize) {
  //if the current blob size is bigger than before, act angry
  if (blobSize > _blobSize) {
    checkLitter(bin, negativeEmotion);
    _blobSize = blobSize;
  }

  //if the current blob size is smaller than before, act happy
  else if (blobSize < _blobSize) {
    checkLitter(bin, positiveEmotion);
    //update current amount of blobs
    _blobSize = blobSize;
  }
}
```

Listing 1. Getting current emotion based on the difference of quantity of detected blobs in the array.

These experiments are meant to verify if the projection mapping on the bin and wall is persuasive enough to make participants that littered violate the tacit rule of the design constraint, seen in Figure 14, and put the litter correctly inside the bin. The pictogram has an essential role in the study because it takes advantage of the social pressure exerted by others to comply with the rules, including tacit rules.

Fig. 14. Design constraint consisting of a pictogram with feet. The pictogram has the role of creating a situation where exists social pressure to comply with the rules. For the study, it was made on a wood sheet with the pictogram engraved with a laser.

The bin will have three states of emotion: angry/sad, neutral, happy/pleased. The experiment will commence with the bin in a neutral state. We then ask users to put the litter in the bin without explaining the role of the design constraint (Fig. 10). If the user misses resulting in littering the floor, the bin will transition to an angry/sad state. Otherwise, if the user correctly places the litter inside the bin or litters but picks it up, it will shift to a happy/pleased state. Whenever there is a design constraint, users are expected to stand on top of it because it is an unspoken rule of the experiment. Users are then confronted with a choice, either they respect the design constraint and try to throw the litter at the bin, or they will violate the tacit rule of the design constraint and place the litter inside the bin. If users choose to stand on top of the design constraint and miss throwing the litter on the bin, they can step outside, pick it up, and correctly place it inside the bin. If that is the case, we know that the bin was persuasive enough to make users violate the design constraint.

3.1.4 Detecting Litter

It is essential to have a mechanism to detect litter on the ground and inside the bin. Using the *Microsoft Kinect* pointed down, it is possible to draw a depth image that detects depth differences on the ground. As seen in Figure 18, this example shows the detection of one piece of litter by representing it in green pixels, referred to as active pixels. We chose green, but any color different from black would suffice, as seen in Listing 2. We can also get a video feed from the *Kinect* to confirm the presence of litter.

```
void checkDepth(int[] rawDepth, int i, float minDepth, float maxDepth){
  if (rawDepth[i] >= minDepth && rawDepth[i] <= maxDepth) {
    depthImg.pixels[i] = color(0, 255, 0); //green
  } else {
    depthImg.pixels[i] = color(0); //black
  }
}
```

Listing 2. Checking depth and setting each pixel green for the presence of litter and black if there's an empty floor. All pixels are stored in rawDepth which are individually analyzed to determine if they meet the depth threshold requirements.

Fig. 15. Litter available in the pilot study ($N = 6$). These were specifically chosen because the *Kinect* does not detect transparent plastic bottles since the infrared light goes through them.

3.1.4.1 Active Pixels

In the project's first iteration, since active pixels are calculated through two for loops, X and Y, it is easy to calculate how many green pixels exist with an iterable variable. We decided not to take this approach because the depth image is very jittery around the edges of the detected object, which made us add a degree of tolerance to compensate for this uncertainty. Furthermore, the difference of active pixels when adding or removing litter, plus the tolerance added, is too small to detect any significant change in the number of green pixels. Our approach was to analyze the depth image instead of calculating the litter with the raw data provided by the *Microsoft Kinect*.

3.1.4.2 Blob Detection

Due to the number of active pixels not having the precision needed to detect the presence or absence of litter correctly, we turned to blob detection methods. Blob detection works by distinguishing the difference of color from the background using the euclidean distance between two colors - in this case, green for litter and black for the background. We could have applied this method to the video feed, but that would require painting the floor and the litter in very contrasting colors. Despite letting us skip the depth image entirely, using less memory, and requiring only a simple camera, we chose to apply this technique to the depth data because that would let us build a more realistic and reliable experience.

```
public void detectBlobs() {
  ArrayList < Blob > currentBlobs = new ArrayList < Blob > ();
  // Begin loop to walk through every pixel
  for (int x = 0; x < depthImg.width; x++) {
    //region of interest
    for (int y = upperLimitRegionOfInterest; y <
    lowerLimitRegionOfInterest; y++) {
      int loc = x + y * depthImg.width;
      // what is current color
      color currentColor = depthImg.pixels[loc];
      float r1 = red(currentColor);
      float g1 = green(currentColor);
      float b1 = blue(currentColor);
      float r2 = red(trackColor);
      float g2 = green(trackColor);
      float b2 = blue(trackColor);
      float d = distSq(r1, g1, b1, r2, g2, b2);
      if (d < threshold * threshold) {
        boolean found = false;
        for (Blob b: currentBlobs) {
          if (b.isNear(x, y)) {
            b.add(x, y);
            found = true;
            break;
          }
        }
        if (!found) {
          Blob b = new Blob(x, y);
          currentBlobs.add(b); }}}}}
```

Listing 3. Setting up blob detection by looping through each axis of the depth image. The y axis is only analyzed between the lower and upper limits of the Region of Interest (ROI). The ROI is used to ignore the wall on the bottom of the depth image. The blobs in each frame are stored in an ArrayList and are compared to another ArrayList that stores blobs over time to add data persistence. Each blob is analyzed to check if each pixel in a frame is near it. If the pixel is near a blob it is added to that blob. Otherwise, if the pixel is not near a blob, we create a new blob. Blobs that do not meet a size threshold are deleted.

As seen in Listing 3, we start by creating an *ArrayList*[8] where we store the blobs on the screen in each frame. To add persistence to the data - to avoid creating new blobs every iteration - we have another *ArrayList* called `blobs` that stores the blobs over time. Looping through each pixel in a double nested *for* loop of both the X and Y-axis, we establish the distance between the tracking color and the background. If the pixel meets the color threshold, we loop through every blob and check if the current pixel being analyzed is near a blob - if it is, we add the pixel to that blob and declare that its blob was found. If a pixel has not found its blob, we create a new blob and add it to our *ArrayList* of blobs. To prevent smaller insignificant blobs, we remove those that do not meet a size threshold.

```
// There are no blobs!
if (blobs.isEmpty() && currentBlobs.size() > 0) {
 for (Blob b: currentBlobs) {
    b.id = blobCounter;
    blobs.add(b);
    blobCounter++;
  }
}
```

Listing 4. Adding the first blob if the ArrayList of historic blobs (blobs) is empty and there is a pixel that meet the color and size thresholds.

In Listing 4, if there is no history of blobs, and there are blobs in that particular frame, we loop through every blob in `currentBlobs` and add them to `blobs`, which is the number of historic blobs.

This distinction between current and historic blobs allows us to have data persistence. There are three possible scenarios we have to account for:

– There are more current blobs than historic blobs (`currentBlobs` > `blobs`);

– There are fewer current blobs than historic blobs(`currentBlobs` < `blobs`);

– There is the same amount of current blobs and historic blobs (`currentBlobs` = `blobs`).

