Improving Waste Separation Motivation on the Campus of the University of Twente

Creative Technology Bachelor Thesis

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August 1, 2023

Abstract

Landfills and the consumption pattern that has developed with modern age are becoming an increasing problem. These problems contribute to the greenhouse gasses that cause global warming. To diminish these landfills, waste separation is crucial. Currently at the University of Twente 31.6% of the PD, 18.5% of the organic, and 17.9% of the cardboard and paper waste is thrown away in the residual waste. The lack of motivation inhibits the individual's waste separation behavior. Therefore, an interactive waste island is developed that motivates and educates the users to separate their waste. The results revealed that for the short term motivation this installation is a success. Moreover, it educated waste separation knowledge using human intelligence. It showed potential to enhance the motivation of separation behavior. This research can be used to influence and motivate the UT community to improve on its waste separation, and help University of Twente achieve their waste plan.

Acknowledgement

I would like to express my deepest gratitude to my supervisors, Richard Bults and Katarzyna Zalewska. For mentoring and guiding me throughout this whole process. Thank you for the enjoyable weekly meetings with laughter and all seriousness when needed. You have helped me to a great extend. I had the pleasure of working together with my co-researcher Marina Stefanova these past five months. We have come a long way together, and helped each other to get to where we are now. Additionally I would like to thank my friends and family for all the support during this process.

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1 Introduction

Today, landfills are a growing problem due to the increasing world population and the consumption pattern that has developed with modern age. The landfills continue to enlarge and therefore increasingly contribute to the greenhouse gases that cause global warming. [1] To diminish these landfills, waste separation is crucial. Waste segregation clears the way for the process of reuse, recycling and recovery of waste. Thus, waste separation contributes to the prevention of further global warming and so it is of high concern to the world nowadays. Since 2020 the University of Twente has implemented a waste plan to increase its sustainability. The objectives of the waste plan are to be a sustainable organisation by 2030 and to be a circular campus by 2050. Therefore, the University of Twente made waste islands to help with the waste separation on the campus. These waste islands contain 4 waste streams: fruit and vegetable, paper and cardboard, PD (plastic and beverage containers), and residual waste, to help the staff and students dispose of their waste in the correct bin. [2] However, this is not always done correctly on the campus. To aid the University of Twente with this issue, smart technology is explored to influence the motivation of the staff and students of the university on waste separation.

Since 2020 the University of Twente has a waste plan to increase its sustainability. There are three main objectives for the topic of waste management. The subsequent goals have been established:

1. To be a single use plastic free campus by the end of 2022
2. To be a waste free campus by 2030
3. To be a circular campus by the end of 2050

The main goal of this strategy plan is to prevent, reduce and improve waste by means of recycling. [2] To achieve this the UT community's behaviour needs to change to be able to create good waste separation habits. However, this does not come without its challenges. The lack of motivation of the staff and students is one of the main factors that inhibits the waste islands from being used to their full potential. Proper waste separation requires more time and effort, which can be a challenge for people. Currently 31.6% of the PD, 18.5% of the organic, and 17.9% of the cardboard and paper waste is thrown away in the residual waste. Which is then burned with the residual waste. This PD and paper could have otherwise been recycled. Therefore, an intervention should be made to tackle these factors and thus change the behaviour of the UT community. A solution to this problem should enable fast and easy separation.

1.1 Research Goal and Question

Currently there is still a disconcerting amount of waste in the wrong waste stream bins at the campus of the University of Twente. This could either relate to the lack of education of what waste goes where or it may also be considered that proper waste separation takes more time and therefore more effort. For many individuals, having to invest more effort into an action is demotivating. Hence, motivation is a key aspect of getting the UT community to separate waste properly. One of the key aspects of motivation is time. Throwing away trash should be as fast and efficient as possible.

This project's goal is to design an intervention that will influence the UT community's behaviour and motivation so that waste separation will be as easy as possible. "How can a smart technology based intervention be used to influence the motivation of the UT community towards proper waste separation at the UT campus?" This is the research question of this project.

1.2 Structure

The report is structured in multiple sections which are divided into chapters to create a cohesive story on the development of the intervention to improve waste separation at the University. This first chapter introduces the challenge and the goals. While the second chapter provides the background research on the topic. It looks into the motivation behind waste separation, and how this behaviour can be influenced positively. Furthermore, interviews will be conducted on the UT community in order to obtain more information about what the motives are behind waste separation and what they think can be done to improve this behaviour. In the third chapter the methods and techniques used during the research are discussed. The design process of Creative Technology is discussed. Chapter four contains the ideation process of the project. How the idea will be implemented and what the intervention will look like. Chapter five will involve the specifications of the research. Thereafter chapter six and seven will consist of the realisation and evaluation of the project. Chapter eight will be the discussion and conclusion. Lastly, chapter nine will discuss the potential future work of the project.

2 Background research

2.1 Literature Review

2.1.1 Separation of Waste

Currently in the Netherlands 60% of the domestic waste is separated. This signifies that 40% of the waste is not recycled and thrown out with the residual waste. Two thirds of the domestic waste consists of valuable recyclable materials, while most of these materials are incinerated with the residual waste. [3] To improve the level of recycled material, the Dutch government wants to improve the quality of the collected waste streams. Therefore, more attention should be paid to waste separation. The government wants to decrease the residual waste per person per year by 75%. To achieve this goal, municipalities are required to follow the agreement of contributing to waste separation. It does not matter how they separate the waste, as long as it is separated. Thus, Enschede also has to adhere to this statement, and therefore, the University of Twente also has to take part of this agreement.

2.1.2 Behavioural Aspects of Waste Separation

There are various theories that analyse the motivation and behaviour of people on waste separation and that can aid with finding the factors that influence the behaviour of waste separation. [4] One of these theories is looked at to find the key issues when it comes to disposing of waste. This is the theory of planned behaviour.

2.1.2.1 The Theory of Planned Behaviour

The theory of planned behaviour helps with identifying the factors that influence waste separation behaviour in the UT community. The theory of planned behaviour uses three variables that are found when predicting behavioural intentions. These three variables are: the attitude towards the behaviour, subjective norms with respect to the behaviour, and the perceived control over the behaviour. [5] The attitude towards behaviour is an evaluation of self performance on a particular behaviour. "They are indications of how hard people are willing to try, of how much of an effort they are planning to exert, in order to perform the behaviour." [5, p.181] The subjective norms relate to a person's beliefs about whether people in their immediate surroundings think he or she should engage in the behaviour. "Generally speaking, people intend to perform a behaviour when they evaluate it positively and when they believe that important others think they should perform it." [6, p.12] Furthermore, the perceived control over the behaviour is about if the individual perceives that the performance of a certain behaviour is feasible. "The importance of actual behavioural control is self-evident: The resources and opportunities available to a person must to some extent dictate the likelihood of behavioural achievement." [5, p.183] The more accessible a certain behaviour is, the more likely one will intend to perform the behaviour. [7] With these three concepts the main factors that influence waste separation behaviour can be deduced.

2.1.2.2 The Theory of Planned Behaviour regarding Waste Separation

According to previous studies there are three main points when it comes to proper waste separation. When looking at the attitude towards behaviour most people that are well educated on the topic tend to care more for the environment. The social factors show that the social aspect of an individual has a high impact. Those who have more consideration for the community and repercussions of recycling focus more on waste separation. Moreover, the perceived control has a high impact on waste separation of individuals. The lack of time and the inconvenience inhibits the individual's waste separation behaviour. [8, 9] The most prominent factor that prevents full potential waste separation is the effort that needs to be put into waste separation. The lack of effort and the lack of knowledge prevents students from separating waste properly. This is one of the key factors that should be taken into account when designing for an improvement of waste separation at the UT.

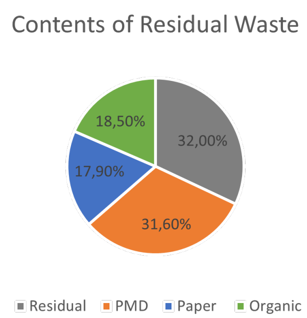
2.1.3 Waste Separation at the UT

2.1.3.1 Current Issues

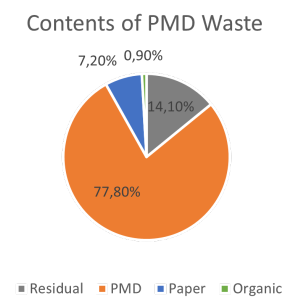
Currently the University of Twente has designed and implemented new waste bins which are called the 'waste islands'. These waste islands contain 4 waste streams: fruit and vegetable, paper and cardboard, PD (plastic and beverage containers), and residual waste. These bins have been implemented since 2017 and were designed to motivate the UT community to separate their waste. Moreover, the trash cans in the lecture halls were removed to urge individuals to use the waste islands. Students in the Netherlands are unassertive regarding separating their trash successfully. Even though students know what items go into which waste stream, the actual sorting behaviour is less accurate. [10] They seem to gather all their waste and dispose of it together without separating it first. [11] This is one of the biggest issues regarding improper waste separation at the University of Twente. Motivation is one of the main issues when it comes to improper waste separation at the university.

2.1.3.2 Current Data

In the waste plan of 2021 data stated that 68% of the waste that is thrown into the residual waste bin can be separated into one of the other bins. This is data from a waste analysis done on January 23rd, 2020. The waste of two or three bins was collected, and then analyzed by sorting the waste into four categories: residual, PMD, paper & cardboard, and fruit & vegetables. When observing the data it can be seen that 18.5% of the residual can be disposed into the organic bin, 17.9% in the paper bin, and 31.6% into the then called PMD (plastic, metal, and drinking cartons) bin, see figure 1a. This implies that the possibility to increase the university's recycling rates is high. Furthermore, 22.2% of the waste disposed into the PMD bins, was supposed to be separated into the other bins see figure 1b. Even though on April 1st of 2023 the PMD changed to PD, this information is still relevant. Now even more waste is thrown away improperly since not everyone of the UT community knows metals currently belong in the residual bin.



(a) Pie chart on the contents of the residual waste bin



(b) Pie chart on the contents of the PMD waste bin

Figure 1: Division of waste in the residual and PMD waste bins

Another waste analysis was done by the researchers of this project and a similar project (Marina Stefanova & Eva Barten, and Hans Nielen & Victoria Tyminski). This research was done on the 17th of may, 2023. During this analysis, the contents of one waste island were analyzed, see appendix A. The contents of every separate bin was analyzed to see how much of the bin was separated correctly. From all the bins together 51.76% of the waste was separated incorrectly according to the separation rules of the UT, see figure 2. Therefore, it can be said there is still a lot to change when it comes to proper waste separation at the UT.

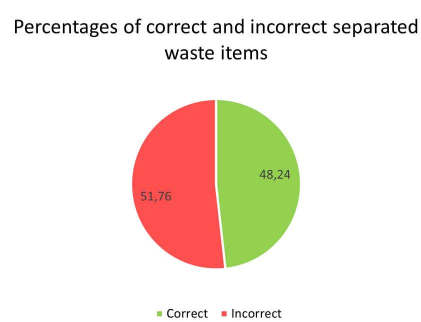


Figure 2: The current percentages of correct separated waste items

2.1.4 Designing for Motivation

2.1.4.1 Psychological Fundamentals of Motivation

There are various factors to consider when designing a smart technology installation for motivation and education. From the findings on behavioural change, it can be said that behavioural components are related to the individual beliefs, the social environment and the external motivation. [5] Several concepts of psychological fundamentals related to behavioural change can be given. These are concepts that help designers motivate the user through the use of technology. The concepts are: self-efficacy, cognitive-restructuring, social influence, vicarious learning, shaping, the nudge theory, and behavioural momentum. [12]

Self-efficacy is about the personal beliefs of the individual to reach certain goals. [13] The users of the technology that will be equipped will have to perceive that they have the capability to use it.

Cognitive-restructuring is the ability to learn new skills, and identifying disruptive behaviours. For example, the use of cognitive-restructuring through virtual reality can be used to treat fear of flying. [14] In this case the concept can be implemented in a way that the user keeps on thinking about waste separation every time the product is used. This will trigger waste separation behavior.

Social influence is the individual's goals that are reached compared to others. The end product can make use of social influence to pressure the user to separate waste, by using social pressure to do the right thing.

Vicarious learning is learning through observation. Seeing someone perform something and learning it through mimicking. [15] This can be used in the installation so that the UT community members can observe each other while separating, and gradually learn from other and the installation.