Listing 5 handles the possibility of detecting more blobs than those previously detected - `currentBlobs` is larger than `blobs` - by adding the difference between

[8]The ArrayList class is a resizable array to store objects.

them to `blobs`. Looping through every blob in `blobs`, for each one, we loop through every blob in `currentBlobs` and check if the distance of their center is small enough to be matched as being the same blob. After matching all blobs from each *ArrayList*, the remaining ones are created and added to `blobs`.

```
else if (blobs.size() <= currentBlobs.size()) {
  // Match whatever blobs you can match
  for (Blob b: blobs) {
    float recordD = 1000;
    Blob matched = null;
    for (Blob cb: currentBlobs) {
      PVector centerB = b.getCenter();
      PVector centerCB = cb.getCenter();
      float d = PVector.dist(centerB, centerCB);
      if (d < recordD && !cb.taken) {
        recordD = d;
        matched = cb;
      }
    }
    matched.taken = true;
    b.become(matched);
  }
  // Whatever is leftover make new blobs
  for (Blob b: currentBlobs) {
    if (!b.taken) {
      b.id = blobCounter;
      blobs.add(b);
      blobCounter++;
    }
  }
}
```

Listing 5. Adding blobs if there are already blobs detected. The system tries to match each blob to the historic blobs. A new blob is created if the system is unable to match all blobs.

In the prospect of having in a frame fewer blobs than those previously detected - `currentBlobs` is smaller than `blobs` - we remove the blobs that cannot be matched, as seen in Listing 6.

```
else if (blobs.size() > currentBlobs.size()) {
  for (Blob b: blobs) {
    b.taken = false;
  }
  // Match whatever blobs you can match
  for (Blob cb: currentBlobs) {
    float recordD = 1000;
    Blob matched = null;
    for (Blob b: blobs) {
      PVector centerB = b.getCenter();
      PVector centerCB = cb.getCenter();
      float d = PVector.dist(centerB, centerCB);
```

```
      if (d < recordD && !b.taken) {
        recordD = d;
        matched = b;
      }
    }
    if (matched != null) {
      matched.taken = true;
      matched.become(cb);
    }
  }
}
```

Listing 6. Removing blobs that the system was unable to match when there's less blobs in the current frame than those previously detected. This situation happens when the user picked up a piece of litter.

In some frames, the algorithm may not detect a blob for a brief moment of milliseconds, which leads the system to delete it and create a new one in the next frame. This behavior is prevalent when the object - in this case, litter - moves too quickly or is too flat. As seen in Listing 7, the solution is to add a lifespan to each blob, so even though the blob stops existing for a frame, the system waits briefly before deleting it and creating a new one. `checkLife` is a timer that decrements lifespan and returns true if the blobs' lifespan reaches zero, thus allowing the function in Listing 7 to run `blobs.remove(i)`.

```
//remove blobs that can't be matched
for (int i = blobs.size() - 1; i >= 0; i--) {
  Blob b = blobs.get(i);
  if (!b.taken) {
    if (b.checkLife()) {
      blobs.remove(i);
    }
  }
}
```

Listing 7. Checking lifespan before removing blobs that could not be matched by the system. Lifespan was added to the algorithm because it may be unable to detect a blob briefly between frames due to the nature of the infrared sensors.

3.1.4.3 Depth Threshold

A minimum depth threshold prevents the system from mistaking a user reaching in to pick up litter with actual litter, while a maximum depth threshold lets the system ignore the floor. These thresholds allow the system to focus only on above the floor by around five centimeters, where the litter will fall (Fig. 16).

All depth detection is relative to the position of the *Kinect*, meaning that some parts of the floor furthest from the source of the infrared sensor and the

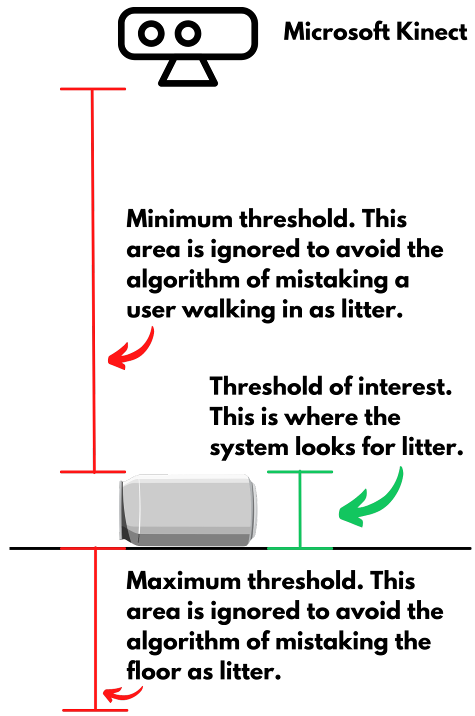

Fig. 16. Depth thresholds are necessary for the algorithm to scan only the depth where the litter will fall. In red, the ignored depths, and in green are the depth that is scanned for litter.

lower part of the wall where the projection mapping occurs are detected as blobs because they meet the threshold requirements, as seen in Figure 17. The infrared sensor the *Kinect* uses to detect depth needs to travel longer to reach points X and Z because it has to travel diagonally relatively to the floor, which is interpreted as a difference in depth and, thus, litter. Using the same depth thresholds as those applied to Y, would make the system believe it is detecting points A and B. For the infrared rays to detect points X and Z correctly, we need to adjust the thresholds in those areas to flatten the blue curve. Figure 17 illustrates the problem along the x-axis, but this situation also persists along the y-axis.

Our approach, seen in Figure 18, was twofold to fix this issue. Firstly, to fix the wrongful detection of the wall where the projection mapping occurs, as seen in sections six, seven, and eight with the red line, we defined a ROI that ignores the bottom part of the depth image. Secondly, we divided the rest of the depth

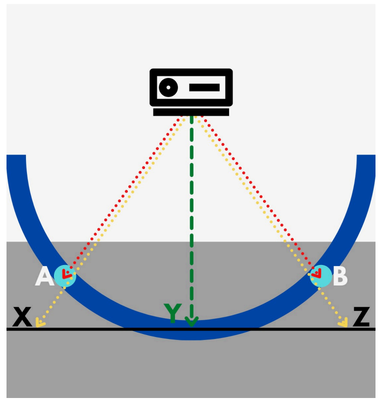

Fig. 17. Importance of fragmenting the depth image. The infrared sensors need to travel a longer distance to reach points X and Z. For this reason, if we apply the same threshold on the whole depth image, the algorithm will believe it is detecting points A and B. For this reason, we fragmented the depth image into sections where we can adjust the threshold individually.

image into nine sections and calibrated the depth threshold values accordingly. These values can also be adjusted during the project's runtime. In sections zero and two of the Figure 18, the system detected two pieces of litter, while in the seventh section, inside the red rectangle, there is the bin that the blob detection system ignores.

3.1.5 Front-end

The front-end is the project segment that handles what is visible to the user. At first, we separated the back-end from the front-end into two distinct windows by creating a Java Applet of the main window. These separated components would let us have a clean front-end without any text above the projection mapping, meant to be seen only by the engineer. Despite that, when we added movies to the back-end applet, we found that the Java renderer could not be used on a child Applet. This constraint forced us to delete the child applet and work with a single-window for both front-end and back-end.

3.1.5.1 Movies

Each reaction is a different video file which Processing calls a movie. The neutral emotion is played on a loop, while the positive and negative responses are played once. To achieve a fade transition between reactions, in Listing 8 a fader is applied to both the current playing movie with either a positive or negative

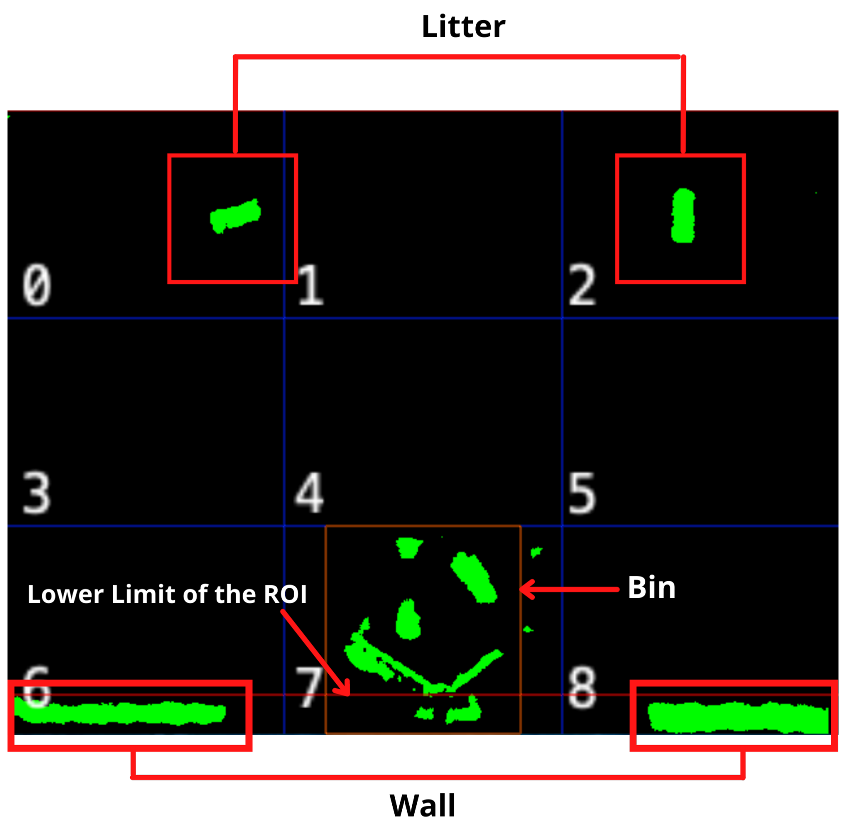

Fig. 18. Depth Image sectioned with tailored thresholds for each. The red line below is the lower limit of the ROI, which ignores the lower part of the wall. The red square represents the bin, and there is litter in sections 0 and 2.

reaction and the previous movie, which is always in the neutral state. The previous movie is progressively tinted black, while the current movie starts black with its tint gradually removed. After each reaction's video file is played, the system goes back to the neutral state.

```
void crossFadeMovies(Movie current) {
  current.loop();
  movieDuration = current.duration();
  movieTime = current.time();
  offscreenBackground.beginDraw();
  offscreenBackground.background(255);
  if (fader < 255 && frameCount > 1) {
    tint(255, 255 - fader);
    offscreenBackground.image(current, 0, 0, width, height);
  }
  if (fader > 0 && frameCount > 1) {
    tint(255, fader);
    offscreenBackground.image(neutralMovie, 0, 0, width, height);
  }
  if (movieTime >= movieDuration && bin.currentEmotion != neutralEmotion
    ) {
    setCurrentEmotion(bin, neutralEmotion);
    setState(neutralEmotion);
    stopAllVideosExcept(neutralEmotion);
  }
  offscreenBackground.endDraw();
}
```

Listing 8. Cross-fading movies. A fader is applied to both the current and the next playing movie. The current movie is tinted black along the fader while the next movie starts tinted black and clears its tint at the same speed.

There are various renderers in Processing, which at first, we chose to work with the default renderer based on Java. Using a Java renderer caused performance issues, especially in video playback. We chose an OpenGL renderer, specifically P3D, for its satisfactory performance.

All videos are declared, but only those on the current experiment are initialized. If the experiment has a normal UI and a normal size, those are the only videos loaded to memory to maintain performance. Initialized videos are paused initially to prevent them from playing all at the same time.

When there is a reaction, there is a change in movies playing. All videos are stopped except the one playing to preserve CPU power. In a first iteration, the bin would loop its reaction while another was not triggered. The bin returns to its neutral state after a reaction, whether it is positive or negative, to prevent the possibility of having multiple pieces of litter on the floor and the user picking one up. Triggering a positive reaction would be counterproductive because some litter remains on the floor while keeping the negative reaction would not reward the participant for picking up litter.

As seen in Figure 19, emotions are determined based on the difference of blobs detected in the depth image produced by the *Kinect*. The bin will react negatively if it detects an increase of blobs. Otherwise, if there is a decrease in blobs, the bin will react positively. If there is an increase in litter inside the bin, it will also react positively. Notice how the bin can go from each state to any other because it does not wait for the movie to finish playing before continuing to search for litter on the floor.

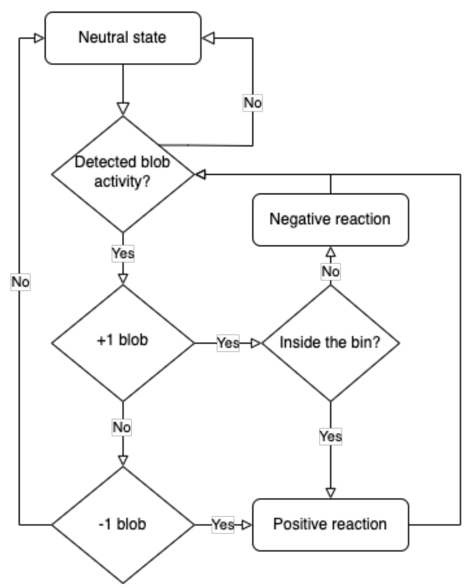

Fig. 19. System flowchart. The system stays in the neutral state while it does not detect a difference in blobs. If a blob is removed, the system triggers a positive reaction of the bin. Otherwise, the system checks if the blob is inside the bin if a blob is added. If a blob is inside the bin, it means the user correctly disposed of the litter, and thus a positive reaction is shown. If not, the system triggers a negative reaction.

3.1.5.2 Sounds

For each type of reaction, several suitable sound effects can be played. The system groups these sounds on different arrays, and each time it is called, it randomly picks a sound and plays it once. All sounds are free and can be used by anyone. In the background, soft music resembling the ocean is played in a loop. These sounds were chosen to provoke a specific emotion in the participant. The sounds associated with a negative reaction are aggressive and resemble a person mumbling and complaining, while the sounds for the positive reaction have a happy tone.