Shaping is gradually shaping the user to perform a specific behaviour.

The nudging theory is when the installation suggests the user in a non-forced way to act in a particular manner. [16] For example, in Eindhoven smart city lights tried to influence individual's behaviour by changing the light intensity and colour of the street lighting in areas of high nightlife crime and disturbance. The lights nudge individuals to calm down or take different routes. [17] This concept can also be introduced in this project in a way that uses technology to persuade users to perform the right separation behavior. For example, by using positive sounds or progress bars.

Behavioural momentum determines the threshold of change. So at what point change is triggered. [12] This is useful during the process of making the product. It is important to see what is needed in the product to trigger change. These concepts are all motivation techniques, and when implemented correctly they can motivate the individual to behave in a certain way using technology.

2.1.4.2 Principles to Design for Motivation

Moreover, when designing for human technology interaction a few motivational principles should be kept in mind. Technology can be an effective tool for motivating people when the concepts of autonomy, competence, and relatedness are clearly defined in the design. This is called the self-determination theory. [18] Autonomy is when the user feels like they are in control of the situation in which the design is used. For example in digital platform design feedback channels are important so they can express their needs and feel like they are contributing and making an impact. [19] The competence factor is about how easy it is for the user to operate the design or installation. Such as when designing a digital platform the focus should be put on the design of intuitive usability. [19] Furthermore, the relatedness reveals the feelings of closeness and belonging to a social group. For example to what extent the user tends to abandon responsibility for the intervention. [18] A product design should revolve around these factors for optimal user productivity.

2.1.4.3 Influence of Technology

Furthermore, there are four ways in which technology can exert influence on the user. These are situated in the two dimensions on which the experience of influence can be classified. These dimensions are force and salience. The force can be experienced from weak to strong and the salience can be experienced as hidden or apparent. [16] With these dimensions the four types of influence can be distinguished: coercive, persuasive, seductive, and decisive design. Coercive design is strong and apparent. For example, having to spend money to buy more lives in games such as Candy Crush. [20] Persuasive design is when the force is weak however, the technology is apparent. For example, persuasive technology can be used to create a sense of self-efficacy in fitness apps, or the km/L meter in the car that persuades the driver to drive more eco-friendly. [21, 22] Seductive design is weak and hidden. Such as self-reflection stimulating feedback technology in the car [23] Furthermore, decisive design is strong in its influence and not visible. For instance, a building without elevators so that physical activity is ensured. [16] These four types of influence can help when designing for behavioural change and motivation.

2.2 State of the Art

To obtain more information about how to find a solution to motivate the UT community on their waste separation, an analysis is made of already existing solutions and technologies. The following state of the art look at the gamification aspect, the theory of planned behavior and persuasive design.

2.2.0.1 The TrashBot

The Trashbot, see figure 3, is a smart recycling bin that sorts items itself. Through the use of robotics and machine learning the TrashBot identifies and sorts items into the correct corresponding waste stream bin inside the robot. This system helps prevent human error in waste separation. The robot has a 95% accuracy in sorting the waste. The company advertises the robot for its ability to increase the user education, reduce recyclable contamination, create a positive recycling return of investment, it is able to get smarter over time with machine learning, and it is a high waste solution for high traffic areas. The bin uses artificial intelligence to recognize the type of trash and learns from this. That is how the TrashBot is able to get smarter over time. It is also able to track the types of waste. This bin helps with the *perceived behavior control* part of the theory of planned behavior. It makes it easier for the user to dispose of waste. [24]

Figure 3: The TrashBot

2.2.0.2 The ReCollect Waste Game

The Rethink Waste game is an interactive game that tests the user's recycling knowledge, see figure 4. It is developed by the city of Surrey to help their inhabitants gain knowledge on what type of waste goes into which bin. It gives feedback on what type of waste is usually separated wrong and gives information on how to separate the waste properly. This game is designed for this city with various waste stream bins that are located in the city. They have six different waste streams: Food waste composting, recycling, residual, yard waste composting, bulk pick ups, and household hazardous waste and electronics. There are five levels to choose from with increasing difficulty. A certain type of waste is shown and the user needs to drag it to the correct bin. The waste does not disappear until it is disposed of correctly. When 5 items are separated correctly the user continues to the next level, and is allowed to drag one of the playground items into their own park. This way the user can design their own park as a reward for proper waste separation. This state of the art uses *gamification* to motivate the users to pay attention to waste separation and makes them learn more about the topic. [25]

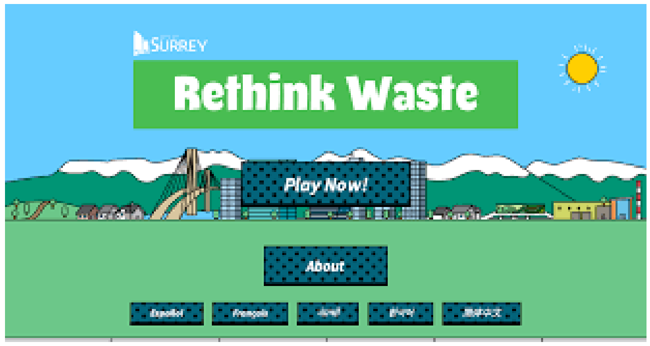


Figure 4: The Recollect waste game

2.2.0.3 The TetraBin

The TetraBin is a combination of artificial intelligence and the internet of things, as seen in figure 5. Sencity is a company that refashions a city's interfaces and transforms them into smart and interactive environments. They want to turn cities into 'joy full playgrounds', to motivate positive behaviours. They developed the TetraBin to encourage proper waste disposal. They argue that when inserting one of these smart bins into a high traffic area a meaning has been given to the people in that area to dispose of their waste. The bin has a LED wrapped exterior to portray a game. The user needs to act and put the waste into the bin at the right time to achieve the goal of the interactive game. The game on the bin can be set to various different games such as Tetris or other old games. The bin allows the user to collaboratively control the blocks on the screen by disposing of a waste object. For the Tetris game the user pushes the block to the bottom by throwing something in the bin. This state of the art also used *gamification* to make a day to day task more fun. The Tetris bin uses social gamification to make the disposal of waste more intriguing. [26]

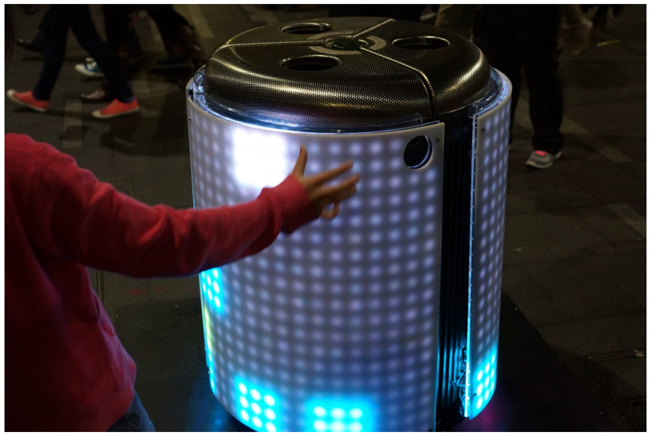


Figure 5: The TetraBin

2.2.0.4 The Fun Theory 2

This is a campaign made by Volkswagen to help keep people from throwing waste into the bin instead of throwing it onto the ground, see figure 6. This bin is situated in a park and makes noise once a waste object is thrown into the bin. The sound it makes is that of an object that does not stop falling for a long time. This sound is also used in cartoons where characters fall down a deep hole or off of a cliff. This sound is intriguing and unexpected, and motivates the audience to keep throwing waste into the bin. This project uses *persuasive sound* to attract the attention of its target audience. [27]

Figure 6: World's deepest bin

2.2.0.5 Graduation Project Senna and Younghun

To be able to answer the question of how to improve the waste separation behaviour of the community of the University of Twente, Senna and Younghun created an installation. This is previous project completed in 2022 on the same topic of waste separation. Their installation helped the UT community separate their waste with the use of human intelligence. They created an interactive installation where the user could select the trash that they needed to dispose of on a display and the installation would show the user in which bin the user's waste should go. This project uses *persuasive design* to persuade the user to dispose of their waste into the correct bin. The project nudges the user to do the right thing. [28, 29]

2.3 Expert Interview

During the first meeting with the client of this project, B. Dragtstra, from the CFM-UT, the most important factors of waste separation were discussed. Furthermore, the unknown waste items were discussed. These are the waste items that are frequently disposed of wrong at the University of Twente. Dragtstra mentioned some of the most common unknown waste items. For example, oily pizza boxes should go into the residual, used tissues and plastics with food residue go into the residual bin, and the paper cups go into the PD bin. Moreover, she gave us updates on various waste separation projects that have started at the UT and how they are going. For example, she mentioned a project made by Greenhub UTwente, they made various posters and visualizations of what type of waste should go where. They also made a video that explains clearly what waste goes into which bin and why proper waste separation is important to uphold.

2.4 Discussion and Conclusion

Currently the UT community is not separating their waste properly. There are multiple main factors that play a role in this. According to the theory of planned behavior. [5] The more people are educated on the topic of waste separation, the more likely it will alter their behavior positively. Furthermore, people that have more consideration for their immediate environment focus more on recycling. Lastly, the lack of time and inconvenience inhibits proper waste separation. The inconvenience of having to separate items that are disposed differently in a home environment than at the UT, can cause confusion and can demotivate the UT community. To be able to motivate the UT community to separate their waste properly using technology, a few design techniques can be applied.

Technology can be designed in a certain way to be able to influence the behaviour and motivation of waste separation. Waste separation should be as effort and time efficient as possible, more attention should be focused on the motivational aspect of waste separation. This can be achieved through the combination of motivational design concepts and principles and the implementation of influential design. Thus, to be able to influence waste separation behaviour, technology should be designed in a way that uses one of the four concepts of influence and combine this with the three principles of motivation and one or more of the concepts for motivational design. This way the optimal technology can be designed to motivate and educate individuals on the approach of proper waste disposal.

The motivational concepts of social influence and the nudging theory are interesting to look at when designing the intervention. These two factors could be very useful for designing for behaviour change in the topic of waste management. The intervention could use social influence to pressure the UT community to work together to achieve the desired goal of proper waste disposal. The nudge theory could help the installation direct the user to throw the waste away in the correct bin. Furthermore, the intervention needs to adhere to the principles of autonomy, competence, and relatedness to make sure that the UT community uses the intervention. Lastly, it is useful to keep in mind the types of influence that technology can create to change behaviour.

3 Methods and Techniques

In this chapter the methods and techniques of this research are described. The key method used during the research is the design method of the Bachelor Creative Technology. Diverse techniques are used to identify the stakeholders and the preliminary requirements. Furthermore, they can be used during the ideation phase to come up with the leading concept. Furthermore, an evaluation method can be used to evaluate if the requirements are achieved.

3.1 Design Method

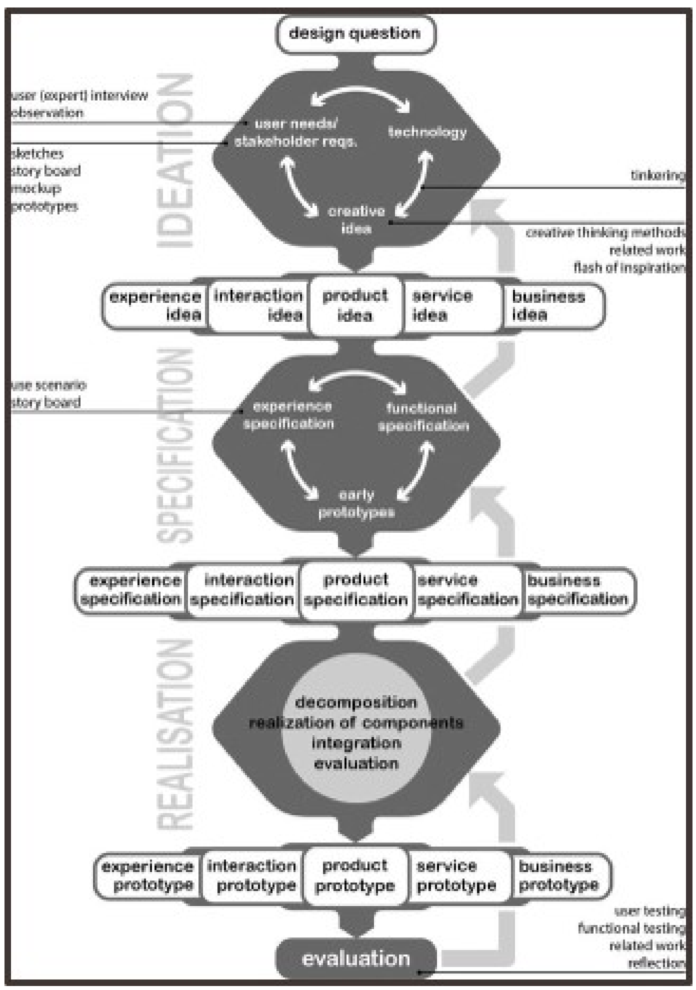


Figure 7: The design process for Creative Technology

During the research the Creative Technology design process is used, see figure 7. The design process is made up of three components. Each accommodating a few steps. First, is the ideation phase. The phase where background research is done, such as, user or expert interviews and observations. The stakeholder needs are taken into consideration and creative ideas are thought of. Afterwards sketches, storyboards and mock up prototypes are fabricated. Next is the specification phase, the phase where the functional and non-functional requirements are identified and user scenario story boards are made. The product is specified and what exact functions are needed in the prototype and how these functionalities work together to make the whole system as smooth as possible. The realization phase is when the prototype is assembled. First is the realization of all the components which make the functionality of the prototype, then the whole system is integrated. The integrated system is evaluated and improved upon during this stage. When the realization is concluded, the final prototype is evaluated. This is achieved through the use of user testing, functional testing, and reflection.

Immediately upon finishing the evaluation step, the process can start all over again if time allows for it. The problems that arise during the evaluation can be handled and improved upon. This way the process can take a step back to the realization so that certain functions can be altered. The Creative Technology process creates the freedom to go a step back and revise the work that has been done.

3.2 Ideation Phase

3.2.1 Stakeholder Identification and Analyzation

The stakeholder analysis is done at the start of the project, this is because it will provide useful insights to help develop the design. It identifies to what extent the stakeholders have influence on the project and on what level they are involved in the project. Furthermore, from this analysis the stakeholder requirements are identified. The Stakeholder analysis used is the Stakeholder Salience Model (SMM) [30] This is where the degree to which the project developers give priority to the stakeholders is analyzed. In this model three intertwining dimensions are shown in a Venn diagram. Therefore, creating eight different categories in which the stakeholders can be classified in. To enumerate these three dimensions are: power, legitimacy, and urgency. Power is the stakeholders ability to influence the project to their own will. The legitimacy category regards the stakeholders relationship with the project and if this relationship is pertinent. The urgency is to what extent the stakeholder can claim urgent attention. The stakeholders can be divided into one of these eight categories to be able to analyze what type of stakeholders they are and to what degree they affect the development of the project, see figure 8.

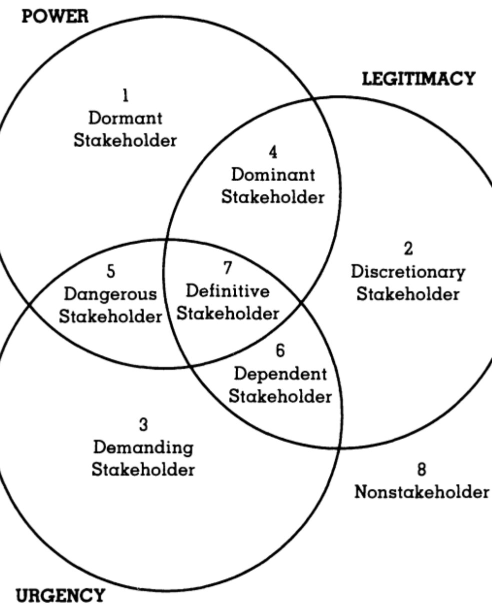


Figure 8: The SMM Venn diagram

1. Dormant: these types of stakeholders have power which they can use to impose their will on a project. However, they do not have an urgent claim or a legitimate relationship.

2. Discretionary: these stakeholders possess legitimacy when it comes to the project, while they have no urgent claim or power.

3. Demanding: stakeholders that have an urgent need however they do not have either legitimacy or power. These stakeholders are not dangerous or important.

4. Dominant: these groups have power and legitimacy, however, have no urgency to act upon these claims.

5. Dangerous: a stakeholder that has power and urgency but does not have legitimacy. These stakeholders can be coercive.

6. Dependent: these stakeholders do not have power, while they do possess urgency and legitimacy. The stakeholders depend on other stakeholders to fulfill their needs.

7. Definitive: the stakeholders that maintain all three dimensions. these are considered to be the stakeholders with the highest priority. They can influence the outcomes of the project.

8. Non-stakeholders: these do not influence the project in any way.

3.2.2 Requirement Elicitation and Prioritization

The requirements are classified using the MoSCoW method, see table 2. [31] This method is when the requirements are divided into three categories: must, should, could, and won't. They are divided based on the needs of the stakeholders and how influential these stakeholders are. The most prominent requirements are listed as must requirements. The end product must have these requirements implemented. The should category is when the features have a fair chance of being implemented, however, when the time and skills are limited they do not have the highest priority. The could category is when there are no problems in implementing the must and the should requirements. Lastly, there are the won't have requirements, these requirements are features where there is no time to develop them into the intervention. There are no won't requirements mentioned since the other three categories specify the requirements well enough.

3.2.3 Brainstorming

During the ideation phase, brainstorming is done in collaboration with co-researcher Marina Stefanova. The brainwriting technique in combination with verbal brainstorming is used. [32] The brainwriting technique is when the researchers write down every idea that comes to mind within a couple of minutes. It does not matter how crazy the idea is. This generates multiple diverse ideas. In this case the researchers write their ideas down on paper at home and take more time to think about the ideas than the technique suggests. Then the ideas are walked through with each other. This is verbal brainstorming. The ideas of both researchers are combined and ten ideas are thought of. Then these ideas are formed into five more detailed technological concepts. Finally, two of the favorite ideas are combined using a SWOT analysis.

3.2.4 Concept Analysis

The SWOT analysis is used to analyze the two best concepts and how these could be altered to create one final concept. A SWOT analysis is when a concept or idea is analyzed using four categories: strengths, weaknesses, opportunities, and threats. [33] The analysis helps assess the internal factors of the product such as the strengths and weaknesses, and it helps to assess the external factors, such as the opportunities and threats. When inserting these categories into the SWOT analysis template, see figure 9, the two ideas can be compared and contrasted.

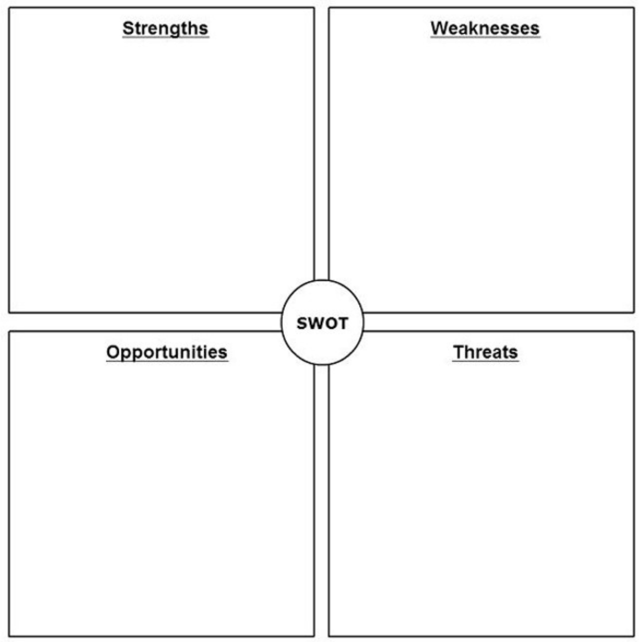


Figure 9: The SWOT analysis template

3.3 Specification

The specification phase starts with an experience identification. Personas are made that can resemble types of stakeholders that would make use of the product. They reflect the end-users of the installation. With these personas, user scenarios can be constructed that imply how these particular persona would utilize the product in certain situations. This way the interactions between the installation and the user can be analyzed. After the user scenarios are studied, the functional and non-functional requirements of the product are identified. These are the technical functions that are needed for the product to work as intended. These requirements can eventually be tested to see if the product succeeds or not. Once the requirements are clear black box models are made to establish the working of the system and how the separate functions are integrated to create one whole product. Three levels of specification are given: level 0, level 1, and level 2. With level 0 showing the inputs and outputs of the system, level 1 describing how the functions are connected to each other, and level 2 showing the details of the functions. Lastly, time sequence diagrams are made for multiple scenarios to indicate the user interaction.

3.4 Realization

During the realization phase, the functions that are designed in the specification phase are realized and integrated. The hardware and software come together to make the prototype of the project. This prototype is then tested on its functional requirements through a functionality test. The researchers need to make sure that the prototype functions well enough before testing it in the evaluation phase of the project. The functional requirements are tested separately and checked off one by one. This is a crucial element of the project since a defective prototype will result in bad results during the evaluation.

3.5 Evaluation

During the evaluation phase user testing will be done to test the final prototype. This way the non-functional requirements of the prototype will be assessed. The user-testing is executed by members of the targeted user group. They can evaluate the prototype to see if their user needs are met and at what level they are satisfied. During the evaluations new user needs can be discovered, that can be added to the project in the future. After the participants have interacted with the prototype, a short interview is conducted with them and they are asked to fill in a survey. With this information the researchers can reflect on the prototype and see what further improvements can be made, to gain better results.

4 Ideation

In this chapter the ideation phase of the project is explained. The first part of this phase concerns the identification of the stakeholders by means of a stakeholder analysis. They are analyzed and their requirements are collected. These preliminary requirements are discussed and narrowed down. Furthermore, the initial concepts are explained and visualized. Finally, the final concept is introduced and a scenario is given. It should be taken into consideration that this concept checks off all the preliminary requirements.

4.1 Stakeholders

The stakeholders are vital to the intervention that improves waste separation at the University of Twente. The development of the project is dependent on the stakeholders and what requirements they set for the intervention. However, they first need to be identified. Stakeholders include any person, company or institution that can affect or be affected by the project. [34] They have an interest in its outcome because it benefits them in a certain way.

4.1.1 Stakeholder Identification

Table 1 shows the stakeholders, what their roles are in the project and who their contacts are. The are several stakeholders who can influence the project.

Stakeholder	**Role**	**Contact**
UT community	Users	-
CFM-UT	Experts	Birgit Dragtstra
Waste Companies	External	-
Supervisors	Decision makers	Richard Bults and Kasia Zalewska
Designers	Decision makers	Marina Stefanova and Eva Barten

Table 1: Stakeholders of the project

4.1.2 Stakeholder Analysis

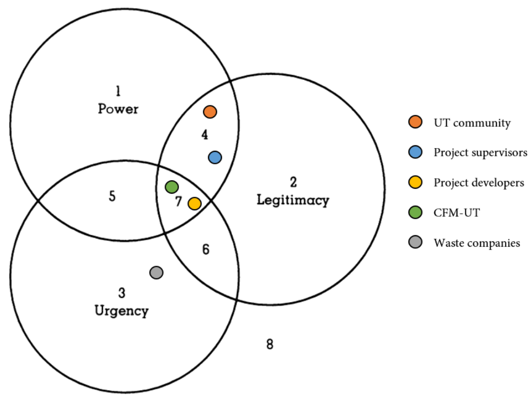


Figure 10: The SSM model of the stakeholders

There are five stakeholders involved when it comes to this project, see table 1. The following are the analysations of the diverse stakeholders that can influence the project, and how much influence they have according to the SSM (Stakeholder Salience Model).

4.1.2.1 The UT Community

The UT community can be seen as a *dominant* stakeholder. The community members are the individuals who produce waste during working and studying hours and make use of the university's facilities. They are the group who make use of the waste islands and decide what waste goes into which waste bin with the current knowledge they have. Therefore, they have a high influence on how effectively the waste is separated at the UT. It can be said that they have high power in regarding this project. Hence, they should be closely involved with the development of the design and functionalities that revolve around the project. Therefore they have a high legitimacy regarding the design. A stakeholder that possesses the combination of power and legitimacy can be called a dominant stakeholder. If specific parts of the intervention do not operate properly for the community then these must be revised and improved upon.