3.1.5.3 Projection Mapping

Using Keystone, movies are played on surfaces that can be warped to fit any shape, in this case, the wall and the bin. This library allows shaping the movie without worrying about perspectives or the projector's position. Projection mapping allows for a more adaptable project since every shape is mappable, while cheaper than a screen or other possible solutions. Clicking the K key starts calibration mode, where it is possible to warp the surface to the projected scenario. Once the projector is set in a fixed position, we match the edges of the movie with the room's edges and save it for future use.

3.2 Installation Guide

The first step is to install Processing[9]. On *macOS*, it is possible to install the app by entering the following command in the terminal:

```
brew install --cask processing
```

Listing 9. Brew is a package management system that downloads and installs all necessary dependencies for a specific app through "formulae". The "–cask" command serves to apply the same logic to GUI macOS applications.

Processing comes with its own Java version, independent of the one installed on the computer. For our particular setup, we had to use the first beta of Processing 4 because only its newer version of Java was compatible with the computer we used.

After installing Processing on the machine, libraries used on this project must be installed, as specified in the "Implementation and Methodology" section. We can code and debug on *VS Code* as the IDE by installing *"processing-java"* on Processing's "Tools" tab.

The *GitHub* repository[10] can be cloned through the link provided in the appendix. This repository does not include the folder with all the movies and

[9] https://processing.org/download
[10] https://github.com/alexgfaria/LitterDetection

sounds because it is too large and surpasses the bandwidth allowed by *GitHub*. Download the data folder by clicking here[11], or copy the URL in the footnote and paste it on your browser, placing the folder inside the project's folder. The main folder must have the same name as the main file; otherwise, Processing will not recognize it.

3.3 Commands

During the project's run-time, it is possible to make adjustments to a number of settings, in particular calibrating layouts for the projection mapping, or thresholds of depth for each section of the depth image. These are the available commands:

- **0 - 8**: Select section to adjust depth threshold individually;
- **S** / **A**: Increase / Decrease minimum depth threshold;
- **X** / **Z**: Increase / Decrease maximum depth threshold;
- **r** / **R**: Increase / Decrease distance threshold;
- **o** / **O**: Increase / Decrease upper limit of the Region of Interest (ROI);
- **p** / **P**: Increase / Decrease lower limit of the ROI;
- **I**: Show / Hide camera feed;
- **M**: Mute / Unmute sounds;
- **H**: Show / Hide advanced settings;
- **K**: Enter / Leave keystone calibration mode to warp and move surfaces;
- **L**: Load saved layout from "keystone.xml";
- **G**: Save current layout to "keystone.xml";
- **B**: Toggle calculation of litter;
- **- (dash)**: Force a positive reaction;
- **. (dot)**: Force a negative reaction;
- **Q**: Quit.

[11]https://testuma-my.sharepoint.com/:f:/g/personal/2021114_student_uma_pt/EoNL-H9LYK9HjIC5dnpMT74BeFYWnkoqZG-ZEb-FJ3x9Xw?e=SPefuR

Commands such as "r / R", "o / O", and "p / P" are case-sensitive since the lowercase letters increase their value while the uppercase letters decrease it. The remaining commands are not case-sensitive and can be used in either way.

3.4 Planned Experiment

The experiment consists of a series of comparative studies where we ask participants to put the plastic litter bottles in the bin without explaining the design constraint in the setups where it is present.

Fig. 20. Projection of the interactive projection mapping - artwork supported by Telmo Silva. The first row depicts a variety of possible neutral states. In the second row, the bin reacts in a more passive-aggressive way, while in the third row, the bin takes a more active angry approach. In its angriest state, what otherwise was the bin, transforms into the bin's mouth.

As seen in Figure 13, if the user correctly puts the litter in Figure 15 inside the bin, what will be projected to the wall and bin is a happy reaction. Otherwise, if the user leaves litter on the floor, the bin will react negatively, becoming angry, seen in Figure 21. Projection mapping is usually merely informative, but this setup is interactive. The planned experiment will test two types of PSE, a visual peak-shift, namely size and UI.

The experiment with its several setups is summarized in Table 1. The first two experiments do not have the presence of any PSE element, giving us a baseline for comparison. In the remaining, there are two types of PSE:

- UI: Special
- Size: Bigger

Fig. 21. Negative reaction of the bin with Special UI and bigger size. It is meant to provoke a healthy amount of fear and anxiety while exerting social pressure. The hands shake violently on the floor, making the whole environment behind the bin shake. The water is dirty in a shade of brown and red.

When the UI is special, visual elements, cues, and different animations are introduced in the projection. A positive reaction when the UI is special makes the bin form hearts with its hands and have heart eyes with special sound effects timed precisely to its gestures. When the reaction is negative, and the UI is also

<table>
<tr><th>Experiment #</th><th>UI</th><th>Size</th><th>Design Constraint</th><th>Peak-Shift</th></tr>
<tr><td>1</td><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td>Yes</td><td rowspan="2">No</td></tr>
<tr><td>2</td><td>No</td></tr>
<tr><td>3</td><td rowspan="2">Big</td><td>Yes</td><td rowspan="6">Yes</td></tr>
<tr><td>4</td><td>No</td></tr>
<tr><td>5</td><td rowspan="4">Special</td><td rowspan="2">Normal</td><td>Yes</td></tr>
<tr><td>6</td><td>No</td></tr>
<tr><td>7</td><td rowspan="2">Big</td><td>Yes</td></tr>
<tr><td>8</td><td>No</td></tr>
</table>

Table 1. Planned experiment with its several setups. The first two experiments do not have any PSE element, which gives us a baseline for comparison. Experiments are divided by UI, with each one further divided by size. Each experiment is tested with and without the DC.

special, the projection adopts more red tones and more dramatic gestures. All of these are the same when we increase the size, except when it is conjugated with a special UI, in which the bin dramatically increase its size and turn the bin into the mouth with the body around the edges and special sound effects timed to the bin's motion (Fig. 21). In this scenario, the bin almost looks like an erupting volcano, with more aggressive facial expressions and gestures, such as banging the ground with its hands and making the whole projection shake.

3.4.1 Baseline model

To set the baseline model for comparison, we perform the study without PSE and with and without the design constraint. This will allow us to assess the role of the design constraint and will establish the baseline for all the following experiments.

3.4.2 Traditional model

This experiment consists in performing the study in the framework of the PSD model with PM, with and without the design constraint and no PSE present, as seen in Table 1. With this experiment, we will learn the role of projection mapping.

3.4.3 Novel model

This experiment consists in performing the study in the framework of the PSD model with PM, while introducing two PSE and testing each with and without the design constraint. In this experiment, we can understand how this novel model performs and determine whether PSE increases PSD persuasiveness, and if so, which variable is the most persuasive. The experiment will compare the visual peak shifts to the traditional model. In the case of visuals, the anthropomorphic bin will indicate exaggerated motion (see Figure 20), bottom-right image.

3.5 Questionnaire

For each participant, we registered the following:

- Did the participant notice the DC?
- Did the participant stay in the DC at all times?
- Form of delivery - throw, carried, or mixed.
- Did the user litter?
- If so, did the user leave the litter on the floor?