4.1.2.2 CFM-UT

Another important stakeholder is the facility management (CFM) at the University of Twente. They are the clients of this project and are pursuing a more sustainable campus. To achieve this they wrote a UT waste plan. [2] Their aim is to improve the quality of waste separation to be able to achieve their main sustainability goals for the upcoming years. CFM-UT is a decision maker and executes environmental policies to sustain their goals. Therefore, CFM has significant power when it comes to the intervention. Furthermore, as a client they have legitimacy regarding the project since they have a lot of influence in the design and functionality phase of the project. According to their waste plan [2] becoming a more sustainable university is crucial for the future of the university and of the environment. CFM-UT can be placed in the *definitive* area of the model since this stakeholder influences the project through having power, legitimacy, and urgency.

4.1.2.3 Pre-Zero

The waste company involved with the waste management at the University of Twente is called Pre-Zero. This company can also be seen as a stakeholder. They would be a *demanding* stakeholder in the case of this project. They would profit from the fact that there is better waste separation at the university. When the university separates waste more properly, it makes waste management for Pre-Zero more efficient. However, they will not be the users of the end product which gives them little influence on the design of the intervention. Thus they do not have power or legitimacy but they do have a higher urgency for the product.

4.1.2.4 The Supervisors

The project supervisors can also be recognised as stakeholders in the project. They can be seen as *dominant* stakeholders. They have high legitimacy since they can directly influence the development of the project. They decide what ideas are approved of and which are disapproved, and in which directions the project develops. They therefore also have the highest power when it comes to the design of the invention. Yet the urgency of this stakeholder is relatively low, they assist the developers in their decision making but do not have the urgency that the clients or developers have. They are key in the process of this project.

4.1.2.5 The Developers

Marina Stefanova and Eva Barten (myself) are the developers of this project. We will be working closely together on the project, however, we have our own section to work on. Marina works on the interactive media parts of the project, and I will focus on the hardware and software of the system. Eventually there might be some overlap between the two sections as they need to be integrated with each other to create the intervention. Since Marina and myself will be collaborating closely together to develop this product we can be identified as *definitive* stakeholders. We have power, legitimacy and urgency as key developers of the intervention.

4.1.3 Preliminary Requirements

The needs and requirements of the stakeholder is an extensive part of developing a project. When designing a product it is important to keep the requirements of the stakeholders in mind and to implement these requirements into the design. Doing background research (chapter two), interviewing the client (Birgit Dragtstra), and having meetings with the supervisors resulted in several preliminary requirements. There are 12 preliminary requirements and they come from communicating with the stakeholders, see table 2.

Number	Requirement	Stakeholders
1.	**Must** not alter the waste islands: no changes in design of the information stickers, size, font, or waste bin holes	CFM-UT
2.	**Must** be designed for motivation	Background research, supervisors
3.	**Must** be time efficient	Background research, supervisors
4.	**Must** educate on the often improper separated waste items	Background research, supervisors
5.	**Must** use human intelligence to educate the waste items that are frequently disposed of incorrectly (unknown waste items)	Supervisors, researchers
6.	**Must** be easy to interact with	Background research
7.	**Must** be an extension of the existing waste islands	CFM-UT, supervisors, researchers
8.	**Must** not alter the current placement of the waste islands	CFM-UT, background research
9.	**Should** increase proper waste separation	CFM-UT
10.	**Should** prevent waste from being thrown into the wrong bin	CFM-UT
11.	**Should** display waste outcomes	CFM-UT, supervisors, developers
12.	**Should** use the principles of autonomy, competence, and relatedness	Background research, developers
13.	**Could** use persuasive technology	Background research, supervisors, developers
14.	**Could** use the nudge theory	Background research, supervisors, developers

Table 2: Preliminary requirements

4.2 Preliminary Concepts

The stakeholder analysis that was carried out in the previous part formed a clear illustration of what the most important stakeholders are and what requirements need to be considered when creating the intervention. According to the preliminary requirements table, see table 2, there are 9 requirements that the end product must have. These should be considered carefully when continuing with the development of the project brainstorming on potential concepts. The concept generation was divided into three different parts: brainstorming, concept selection and the SWOT analysis. The brainstorming was first done individually and then collectively with co-researcher Marina Stefanova. The concept selection and the SWOT analysis were done collectively as well.

4.2.1 Brainstorming

First an individual brainstorming session was conducted. Here both developers had come up with 5 different general ideas on how to design an intervention for motivating the UT community. Inspiration was taken from the state of the art when coming up with the ideas. Then these ideas were discussed.

1. Creature idea: keep the creatures alive by feeding them waste.
2. Reward system: fill a bar by disposing waste and see what happens once the bar is filled.
3. Reward system: make use of blinking lights and attention grabbing sounds to persuade the user to dispose of the waste.
4. Sound design: make use of persuasive sounds when waste is disposed of.
5. Being able to talk to the waste island: Ask the waste bin where a certain waste item should go.
6. Led strips to show how much the bins are filled.
7. Liquid disposer next to the waste bin to dispose of unwanted liquids
8. Gamification: Make a basketball game where the user disposes of the waste by throwing it into the bin.
9. The screen shows the user an animation about where the waste ends up, depending on which waste stream the waste is disposed of.
10. A waste bin that asks you to give it waste and thanks the user for disposing of the waste.

4.2.2 5 Preliminary Concepts

With these 10 ideas of how to motivate the UT community to improve their waste separation, 5 main concepts were formed. The ideas were used as inspiration to think of more detailed concepts.

4.2.2.1 Concept 1:The BinBuddies

This concept was inspired by the game Tamagochi where the user has a small game console where a little creature is displayed. The user needs to keep this creature alive by nursing it and feeding it. For the concept there would be one creature for every waste stream in the waste islands. These creatures are called the BinBuddies. These BinBuddies are shown on a display that is hanging right above the waste islands. The UT community would have to work together to keep the BinBuddies alive. This is achieved by feeding the BinBuddies through disposing of waste in the waste stream bins. If this is not done the BinBuddy for that particular waste stream gets smaller and sadder as time goes by. Therefore, the user feels motivated to feed the creatures. During the day the BinBuddies show thinking bubbles. In these bubbles, waste items are shown which are frequently disposed of wrong. This educated the user on the unknown waste items.

Figure 11: The BinBuddies concept

4.2.2.2 Concept 2: The Owl Guide

This concept is where the trash can keeps talking to the user and asks them about their waste and if they know where it should be properly disposed of. This is done through a character shown on a display. This could potentially be an owl, because the connotation that comes with owls is that they are wise and know everything. The owl will provide fun facts that tell the user where to put a particular item. The items he tells the user about are the items that are usually disposed of wrong. Subtitles are shown in the case that the area of the waste bin is crowded.

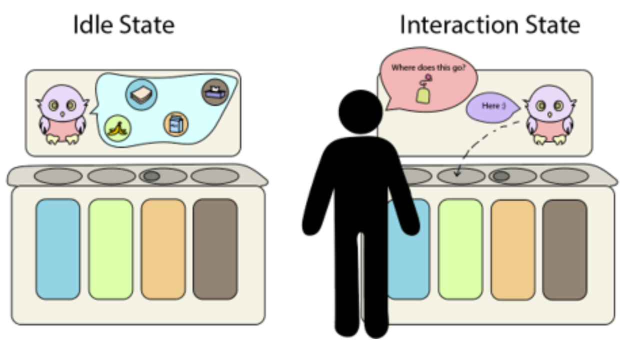


Figure 12: The owl guide concept

4.2.2.3 Concept 3: LED Strips and Sound Design

A LED strip is used to show how much each of the waste stream bins is filled. When a waste item is thrown into one of the bins a positive sound is made. The sound gets more pleasant as the bins get filled more. The screen shows the unknown items and in which these waste objects should go. There could be different sounds depending on what waste stream bin the waste is thrown into. There are LEDs on the bins that portray the level of waste that is in each bin.

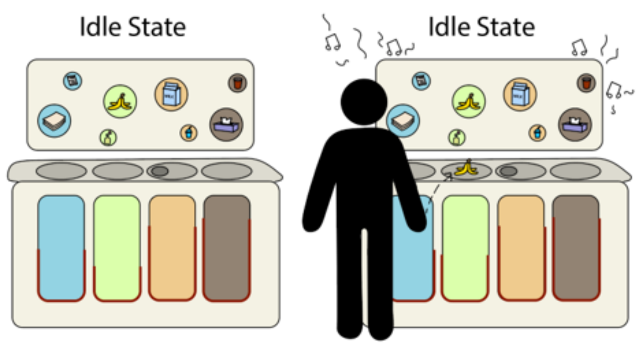


Figure 13: The LED strips and sound design concept

4.2.2.4 Concept 4: Tetris Game

With this concept a reward system is created. When a waste object is thrown into one of the waste bins, a game of Tetris is shown on a display. For each waste object a Tetris piece falls down on the screen. This way the UT community can work together to play the Tetris game. The user can not actually play the game of Tetris. They slowly see the screen get filled. During the time that the game is not activated the display presents bubbles which show the unknown items and in which waste stream bin the particular waste item should go in.

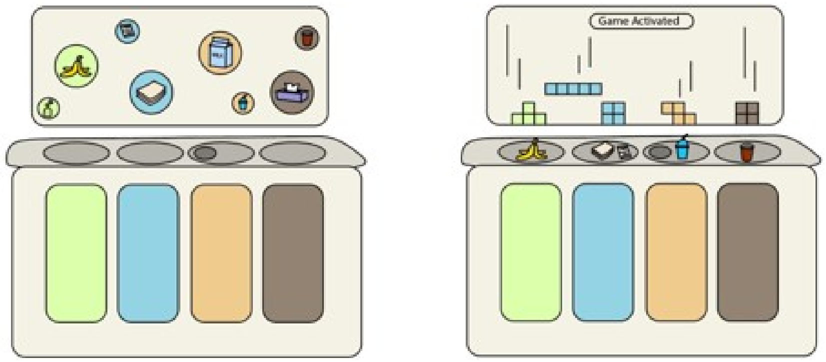


Figure 14: The Tetris reward system

4.2.2.5 Concept 5: Animation

This concept is when the display shows the user an animation of what happens to the waste after it is disposed of. This varies for the divergent waste streams. The animations show the unknown waste items, so that the user gets educated on these items and where they should go.

4.2.3 SWOT Analysis

A SWOT analysis (chapter 3) was done on the two favorite ideas. These ideas were the concept of the Tamagotchi creatures and the Tetris reward system. They were the favorites since they covered most of the must haves from the preliminary requirements. The SWOT analysis was done to see what strengths and weaknesses the ideas had and in what way these two concepts could be combined to make one final concept that covered all the requirements that the concept must have according to the stakeholders.

4.2.3.1 SWOT Analysis Tamagotchi Creatures

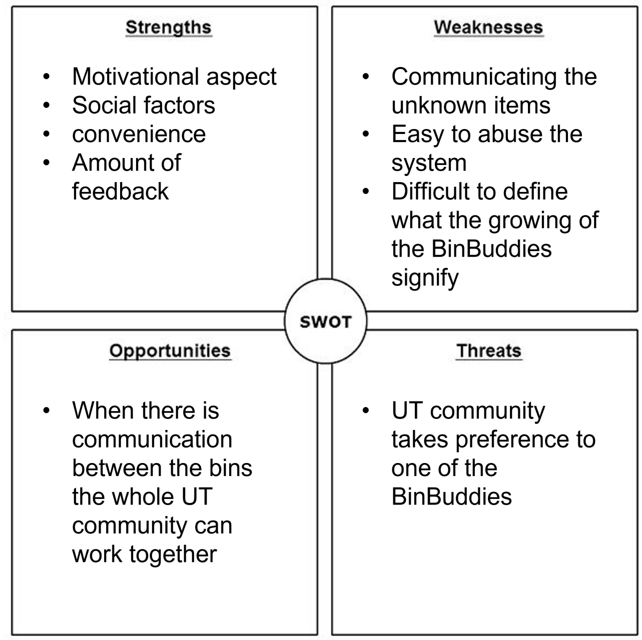


Figure 15: The SWOT analysis BinBuddies concept

The key points to take away from this SWOT analysis are that this concept is strong in the motivational aspect. The idea to keep the Tamagochi alive can be very motivational for the UT community. However, the concept is weak in educating the community about the waste items that are often discarded incorrectly. Furthermore, a potential threat to the concept is that the community would take preference to one of the characters, and would start throwing every waste item they have into that definite bin.