After the study, we asked the following questions:

1. What did you like about the experiment? - [Q1]
2. What did you not like about the experiment? - [Q2]
3. How effectively do you think this experiment was in making you toss in the litter? - [Q3]
4. Additional feedback - [Optional]

4 Results and Discussion

The results of the research conducted will be shown in this section. We conducted the pilot test from October 25th through October 29th of 2021, with 20 participants aged 17 to 50. Each participant performed every configuration of the study. Each questionnaire result can be found in section 6. Figure 2 compresses individual results in the number of participants.

The first three columns of Table 2 explain each configuration of the study, with the type of UI, size, and whether the DC was present or not. We also registered if the participant stayed in the DC at all times and the type of delivery, whether the participant carried the litter into the bin, threw the litter, or a mix of both. Some participants did not acknowledge the presence of the DC, which is why we registered those numbers in the fourth column. Interestingly, a few participants refused to participate in specific configurations thinking they were asked to pollute the ocean which was in the background of the bin, or that the litter used in the pilot study was not all from the same material, so they had no possible way of separating their recycling. Not all participants had the opportunity to pick up litter or leave it on the floor because they did not miss when putting the litter inside the bin or refused to participate. Finally, from the population of participants that did litter, we registered their reaction to missing - how many of those picked it up or left it on the floor.

UI	Size	Design Constraint	Saw DC	Stayed in DC at all times?	Type of Delivery			Refused to participate	Littered	Did not pick up litter	Picked up litter
					Delivered	Mixed	Throw				
Normal	Normal	Yes	18	12	6	1	13	0	12	6	6
		No			8	1	11	0	8	2	6
	Big	Yes	17	9	7	2	10	1	7	3	4
		No			9	1	9	1	7	2	5
Special	Normal	Yes	17	9	6	2	11	1	9	4	6
		No			5	1	13	1	8	3	5
	Big	Yes	18	6	5	4	11	0	11	3	8
		No			5	1	13	1	7	2	5

Table 2. Summary of results in number of participants ($N = 20$). The first three columns describe the experiment's setup, while the others are figures we took note of during the study.

4.1 Model Analysis

In the coming subsection, this dissertation provides the analysis of the system under the Persuasive Systems Design model.

4.1.1 Primary Task Support

The design principles of the primary task category are designed to support the primary task. The primary task support in this system does not conform to many principles because the tasks we ask participants to perform are undemanding and straightforward.

- **Primary task**
  - **Simulation**: There is a straightforward means for observing the link between the cause and effect because the bin reacts to the participants' actions;
  - **Rehearsal**: The system itself is a daily task of putting thrash in a bin;
- **Dialogue**
  - **Praise**: The bin praises the user by reacting positively when they correctly place the litter inside the bin;
  - **Suggestion**: The bin points to itself when in the neutral state, suggesting the user to throw the litter inside it;
  - **Similarity**: The bin has an anthropomorphic shape,
  - **Liking**: The system is visually attractive;
  - **Social role**: Adopts a social role promoting littering prevention;
- **System credibility**
  - **Surface credibility**: Initial assessments of the system allow the users to establish the credibility of the system;
- **Social support**: The system has a competent look and feel;
  - **Social learning**: It is possible to observe others perform the behavior;
  - **Normative influence**: The system applies normative influence by turning the ocean dirty and void of fish when the user litters;
  - **Social facilitation**: Users can perform the task along with others, but the system does not distinguish them apart;
  - **Cooperation**: The user can ask others for help;
  - **Competition**: Competition can occur by seeing who misses less.

4.2 Experimental Findings

The type of delivery of each piece of litter is important for this study. It is unique for a user to be exposed to a negative reaction if they deliver it by hand. Contrarily, there is a higher probability of missing when the user throws the litter, triggering a reaction. Fig. 22 shows that most participants threw the litter independently of the study configuration, which is beneficial for this study. Fewer people carried the litter to the bin with less mixed types of delivery.

After counting the number of participants that missed and littered, it is essential to distinguish the participants who left it on the floor from those who did not. As expected, the study configuration without any Peak Shift Effect produces no effect in persuading participants to pick up litter. From Fig. 23, we know that every study configuration, except the one previously mentioned, produced a positive change in the participants' reaction - more people picked up trash than those that did not. From the same figure, it is possible to conclude that the **Special UI, Big Size, DC** configuration with the presence of both PSE variables had the most difference between the number of participants that picked up the litter and the number of participants that left it on the floor. Figure 24 shows that the more the PSE effect, whether it is UI or size, the fewer people stay in the DC.

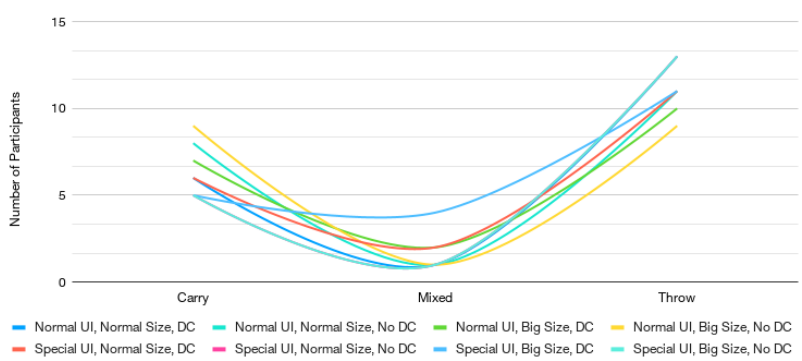

Fig. 22. How people leave litter. The primary form of leaving litter inside the bin is throwing, followed by carrying and mixed. The setup with special UI, bigger size, and with no DC had the most participants throwing litter. Participants carried litter more frequently when the setup had the normal UI, bigger size, and no DC. Combined with the fact that it was the most stable setup regarding how people leave litter, the setup with special UI, bigger size, and with DC had the most participants with mixed types of delivery.

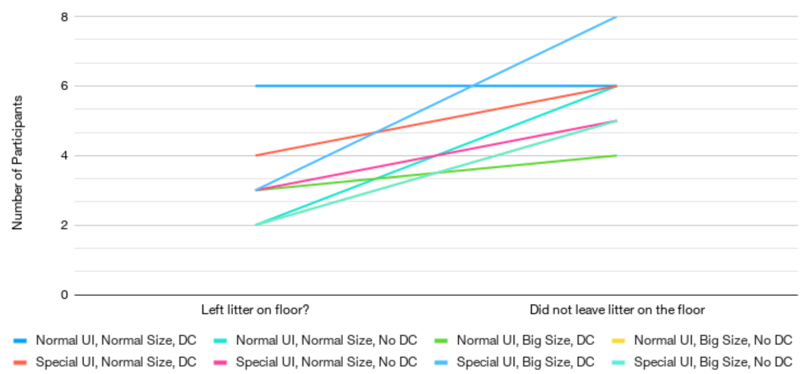

Fig. 23. Participants that picked and did not pick the litter. When the setup was a normal UI and size with the DC, there was no difference between the users that littered and did not leave litter on the floor, suggesting it did not affect the participants. The setup with the most significant difference is with special UI, bigger size and with the DC with only three people leaving litter on the floor and 8 picking it up, even with the presence of the DC.

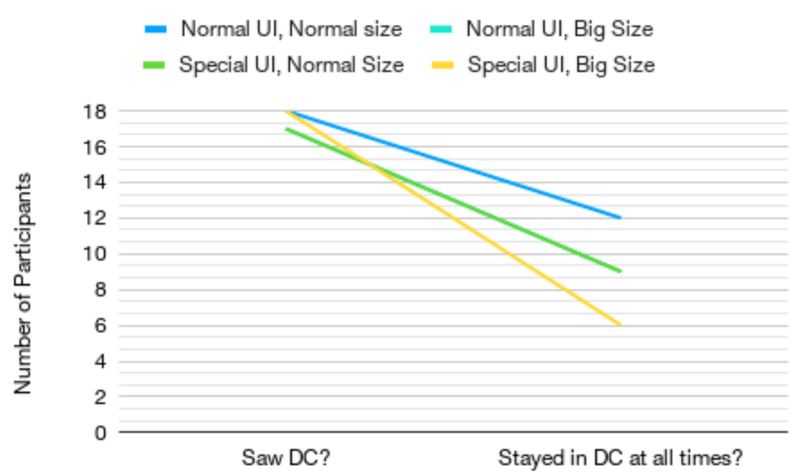

Fig. 24. Influence of the DC on participants. The setup with special UI and bigger size had the least number of participants staying on top of the DC during the study with only six compared with 12 from the setup with normal UI and size. The setups with normal UI, bigger size, and special UI and normal size have the same results, with 18 participants seeing the DC and only 9 participants staying on top of the DC during the study.

Interestingly, according to Fig. 24, when there was not Peak Shift Effect present in the study configuration, i.e. **Normal UI and Normal Size**, more participants stayed on top of the DC during the whole study. Configurations with the presence of Peak Shift Effect elements, **Normal UI and Big size**, and **Special UI, normal size**, results were identical with less participants staying in the Design Constraint at all times in relation with the previous configurations. Finally, the study configuration with both types of PSE, UI, and size was the most persuading in making participants leave the DC, with only 6 participants out of 18 remaining. From Figure 25 and Table 3, we can determine that when the UI is normal, participants pick up litter more times when there is no DC, as expected since there is no tacit rule to the experiment to stay in one place. Contrarily, when the UI is special, participants picked up litter more times, even in the presence of the DC.

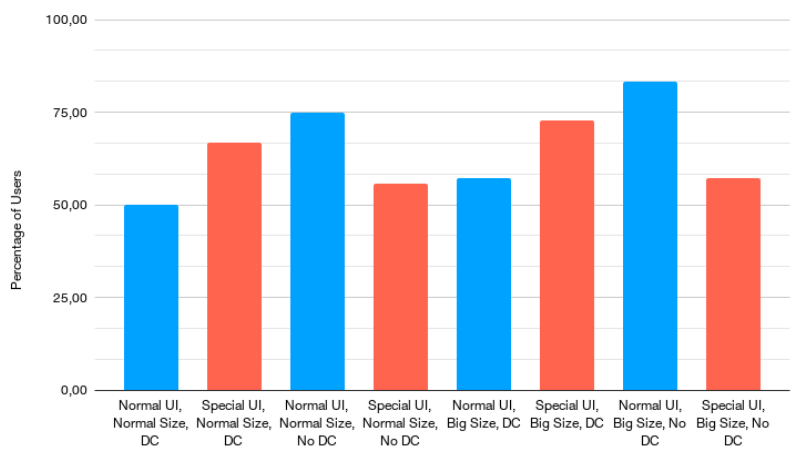

Fig. 25. Percentage of users that littered but picked it up, separated by UI with normal in blue and special in red. In the first two blue bars and the next two blue bars, the first of each is smaller than the next bar in its color. Contrarily, in the first two red bars and the next two red bars, the first of each is bigger than the next bar in its color.

With this pilot study, we have a strong case for arguing that UI had a strong influence in persuading users to refrain from littering, and thus, adopting more pro-environmental behaviors.

UI	Size	Design Constraint	Percentage of users that picked up litter
Normal	**Normal**	**Yes**	50,0%
		No	75,0%
	Big	**Yes**	57,1%
		No	71,4%
Special	**Normal**	**Yes**	66,7%
		No	62,5%
	Big	**Yes**	72,7%
		No	71,4%

Table 3. Explaining the inversion of the behavior around the DC and the UI. When the UI is **normal** (in blue), participants picked up litter **more** when there was **no DC**. Contrarily, when the UI is **special** (in red), participants picked up litter **more** when there **was a DC**. This is a strong argument that the UI has a big influence on persuading participants to adopt more pro-environmental behaviors because it performed even better when the DC exerts its pressure to comply with tacit rules.

4.3 Research Contributions

Conducted experiments using the pro-environmental installation indicate the possibility of using persuasion combined with the Peak Shift Effect as a means to provoke more sustainable choices and ultimately more sustainable behavior.Findings suggest that the PSE in the form of the UI is more effective than size and no PSE at all.

Much like the Milan piano stairs, this system has a more social approach to persuasion, with undemanding and straightforward tasks, making it challenging to apply several design principles other than those of social support.

Circling back to the research questions in section 1:

- **[RQ1].** How can a current widely adopted PSD model create persuasive actions for the greater audience to produce less litter?

The Persuasive Systems Design model is an effective model to describe persuasion techniques in computer systems but lacks mechanisms to measure persuasion. In this dissertation, we took the current widely adopted model and added a variant (Peak Shift Effect) to determine if this effect helps contribute to persuading users, in this case, to produce less litter. Our results are strong arguments that the PSD combined with the PSE, especially in the form of UI is a powerful means to ask users to reduce their littering.

- **[RQ2].** What is the role of technology against traditional design when persuading the audience to produce less litter?

Having bins in every corner outside is a persuasive measure in itself, but augmenting a single bin with anthropomorphic characteristics that reacts if the user litters is a memorable experience that can lead to long-term persuasion. Detecting litter on the floor with our system is cheap and simple to recreate and can be set in places with large audiences, much like the piano stairs in Milan. Technology has the benefit of automating persuasion and reaching larger audiences to disseminate, particularly in the scope of this dissertation, pro-environmental behaviors.

4.4 Future Work

In this study, we considered the role of the User Interface and size in Peak Shift Effect applied to persuading users to avoid littering. In possible future work, we suggest experimenting with other variables such as acoustic types of PSE. The place of the study played a role in the results, so it can be interesting to change the scenery. Since each study was conducted with only one participant, setting the system in a public environment could introduce a crowd factor that can be studied for its role in persuading pro-environmental behaviors, namely a more substantial social pressure. Future works in conducting the previous experiments and collecting the set of scales and semi-structured interviews serve as a backdrop for aspiring pro-environmental behavior caused by the proposed system.

5 Conclusion

With global warming being contested outside the scientific community, the anthropogenic impact is recognized by the overwhelming carbon dioxide production, which causes acidity to the world's oceans. Marine littering remains a threat to humans and worldwide ecosystems. World nations fail to reach a consensus on mitigating climate change. While there are numerous techniques to aspire to pro-environmental behaviors, one is using persuasive interactions and persuasive technologies.