4.2.3.2 SWOT Analysis Tetris Reward System

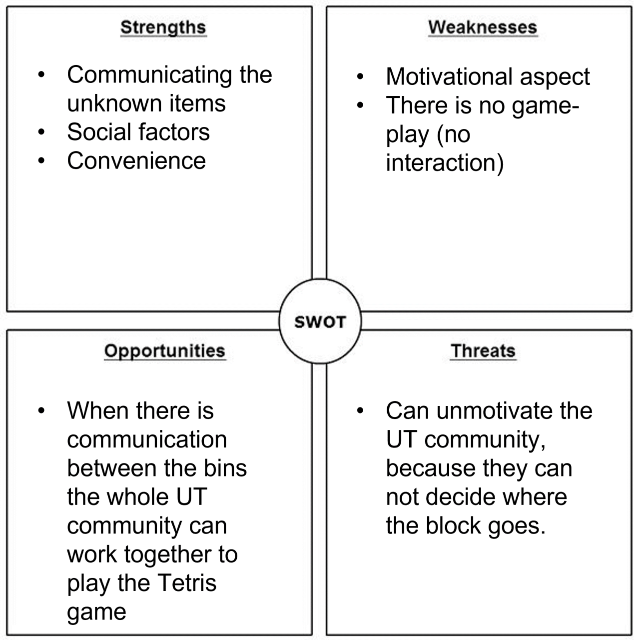


Figure 16: The SWOT analysis Tetris concept

The key points to take away from this SWOT analysis are that this concept is weaker in the motivational aspect than the previous concept. The idea of the UT community not being able to play the game of Tetris themselves might work counter effective. When the user sees the game of Tetris they might want to be able to influence the game themselves and therefore, they might become demotivated by the system. However, the concept is strong in educating the community about the waste items that are discarded incorrectly. The idle state, when the game is not activated, clearly demonstrates what unknown item goes into which bin.

4.3 Final Concept

By combining the strengths of both the ideas the final concept is created. This is where the Tamagotchi creatures are merged with the idle state of the Tetris reward system. The final concept is called the BinBuddies. This is the name given to the concept since the user should see four creatures displayed as buddies that help them separate waste.

The final concept has three phases. The first phase is the starting phase. The BinBuddies start out small. They grow bigger once they are fed waste items. During this state there are small portals that are situated underneath every one of the creatures. Between these portals little bubbles fall from the first portal into the second portal which symbolizes that the waste object that is situated in the bubble falls into the waste bin. This is how the unknown waste objects are portrayed.

Phase two is where the system is activated. The user discards a waste item, and the BinBuddy that belongs to the bin that has been activated thanks the user for disposing of their waste. There are two options for phase two. Firstly, the BinBuddy shows up bigger on the screen and thanks the user through the use of a speech bubble. Secondly, a spotlight is aimed at the BinBuddy belonging to the bin. The second option is designed for the situation in which an user throws away more items simultaneously.

Phase three is the idle state. When the bin is not utilized the BinBuddies are displayed and indicate the situation of the bins. Their expression and size changes according to the amount of waste that is thrown into each bin. For example, the paper bin is regularly not used very often. Therefore, the BinBuddy of the paper waste bin might be smaller and might have a sad expression.

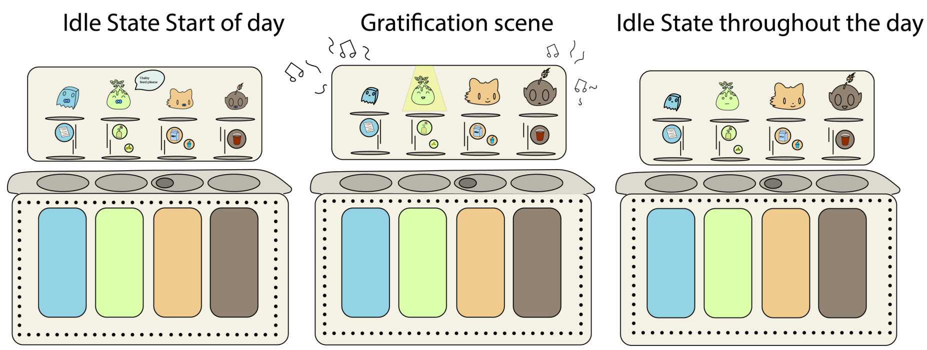


Figure 17: The Final concept

5 Specifications

In this chapter the specification phase of the project is explained. Before creating the final product, the system specifications need to be identified. The first part of this phase is when various personas are identified. These personas could be seen as potential users and this way the needs and interactions between them and the system can be carefully analyzed. Then the interaction scenarios between the personas and the system are interpreted. Which then leads to the functional and non-functional requirements that the system is going to need. Whereof the functional architecture will be decomposed into multiple diagrams.

5.1 Persona

Three different personas are established to create a deeper understanding of the users of the system and in which way the final product should be designed to include their envisioned needs. When composing these personas it is of the utmost importance that they are relevant to the project and portray the broad scale of users adequately. The different persona types are specified in three different classifications: climate aware, not environmentally aware, and indifferent. The following diagrams illustrate the personas and their character traits, goals, and personalities. Furthermore, their behavior towards the environment is rated.

5.1.1 Persona 1: Climate aware

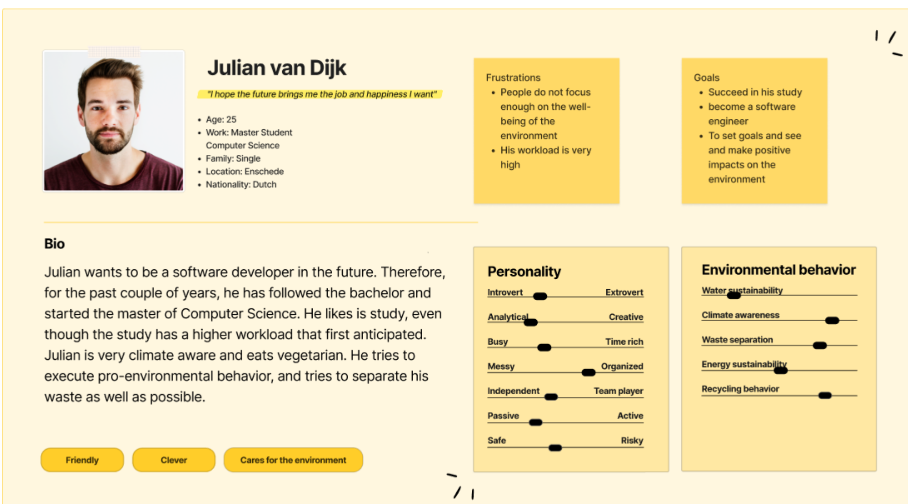


Figure 18: Persona 1

5.1.2 Persona 2: climate indifferent

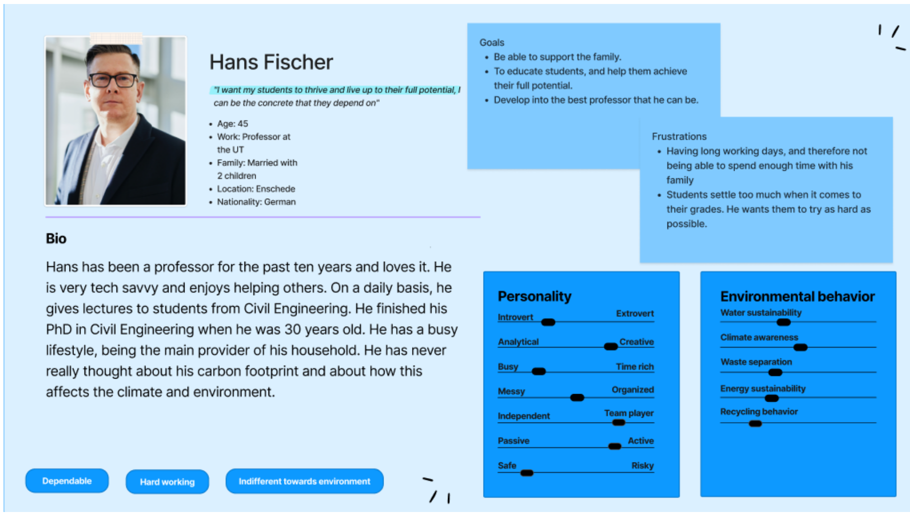


Figure 19: Persona 2

5.1.3 Persona 3: not climate aware

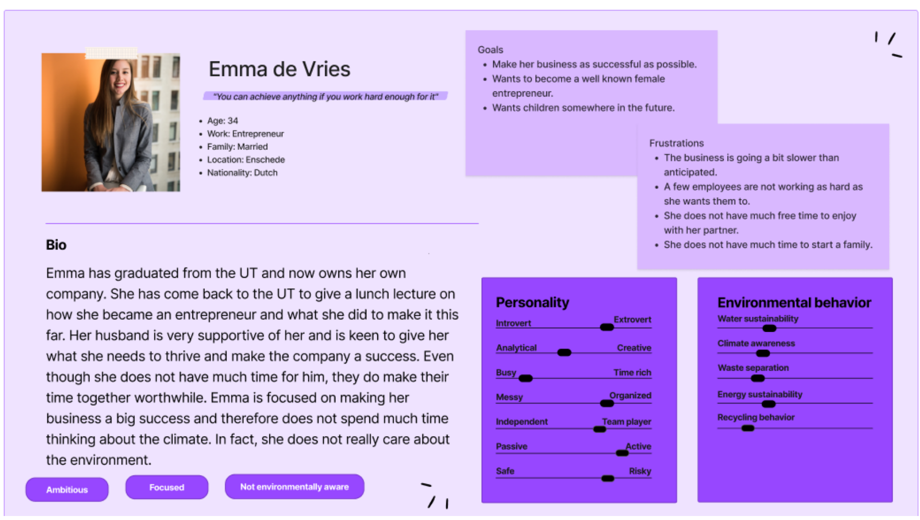


Figure 20: Persona 3

5.2 Interaction Scenarios

Multiple interaction scenarios are given to describe the interactions that are possible when using the system. There are six different scenarios that illustrate multiple ways of interacting with this system.

5.2.1 Story 1: The product is seen, and the waste is disposed

5.2.1.1 Scenario 1: Waste is Disposed Correctly

Scene 1: Julian is studying in the Vrijhof library on a Tuesday morning. It is 10:13. He has 3 exams next week and therefore he decided to sit in the library so that he could focus on studying for the exams. He has his exam books laid out on the table and is making summaries of the exam components.

Scene 2: He just drank the coffee he got from the vending machine and wants to dispose of the paper cup the coffee came in so that it does not take up unnecessary space. He stands up quietly without disturbing anyone and walks towards one of the waste islands. When walking towards the nearest waste island and from 10 meters afar he sees something out of the ordinary. A display is hanging above the waste island. He is very curious so he starts walking a bit faster towards the waste island.

Scene 3: As Julian walks closer to the bin the screen gets more clear. He is 7 meters from the bin. There are four BinBuddies and bubbles that are raining down. He can not see what exactly is in the bubbles. He sees someone stand in front of the system and watches them look at the screen and throw a dirty salad container into the residual bin. He is a bit confused why the plastic is thrown into the residual instead of the PD bin. He walks closer to the bin.

Scene 4: He stands half a meter in front of the system and looks at the display. There are four cute creatures that are small and a bit sad looking. He wonders why they are sad. He sees the bubbles underneath the creatures. There are icons in the bubbles that depict certain types of waste. He sees that above the residual bin a bubble falls down that illustrates a dirty plastic wrapper. Then suddenly he gets the idea of the bubbles. They show what waste goes where.

Scene 5: A bubble filled with a paper cup falls down just below the PD creature. He drops his paper cup into the PD bin. The PD creature gets a spotlight and a speech bubble appears. The creature is thanking him for feeding it, and the creature becomes a bit happier. Julian did already know the paper cup should go into the PD bin. However, he did have his doubts because the cups were made of paper. The system confirmed that the cup belonged in the PD.

Scene 6: Julian likes the system and that the creature he fed became a little bit happier and bigger. Moreover, now he knows that the paper cups from the vending machines are indeed supposed to go into the PD bin.

Scene 7: Julian is done interacting with the waste bin and decides to return to his study desk to do some further preparation for his exams.

5.2.1.2 *Scenario 2: The Waste is Disposed Incorrectly*

Scene 1: It is 12:15 and Emma is visiting the university where she graduated some time ago. It feels strange to be back in the place she had studied and lived so long ago. The buildings are still relatively the same. The university had asked her to provide a lunch lecture for the students of the university. They asked her to talk about her career and how she got to this point. She prepared a presentation. Even though she is used to speaking in public, she is a little nervous to present for students of the university. She is walking towards the lecture hall where the lecture begins in 15 minutes.

Scene 2: While walking she finishes her Starbucks coffee she got from the Educafe, and is looking for a bin to throw her cup into. At the end of the hallway, just around 10 meters away, she sees something that looks like a garbage can, however, a display is hanging right above it. She is a little confused but walks towards the waste bin. She wants to get to the lecture room on time to prepare for the lunch lecture and try to figure out how to connect her laptop to the projector.

Scene 3: She walks closer to the bin and from 5 meters away she can see what is on the display. There are four small cartoon creatures and bubbles that are raining down. She can not see what exactly is in the bubbles. She keeps walking towards the bin. Moreover, she sees that she has to separate her waste.

Scene 4: When she is a meter away from the waste bin she sees that there are four cute creatures that are small and a bit sad looking. Emma feels like she does not really have time to interact with the system. She reckons that her paper cup goes into the paper bin since it is made from paper. She sees one of the bubbles showing a paper cup that is supposed to go into the PD. She is confused why that is so she throws it in the paper waste stream, and continues walking to the lecture hall. She chooses to ignore the system due to time constraints and confusion.

From these scenarios can be deducted that Julian (persona 1) is more aware about separating waste while Emma (persona 2) does not really care for waste separation and does not take the time to do it correctly. Hans (persona 3) could react to the system in both scenarios since he is indifferent about the idea of climate change. He could either react to the system in curiosity and see what the product does and separate waste correctly. While he could also be too lazy or he could not have enough time to interact with the system and therefore separate his waste incorrectly. Furthermore, it might be that when Julian is stressed or does not have enough time, there might be a chance that he separates the waste wrong as well. He might not have the time to observe the bubbles and see where his waste object belongs.

5.2.2 Story 2: The Product is Seen, and no Waste is Disposed

Scene 1: It is 10:30 on a Wednesday morning and Hans just told his students that they can take a break of 15 minutes. He is giving his usual lecture on structural mechanics to the first year Civil Engineering students. Since he has some time before he wants to continue the lecture he decides to take a short walk to get a coffee from one of the machines.

Scene 2: When walking in the hallway he sees one of the waste islands at the end of the hallway. It is 10 meters walking to the waste bin. He observes that there is a display that hangs above the waste islands.

Scene 3: As Hans walks closer to the bin the screen gets more clear. He is 7 meters from the bin. There are four small cartoon creatures and bubbles that are raining down. He can not see what exactly is in the bubbles. So he decides to explore the waste bin and see what the display shows.

Scene 4: He stands half a meter in front of the system and looks at the display. There are four creatures that are small and a bit sad looking. He wonders why they are sad. He sees the bubbles underneath the creatures. There are icons in the bubbles that depict certain types of waste. He observes the system for a couple of seconds and looks at the waste bubbles and in which bin they are going. After a short while he decides to continue his walk to the coffee machine.

Scene 5: Hans gets his coffee, returns to his lecture hall, and continues to teach his nice pupils on his favorite subject: structural mechanics.

The two other personas would probably react differently to the system than Hans. The persona that cares more for the environment will probably be more enthusiastic about the product and would want to spend more time interacting with it while the indifferent persona might not want to interact with the system at all when there is no need for it.

5.2.3 Story 3: Product is Overlooked, Waste is Disposed off

5.2.3.1 Scenario 1: Waste is Disposed of Correctly

Scene 1: On a quiet Wednesday morning around 11:00 AM, Julian is seen studying at the Bastille building at the UT campus. It is at the end of his module, and he is studying hard to prepare for his upcoming exams. He's working on a tight schedule to finish with revisions and making practice exams in time.

Scene 2: Around 12:30 he takes a lunch break by going to the nearby grocery store called the Coop and purchasing a sandwich and a refreshing iced tea drink. After which he returns to his seat at the Bastille to finish his lunch. When he finishes his lunch, he decided to clean up his working area so there are no more distractions around and so he could get back to work as per his schedule.

Scene 3: Julian begins to gather all the waste from his desk and group them per category to make it easier for himself when throwing away his waste. He then grabs his phone and proceeds to check his calendar and his to do list, whilst walking towards the nearest waste separation island.

Scene 4: Julian has approached the nearest waste bin and noticed a screen placed by the waste islands which turns on and displays four creatures called BinBuddies, above each waste bin. Julian became a bit confused as to what is the purpose of these creatures and decided to proceed to throw away his waste as he had prepared it. Julian is aware of the waste separation guidelines at the University of Twente and therefore he performed correct waste separation, even without observing the screen with the BinBuddies.

Scene 5: Quickly he checks his phone and sees the time and that he is behind on his schedule. He decides to turn back and return to his study place, leaving the waste islands and missing the reactions of the creatures (BinBuddies) to his disposed waste.

5.2.3.2 Scenario 2: Waste is Disposed of Incorrectly

Scene 1: It is 17:30 on a Thursday afternoon, Emma has just finished her last guest lecture in the Horst. The university asked her to talk about her career and how she got to this point. She prepared a presentation. Even though she is used to speaking in public, she was a little nervous beforehand to present for students of the university. The presentation went way better than she had expected. The students asked a lot of questions.

Scene 2: After grabbing her laptop and the rest of her belongings, she realized that it was already kind of late and still had to drive home for 1,5 hours. She knew she would get hungry on the way there, and that there was a coop located on the campus. She walked to her car.

Scene 3: She drove her car to the coop and parked on the other side. Walked to the Coop and purchased a few Bio healthy muesli bars. She then proceeded to eat a few of them on her walk back to the car. She wanted to get to the car as quickly as possible, she looked around for a waste bin she could throw away her wrappers in.

Scene 4: While walking through the Bastille, she saw a waste bin and approached it. As she was about a meter away, a screen turned on from above the waste bins and displayed four cute creatures called BinBuddies. Confused about the screen and in a rush to not be late for training, Sarah looked at her waste and threw her packaging into the paper bin as it seemed to be made from paper, where in reality it was a mix of paper and plastic, and should have therefore been thrown away in the PD bin. At the corner of her eye she notices the creature above the paper bin reacting to her throwing her waste in the paper bin, however she chooses to ignore it and rush to the car.

From these scenarios it can be concluded that Julian (persona 1) is more aware regarding correct waste separation while Emma (persona 2) is not as aware and does not necessarily care about it. In the situation of Hans (persona 3) who is indifferent regarding climate awareness and waste separation, both scenarios could have been performed mostly depending on the waste to be separated. Since both Julian and Emma chose to overlook the system due to being in a rush or general time constraints Hans could have also performed the same. In the situation that both Julian and Emma have more time on their hands, it is expected that Julian shows more interest in the system as of contrast of Emma, since Julian is in general more climate aware and passionate about performing correct waste separation

5.2.4 Story 4: Product is Seen, Product is Abused

Scene 1: Julian and a few of her friends are sitting at the Bastille lounge area enjoying snacks and chatting about recent events and plans for parties they would want to attend. Throughout that time, they have gone through a few bags of chips and cookies alongside fruits and chocolate. Around 18:00 PM they decide that it is time for them to leave and go home and so they gather all their waste to find the nearest waste separation island and throw out the waste.

Scene 2: After walking around a bit, Julian and his friends see a waste island and begin to approach it. From a distance they can see that there is a screen present beside the waste bins and interested in it they walk quicker to the waste bins. They see that on the screen there are four BinBuddies with different sizes visible and each one is hovering on top of a different waste bin. They then understand that these creatures represent the waste bins.

Scene 3: After a few seconds of observing the creatures, they notice that the paper and the organic bin creatures seem sadder than that of the PD and Residual waste. Confused about why that is, they proceed to throw away some of the waste into the PD waste bin. Julian sees a spotlight appear on top of the PD creature, and the creature becoming bigger and happier whilst it thanks them for her waste (feeding it). After this interaction they all understood what the purpose of the waste bin creatures is.

Scene 4: Julian felt bad for the organic buddy and so he and his friends decided to rip their banana peels into smaller pieces and feed the organic buddy. At first he ripped up all his organic waste in the organic bin. Then he proceeded to rip up his note paper into many pieces and feed all the little bits to the paper buddy. As a result of being fed the creatures got happier and happier.

Scene 5: After 10 seconds of being constantly fed the small pieces of paper, the paper creature started to become sick. Julian was confused. The paper creature had become sick and sadder looking since the system was aware that the system may have been abused. Julian felt bad for his overfeeding actions and proceeded to throw the remaining waste into the correct bins, and return home.

5.3 System Requirements

The system requirements can be categorized in two different types: functional requirements and non-functional requirements. The functional requirements describe the functions and features of the system, so what the system must be able to do. While the non-functional requirements describe the general properties of the system, so how the system will function and what quality constraints the system must have.

5.3.1 Functional Requirements

Number	Functional Requirement
1.	The waste island *must* sense when a user is in a proximity of one meter.
2.	The waste island *must* know what bin waste has been disposed of.
3.	The system *must* show the idle state when there is no user in the one meter proximity.
4.	The size of the BinBuddies *must* increase by 1.05 every time a waste item is thrown into the waste island.
5.	Each separate BinBuddy *must* thank the user when they dispose of waste by showing a speech bubble with the words "Thank You" once an item is thrown into one of the bins.
6.	User feedback *must* be given when the system is active through the use of colored LEDs, the colors of the LEDs represent each bin separately. Blue for paper, green for organic, orange for PD and gray for residual.
7.	The waste bin *must* detect two waste items for the facial expression of the BinBuddy to change from sad to neutral, and three items for it to change from neutral to happy.
8.	The maximal size of the BinBuddies *must* be 235 by 260 pixels to still fit properly onto the screen.
9.	The waste island *should* detect waste of any size in every waste bin.
10.	The waste bin *should* detect waste fast enough to detect the various waste items that are dropped into the bin from a 10 cm height.

Table 3: Functional Requirements

5.3.2 Non-functional Requirements

Number	Non-functional Requirement
1.	The system must be easy to interact with.
2.	The system must educate on improper separated waste items.
3.	There must be no alterations to the existing waste islands.
4.	The system should be interesting to use.
5.	The user should be motivated by the installation.

Table 4: Non-functional Requirements

5.4 Functional Architecture

When designing the infrastructure of the system there are a few levels of specifications that can be used to illustrate how the system will work and what functions will be connected with each other. These can be portrayed in black box models. In this case the most detailed model that will be provided is the level 2 black box model since this model will provide enough information about the setup of the system to fully understand the functionalities of the product.

5.4.1 Level 0

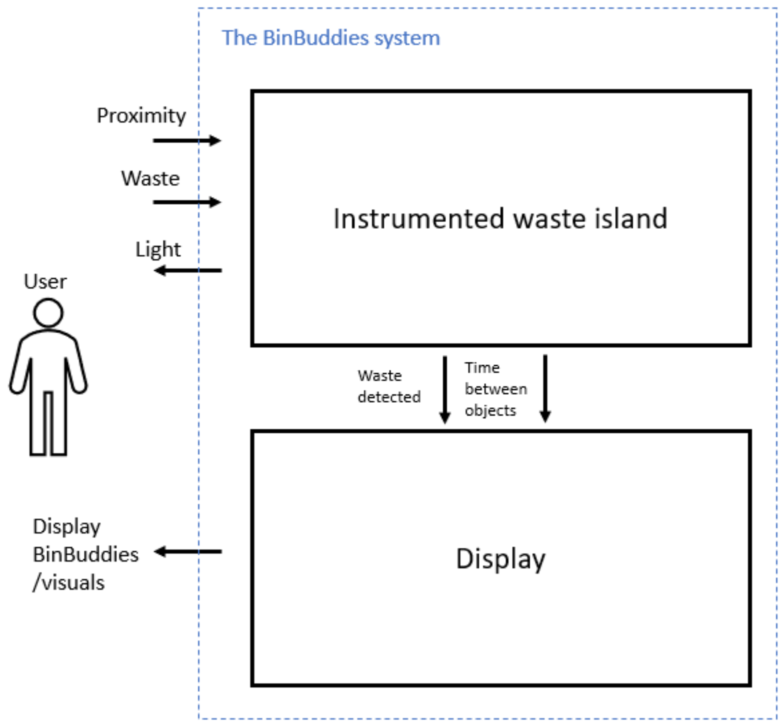


Figure 21: Level 0 black box model

Firstly the level 0 black box model is made to portray what inputs and outputs the system will need. The proximity detection is important for the system to recognize if a user is in a 1 meter proximity of the waste islands. This way the system activates when the user is in range. The proximity detection triggers the lights and the waste detection. The waste detected and time between objects information is given to the display which acts accordingly and displays the correct content.