This dissertation seeks to use persuasion to provoke sustainable actions in users using interactive technologies. The dissertation expands the well-known Persuasive Systems Design framework and leverages it further with the peak-shift principle as an artistic experience. The experimental validation procedure of such a novel model is built using interactive projection mapping and, in particular, motion capture. Users are asked to toss the litter items into the animated, anthropomorphic bin. The dissertation compares the role of an introduced peak-shift element and the role of design against interactive design in persuading people to be more pro-environmentally oriented.

The dissertation depicts the role of design, interaction design, and emotional interactive design in fostering pro-environmental actions. The proposed apparatus, consisting of affordable persuasive technology-based on projection mapping and motion capture, provides an easy setup for the wider audience to replicate and a means to aspire to pro-environmental actions. Findings obtained from the pilot study indicate that the interactive user interface may effectively reduce anthropogenic hazardous behaviors such as littering and the generation of marine plastic pollutants.

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6 Appendix

6.1 Questionnaire results

6.1.1 Participant 1

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
<tr><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td>Yes</td><td colspan="2" rowspan="8">No</td><td rowspan="8">Carry</td><td colspan="2" rowspan="8">No</td></tr>
<tr><td>No</td></tr>
<tr><td rowspan="2">Big</td><td>Yes</td></tr>
<tr><td>No</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td>Yes</td></tr>
<tr><td>No</td></tr>
<tr><td rowspan="2">Big</td><td>Yes</td></tr>
<tr><td>No</td></tr>
</table>

Table 4. Results from Participant 1

- **Q1 -** "I liked the subaquatic scenario"
- **Q2 -** "This study was very repetitive"
- **Q3 -** "It didn't have to be effective because I already decided to put the trash in the bin. I didn't need to be persuaded"
- **Additional -** The amount of litter allowed me to carry all of it with me at once. If I had more litter, it could encourage me to try a different approach.

6.1.2 Participant 2

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
<tr><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td>Yes</td><td>Yes</td><td>No</td><td rowspan="3">Throw</td><td>Yes</td><td rowspan="8">No</td></tr>
<tr><td colspan="3">No</td><td rowspan="7">No</td></tr>
<tr><td rowspan="2">Big</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="3">No</td><td>Carry</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td>Yes</td><td>Yes</td><td>No</td><td rowspan="4">Throw</td></tr>
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<tr><td rowspan="2">Big</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="3">No</td></tr>
</table>

Table 5. Results from participant 2

- **Q1 -** "Loved everything about it. It felt like magic. I liked the hearths and the love he sent me. I liked making him happy by doing the right thing."
- **Q2 -** "I didn't like that the bin got mad because I missed once"

- **Q3 -** "I would normally already put the thrash in the bin but the pressure of seeing him mad when I missed pressured me into picking up the litter on the floor"
- **Additional feedback -** "It was a cute experience, and a good idea if people react well to the bin's reactions."

6.1.3 Participant 3

UI	Size	DC	Saw DC?	Stayed in DC?	Delivery	Littered?	Left litter on floor?
Normal	**Normal**	**Yes**	Yes	No	Mixed	Yes	No
		No			Carry	No	
	Big	**Yes**	Yes	No			
		No					
Special	**Normal**	**Yes**	No				
		No					
	Big	**Yes**	Yes	No			
		No					

Table 6. Results from participant 3

- **Q1 -** "Fun, funny. If it were a show for kids to teach these matters it would be really cool. It's immersive."
- **Q2 -** "I thought I had to recycle the trash. I needed more instructions. This looks like a toy."
- **Q3 -** "The images were pretty effective."

6.1.4 Participant 4

UI	Size	DC	Saw DC?	Stayed in DC?	Delivery	Littered?	Left litter on floor?
Normal	**Normal**	**Yes**	Yes	No	Carry	No	No
		No					
	Big	**Yes**	Yes	No			
		No					
Special	**Normal**	**Yes**	Yes		Throw	Yes	
		No				No	
	Big	**Yes**	Yes	No		Yes	
		No					

Table 7. Results from participant 4

- **Q1 -** "I liked the interactivity. It detects the objects (litter) well."

- **Q2 -** "Instructions are not very clear but I eventually got it."
- **Q3 -** "Not that much but I understood the game because of the repeatability of the reactions. It wasn't explicit if I had to throw the litter."

6.1.5 Participant 5

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td rowspan="2">Big</td><td>Yes</td><td colspan="2">Yes</td></tr>
<tr><td colspan="3">No</td></tr>
</table>

Table 8. Results from participant 5

- **Q1 -** "I felt satisfaction when I got it right multiple times. It has a nice atmosphere."
- **Q2 -** "I felt that I was polluting the ocean and was being rewarded for it because it sounded positive when I got the thrash inside the bin and when I missed, it reprimanded me."
- **Q3 -** "It was very much effective."
- **Additional feedback -** "Having two cups of coffee and four bottles of juice made me think there was some meaning behind it. I thought the thrash had to be recycled. The visual component of it is impactful, but the sound component is what stood up for me. I was genuinely scarred when it got really angry."

6.1.6 Participant 6

- **Q1 -** "I liked the interaction with the bin, I found it funny when I missed and he would react negatively/mad."
- **Q2 -** "Sometimes it wasn't very precise, because there were times that I didn't miss and it acted angry."

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td>Yes</td><td>Yes</td><td>No</td></tr>
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<tr><td colspan="3">No</td><td>Throw</td><td>No</td></tr>
</table>

Table 9. Results from participant 6

- **Q3 -** "I was waiting the bin's reaction. It made me want to throw the litter to the ground and pick it up because I wanted to see what the bin would do."
- **Additional feedback -** "It would be interesting if it could detect different types of litter. It could be used to teach how to recycle, it could be an interesting future work."

6.1.7 Participant 7

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td><td rowspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="3">Yes</td><td rowspan="2">No</td></tr>
<tr><td colspan="3">No</td></tr>
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<tr><td rowspan="2">Big</td><td colspan="3">Yes</td><td>Yes</td></tr>
<tr><td colspan="3">No</td><td>No</td></tr>
</table>

Table 10. Results from participant 7

- **Q1 -** "I like the expressions of the bin, it was really expressive."
- **Q2 -** "The algae was distracting me because they were so different from the rest. In the last positive reaction, the big heart also distracted me."
- **Q3 -** "Without the feet I felt free to put the litter inside the bin that fell on the floor."
- **Additional feedback -** "The projector could be in another position to avoid shadows. If the conditions of the setup were better, the experience would be more immersive."

6.1.8 Participant 8

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
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<tr><td colspan="3">No</td></tr>
</table>

Table 11. Results from participant 8

- **Q1 -** "The bin was really funny. I liked its reactions."
- **Q2 -** "Nothing. But it wasn't great either. I was confused on what I was expected to do."
- **Q3 -** "By telling me the rules of the experiment, it was always my idea to put the litter inside the bin."

6.1.9 Participant 9

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td rowspan="2">Big</td><td colspan="3">Yes</td><td>Throw</td><td colspan="2">No</td></tr>
<tr><td colspan="3">No</td><td colspan="3">-</td></tr>
</table>

Table 12. Results from participant 9

- **Q1 -** "I liked the projection and the character in the bin."