5.4.2 Level 1

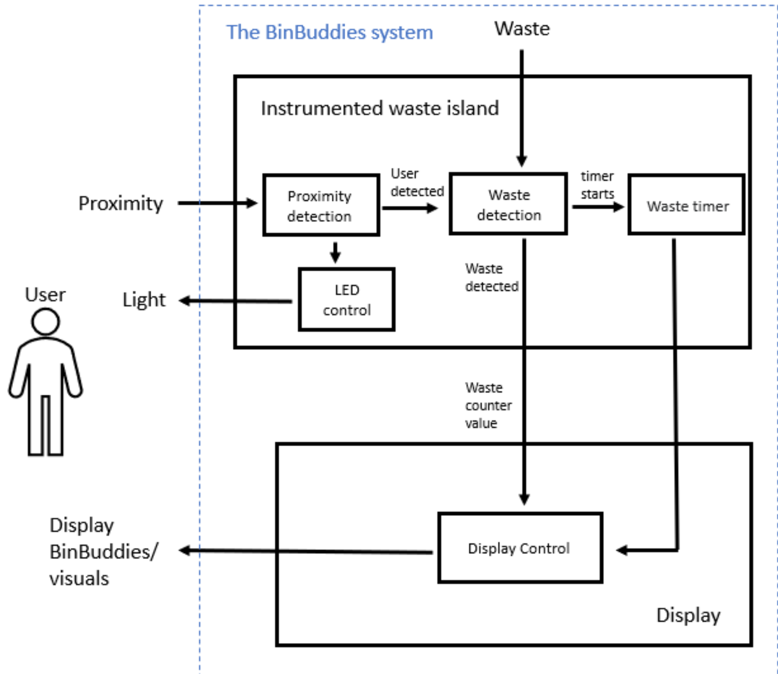


Figure 22: Level 1 black box model

Following the level 0 comes the level 1 black box model. This model is more detailed than the level 0. It shows how the functions of the system are connected to each other and how they work together to make the system work properly. It starts with a proximity input. The distance of the user is always measured. Once the user is in a proximity of one meter the other sensors and LEDs will turn on. The LED lights are an output given to the user to show that the system is on and that they can dispose of their waste. The user then deposits a waste item into one of the bins. A waste item is detected and a timer starts. This timer sees if multiple items are disposed of within two seconds. If this does happen the waste system will only regard this as one waste item and the corresponding waste bin counter will go up. This counter value is sent to the display control as well as the timer value. The display control takes these two inputs and displays the BinBuddies and other visuals.

5.4.3 Level 2

5.4.3.1 *Proximity Detection*

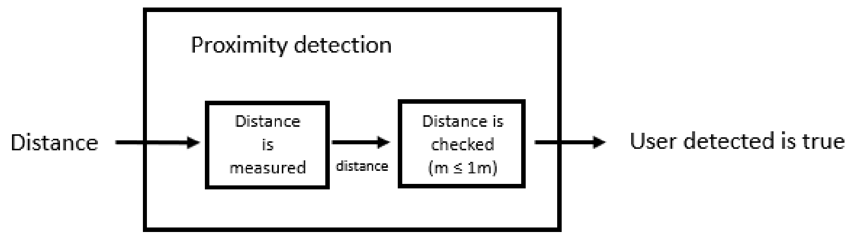


Figure 23: Level 2 proximity detection black box model

The black box of proximity detection can be explained in more detail. The input of this function is the distance between the user and the waste island. The distance is constantly measured. The proximity detection constantly measures if a user is in a one meter proximity. A boolean toggles every time a distance signal is sent out. If there is nothing in front of the proximity detection the boolean is false, and if a user is in the correct proximity then the boolean toggles to true. If the boolean is set to true the output is sent to the next part of the system. This means that once the proximity detection is activated the rest of the system turns on. This way the system does not constantly keep running.

5.4.3.2 *LED Control*

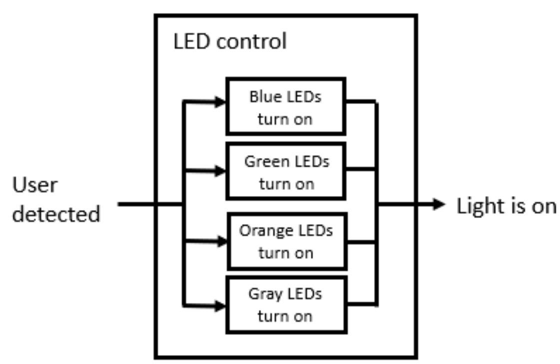


Figure 24: Level 2 LED control black box model

Another part of the level 1 black box is the LED control. The LED uses the output of the proximity detection as input. If the boolean of the proximity detection is set to true the LED strip turns on with each bin having their own color: blue, green, orange, and gray. The output of this function can be seen by the user. As soon as the boolean returns to false the LED strip turns off.

5.4.3.3 Waste Detection

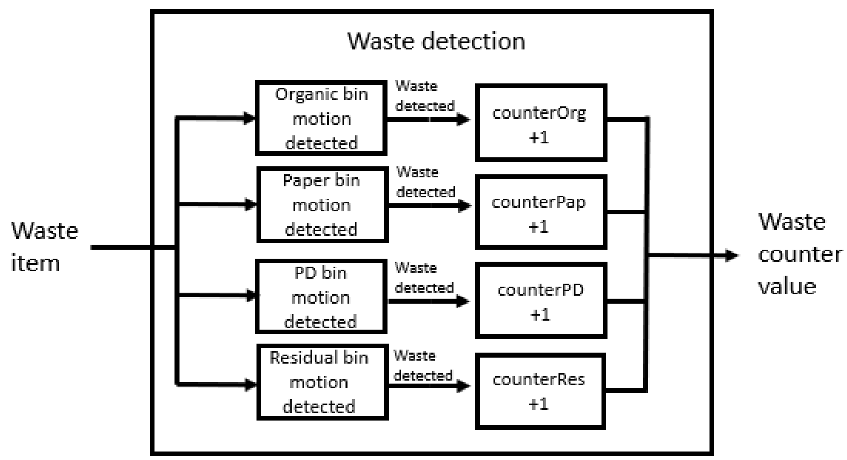


Figure 25: Level 2 waste detection black box model

Once the proximity detection has detected a user, the waste detection part of the system is activated. This part of the system detects if a waste item is disposed off and in which of the four bins. The input of this system is waste that is thrown in one of the bins. Each of these bins has a motion detection function. This motion detection measures if there is motion in the opening of the bin. If there is motion, waste is detected and a boolean is set to true. When the boolean is set to true the counter belonging to that certain bin increases by one. This way the system keeps track of the amount of items that are placed in the bins. When one of the counters increases it signifies that waste detected. The waste counter values are sent to the display control.

5.4.3.4 Waste Timer

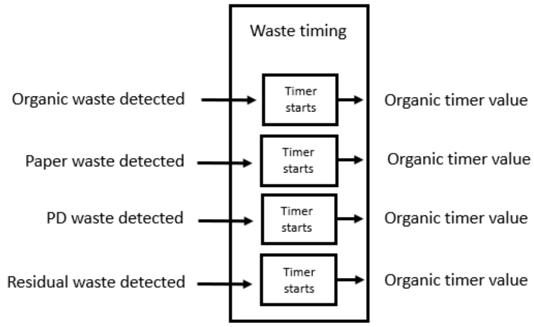


Figure 26: Level 2 waste timer black box model

The waste detection starts the waste timing section of the system. Once waste is detected per bin a timer starts. Once there are more than one item thrown into the bin in two seconds then the waste timer should only give one output. This way the system will be more controlled and secure.

5.4.3.5 Display Control

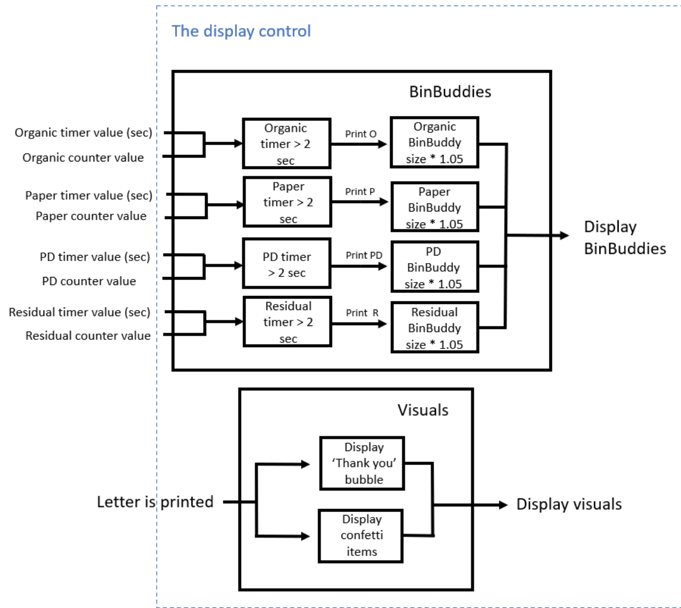


Figure 27: Level 2 display control black box model

The counters of the waste detection are then sent to the display control. This is where the size and the happiness of the BinBuddies are controlled. As the counter increases, a letter is printed and the Binbuddies grow bigger and get happier for every letter that is printed. The letter that is printed stands for the bin that is activated: P for the paper bin, O for the organic bin, PD for the PD bin, and R for the residual bin. The visualizations that the user sees and observes, are then shown on the display as an output. Furthermore, the other part of the display control controls the other visuals of the BinBuddies. Once one of the letters is printed the 'thank you' bubble and confetti are shown for that particular bin.

5.5 Time Sequence Diagram

Time sequence diagrams are interaction diagrams that show how users interact with a product and how the product operates. They show the important interactions between the main parts that make up the system. Multiple sequence diagrams are constructed to visualize multiple interaction scenarios between the user and the BinBuddies system.