- **Q2 -** "I didn't found the logic behind it being happy for having thrash inside but it must be because it can't distinguish the types of thrash."
- **Q3 -** "Not everybody will understand what is supposed to do. It's not very intuitive, I just understood it at my third try."
- **Additional feedback -** "I threw only the coffe cups because I thought I had to recycle."

6.1.10 Participant 10

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="3">Yes</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td colspan="3">Yes</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="3">Yes</td></tr>
<tr><td colspan="3">No</td></tr>
</table>

Table 13. Results from participant 10

- **Q1 -** "I found this experiment dynamic. I liked throwing the litter in the bin. I think it's a good game. If I had this game at home, I would play it."
- **Q2 -** "Nothing."
- **Q3 -** "I think it was very effective because of the bin's gestures. It got angry when the litter hit the floor and that was really convincing."
- **Additional feedback -** "It would be fun if the bin moved side to side."

6.1.11 Participant 11

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
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<tr><td colspan="3">No</td><td>Throw</td><td rowspan="3">Yes</td></tr>
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<tr><td colspan="3">No</td><td>Throw</td></tr>
</table>

Table 14. Results from participant 11

- **Q1 -** "I liked the freedom to chose the way to put litter inside the bin. The animations were beautiful."
- **Q2 -** "Nothing."
- **Q3 -** "It was, because it got angry when I missed and I didn't want it to be angry,"
- **Additional feedback -** "This experiment was so fun."

6.1.12 Participant 12

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="3">Yes</td><td>No</td></tr>
<tr><td colspan="3">No</td><td rowspan="4">Yes</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td colspan="2">Yes</td><td>No</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="2">Yes</td><td>No</td></tr>
<tr><td colspan="3">No</td><td>No</td></tr>
</table>

Table 15. Results from participant 12

- **Q1 -** "I liked throwing the litter to the bin. I was eager to see the bin's reaction."
- **Q2 -** "Nothing."
- **Q3 -** "When I miss, I always picked it up. In a normal bin I wouldn't do that."
- **Additional feedback -** "It was very repetitive because I had to do the same thing several times. I suggest adding levels of difficulty."

6.1.13 Participant 13

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
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<tr><td rowspan="2">Big</td><td colspan="2">Yes</td><td>No</td><td rowspan="2">Yes</td></tr>
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Table 16. Results from participant 13

- **Q1 -** "I think the bin's expressions were funny."
- **Q2 -** "Sometimes it wouldn't detect the litter correctly because it got mad even though I didn't miss."
- **Q3 -** "It was effective. I was the one that wasn't very effective at hitting the bin."

- **Additional feedback -** "I noticed there was two versions of happy and mad. I liked very much the more expressive one (Special UI). This could be a bit aggressive for children."

6.1.14 Participant 14

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
<tr><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td>Yes</td><td>No</td><td>-</td><td rowspan="8">Carry</td><td rowspan="3">No</td><td rowspan="8">No</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td>Yes</td><td>No</td><td>-</td></tr>
<tr><td colspan="3">No</td><td>Yes</td></tr>
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<tr><td colspan="3">No</td></tr>
</table>

Table 17. Results from participant 14

- **Q1 -** "I liked it, it was fun."
- **Q2 -** "Nothing."
- **Q3 -** "I was already going to put it inside the bin."
- **Additional feedback -** "At first when the bin was big and mad I got scarred."

6.1.15 Participant 15

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
<tr><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td colspan="3">Yes</td><td>Throw</td><td rowspan="2">Yes</td><td>Yes</td></tr>
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<tr><td colspan="3">No</td><td>Carry</td></tr>
</table>

Table 18. Results from participant 15

- **Q1 -** "I liked the idea of animating the bin, it looked like a cartoon."
- **Q2 -** "I was confused on what was expected of me."
- **Q3 -** "It was effective."

6.1.16 Participant 16

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td rowspan="2">Big</td><td colspan="3">Yes</td><td rowspan="2">Yes</td></tr>
<tr><td colspan="3">No</td></tr>
</table>

Table 19. Results from participant 16

- **Q1 -** "Very fun game. It was very well made."
- **Q2 -** "This was a bit too repetitive."
- **Q3 -** "It was effective because it got happy when I threw the litter and mad when I missed. I understood what it wanted from me."
- **Additional feedback -** "Could be fun to show this in schools because it's so interactive. Kids will love it."

6.1.17 Participant 17

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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<tr><td colspan="3">No</td></tr>
</table>

Table 20. Results from participant 17

- **Q1 -** "The overall environment of the set was magical. Beautiful animations."
- **Q2 -** "I didn't like when the bin got mad"
- **Q3 -** "It was very effective. I wanted to see the bin happy"
- **Additional feedback -** "Maybe change the bin from being so mad and be disappointed instead."

6.1.18 Participant 18

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
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</table>

Table 21. Results from participant 18

- **Q1 -** "I was excited to see what reactions the bin was able to show."
- **Q2 -** "It was very repetitive but I was ok with it because I wanted to see what would happen."
- **Q3 -** "I think it was because after missing once, I didn't leave litter on the floor again."
- **Additional feedback -** "I would like to see this in a set with better conditions, a bigger room, a better projector."

6.1.19 Participant 19

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
<tr><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td>Yes</td><td colspan="2">No</td><td rowspan="8">Carry</td><td colspan="2" rowspan="8">No</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td>Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td>Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="3">No</td></tr>
<tr><td rowspan="2">Big</td><td>Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="3">No</td></tr>
</table>

Table 22. Results from participant 19

- **Q1 -** "It was fun, I liked the background music. It was very peaceful."
- **Q2 -** "I didn't understand what this was for, but maybe that was the goal."
- **Q3 -** "I didn't litter."

<table>
<tr><th>UI</th><th>Size</th><th>DC</th><th>Saw DC?</th><th>Stayed in DC?</th><th>Delivery</th><th>Littered?</th><th>Left litter on floor?</th></tr>
<tr><td rowspan="4">Normal</td><td rowspan="2">Normal</td><td colspan="3">Yes</td><td rowspan="4">Throw</td><td colspan="2">Yes</td></tr>
<tr><td colspan="3">No</td><td colspan="2" rowspan="2">No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="3">Yes</td></tr>
<tr><td colspan="3">No</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="4">Special</td><td rowspan="2">Normal</td><td colspan="2">Yes</td><td>No</td><td>Mixed</td><td>Yes</td><td rowspan="4">No</td></tr>
<tr><td colspan="3">No</td><td>Throw</td><td>No</td></tr>
<tr><td rowspan="2">Big</td><td colspan="2">Yes</td><td>No</td><td>Mixed</td><td>Yes</td></tr>
<tr><td colspan="3">No</td><td>Throw</td><td>No</td></tr>
</table>

Table 23. Results from participant 20

6.1.20 Participant 20

– **Q1 -** "I had fun. The idea is amazing, it almost feels like I was in the ocean."

– **Q2 -** "The instructions were a bit mystical."

– **Q3 -** "It was because when it got really angry I felt pressured to not miss."

– **Additional feedback -** "It could be cool to have a score shown and have a competition with other people."