5.5.1 The waste island is observed and waste is disposed off

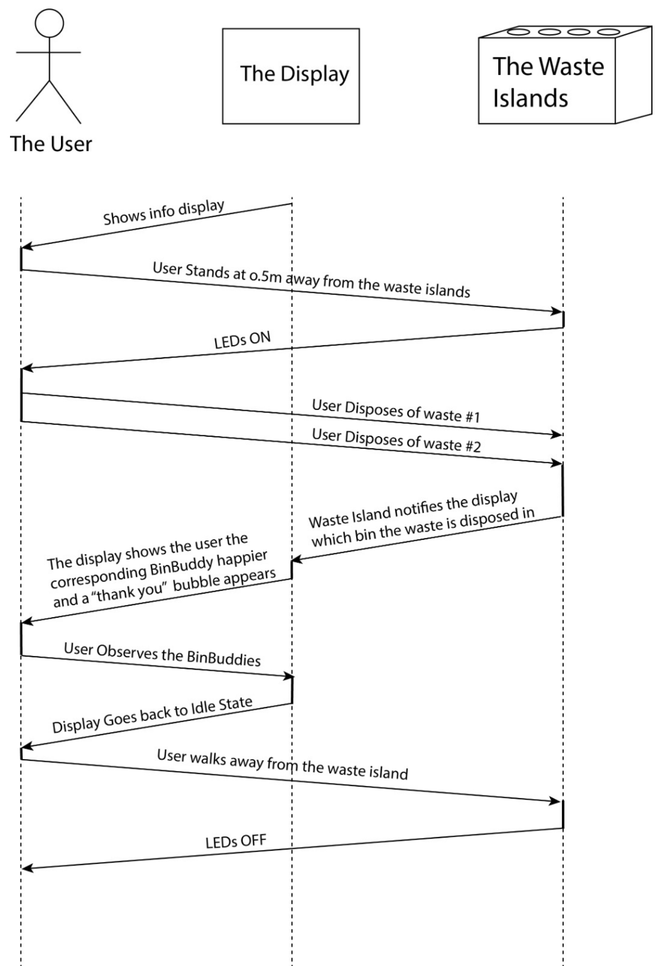


Figure 28: Time sequence diagram 1

5.5.2 The waste island is observed and no waste is disposed off

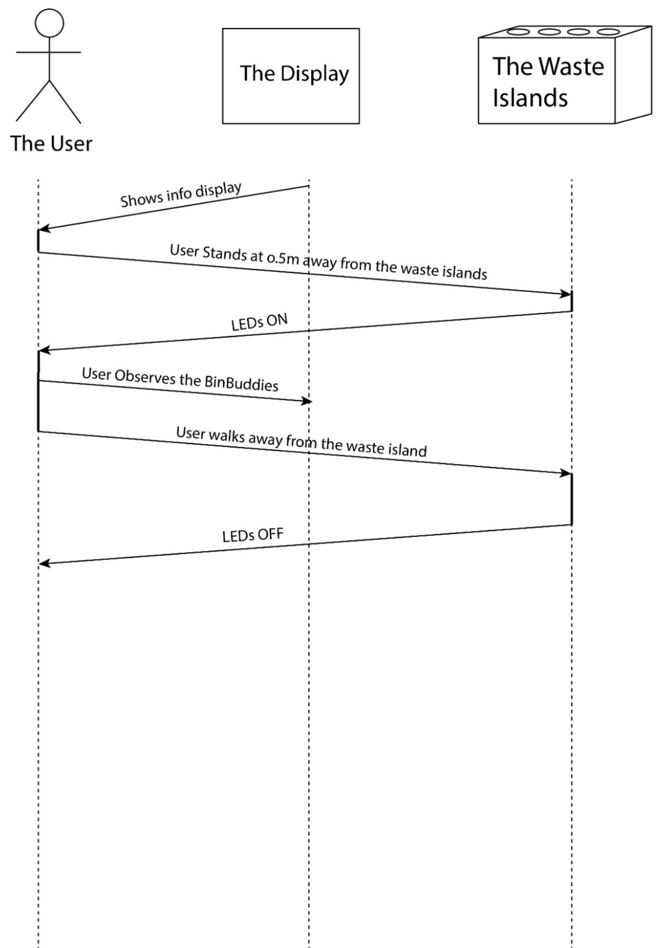


Figure 29: Time sequence diagram 2

5.5.3 The waste island not observed and waste is disposed off

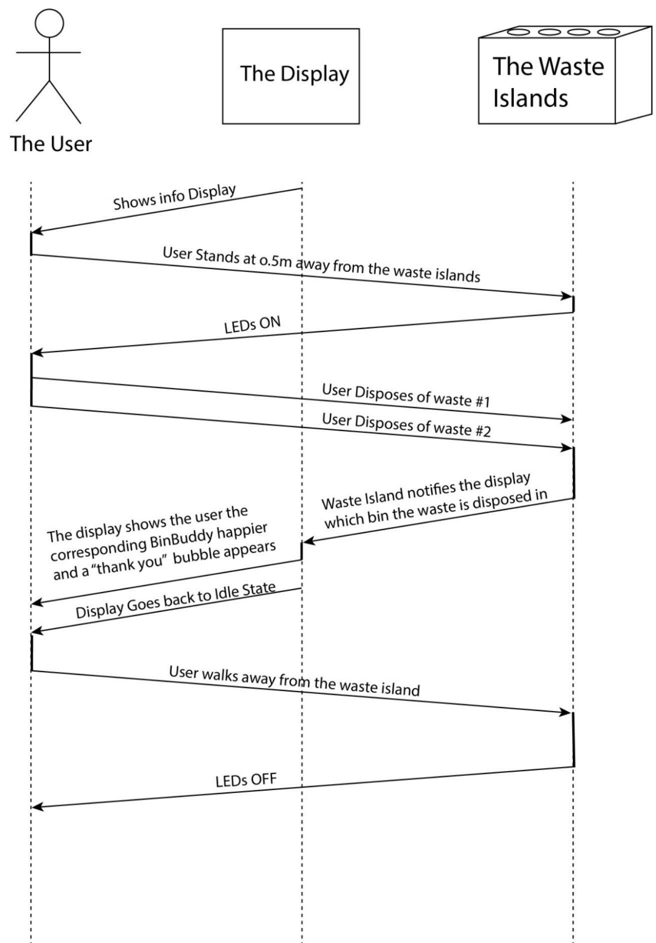


Figure 30: Time sequence diagram 3

5.5.4 The waste island is observed and the waste island is abused

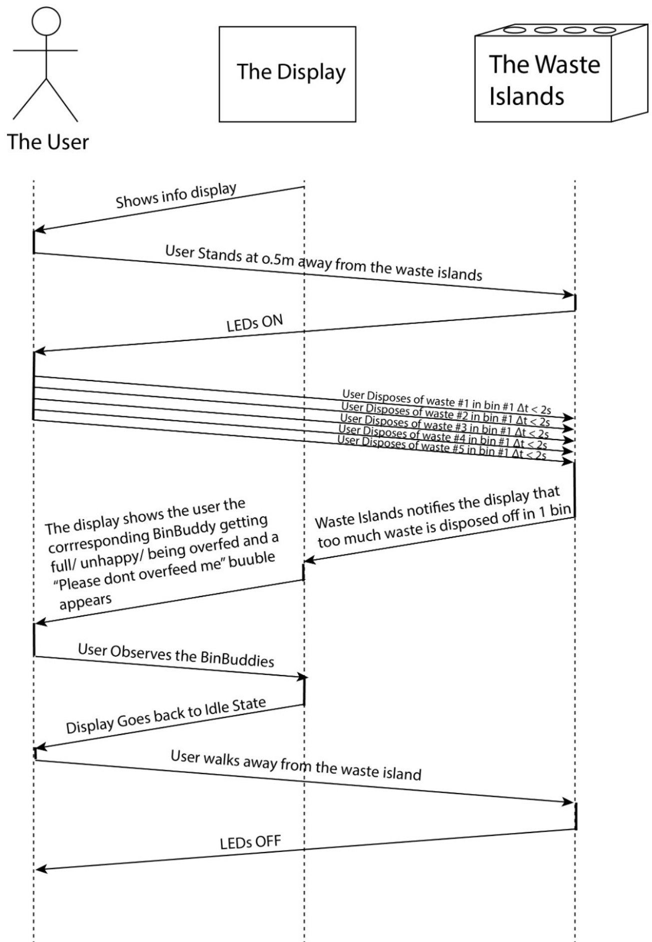


Figure 31: Time sequence diagram 4

6 Realization

In this chapter the realization part of the project will be explained. The different functions mentioned in chapter 5 are realized with the help of hardware and software. The proximity detection, light control, and waste detection need hardware to function properly while the other functions are made using software. First, all the separate parts are identified and how they contribute to the whole of the system. Then, the integration of all the parts is explained. Finally, the system is tested on the ability to uphold the functional and non-functional requirements.

To be able to make the prototype there are multiple parts that need to work together for it to work properly. Therefore, the design is divided into three different parts. This way there is a better overview of the whole system and how each sub-part is implemented. Each of these parts are equally important. For the system to work properly all three of these parts need to be designed very precisely. They are: The visual part, the hardware part, and the coding part. The visual part is realized by Marina Stefanova, consequently, in this report that part will not be described in detail. In this report the hardware and the coding are designed in detail.

6.1 Hardware

The hardware of a system are the physical components of the system. This includes the electric components that obtain input and distribute output signals, the display screen, the waste island, and the laptop.

6.1.1 The Electric Components

6.1.1.1 The Micro-controller

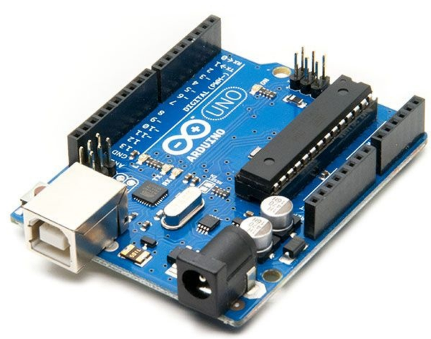


Figure 32: Arduino Uno R3

A micro-controller is a compact integrated circuit board that can be seen as a small computer. It contains a processor, memory, and input and output pins.

This small computer is used to control the whole system. It is the link between the sensors that gather information signals and the software that implements the information signals. In this case the Arduino Uno R3 is used, shown in figure 32. This is a type of micro-controller that has 14 digital input/output pins, 6 analog inputs and a USB connection. For this project there are no more than 6 analog inputs used and no more than 4 digital pins. [35] Therefore this micro-controller is good enough to manage the system.

6.1.1.2 Proximity Detection

Figure 33: HC-SR04 ultrasonic sensor

For the proximity detection, an ultrasonic sensor is used, see figure 33. To be exact the HC-SR04 ultrasonic sensor is used. This sensor can measure the distance from 2cm up until 4m. It has a resolution of 3mm. This means that the smallest distance change that the sensor can measure is 0.3cm. This is precise enough for this particular project. Furthermore, the sensor has an effectual angle of 15°. This indicates that the sensor can measure the distance from an angle of 15° as well as the objects straight ahead. Therefore, if a user would stand about 30cm to the right or left of the sensor it would still detect the user. The sensor works with a 40KHz signal. The transmitter (trigger pin) sends out a 40KHz pulse which travels through the air until it reaches an object. The pulse then proceeds to bounce back from the object to the receiver pin (echo pin) of the sensor.

To be able to calculate the distance between the object and the sensor equation 1 is applied. This equation multiplies the time it takes for the pulse to be sent out and received by the sensor with the speed of the sound in air of 20°C. This sensor is selected for this project since they are precise enough to measure if a user is in the range of 1m and the range of the sensor is wide enough to sense when a user is not standing directly in front of the bin but at an angle. [36]

$$Distance = Time \text{ x } Speed \tag{1}$$

6.1.1.3 Waste Detection

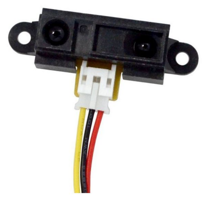


Figure 34: GP2Y0A21YK0F infrared sensor

For the waste detection part of the system sensors are needed that can be able to detect motion within a distance of 15cm. This is the diameter of the waste bins. This way if waste is thrown into one of the bins then the sensor can detect the motion of the waste item falling into the bin. Both ultrasonic sensors and infrared sensors are able to do this. However, to decrease costs and space infrared sensors are used. There is little space between the side of the waste island and the bin the waste is collected in. The ultrasonic sensor would be too large for it to fit properly into this space. The infrared sensors fit just right. Furthermore, ultrasonic sensors can be influenced by the signal bouncing on the other sides of the waste island. This can interfere with the measurement. While this is not as big of a problem for infrared sensors. The infrared sensor used is the Sharp GPY0A21YK0F. This sensor works by sending out an infrared signal which travels through the air and bounces back from an object and then receives the signal. This works almost the same as the ultrasonic sensor, however the infrared sensor works with light signals while the ultrasonic sensor works with sound signals. [37]

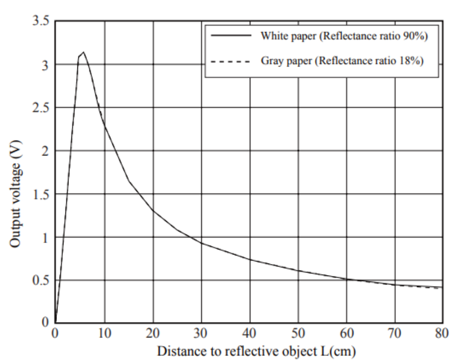


Figure 35: Distance measuring characteristics GPY0A21YK0F infrared sensor

The infrared sensor has a working range from 10cm to 80cm. It has an analog input, this means that it receives a measurement between 0V and 5V. Based on the voltage value received, in the code the distance can be calculated between the sensor and the obstacle. For the first 8cm the sensor is not very accurate. It might sense the same voltage measurement at a distance of 3cm and at a distance of 12cm. Therefore if an object is within the 8cm range the measurements might be inaccurate, see figure 35.

6.1.1.4 LED's

Figure 36: The NeoPixel LED strip

A NeoPixel LED strip is used. This type of LED strip only needs one pin to be controlled. Furthermore all the LEDs on this strip can be controlled individually. Therefore this LED strip is convenient for this prototype. There are not many wires needed to fit into the waste island and the LED strip can be programmed to change the color of the parts of the strip that belong to the waste bins. For example, the part of the strip below the organic would be green and the part below the paper would be blue. This makes the system more integrated and makes the prototype feel more like an installation.

6.1.2 Display Screen

To be able to display the BinBuddies a screen is needed. This is what the CTOUCH is used for. This screen has almost the same width as the waste island and is therefore a good screen to display the BinBuddies on. The screen can also be used as a touch screen. However, for this prototype this is not a necessary function.

6.1.3 Waste Island

To be able to make the system one of the waste islands is needed. The waste island is provided by CFM and it is the exact same design as the islands that are placed around the campus of the university. The island has four different colored bins. One for each waste stream. The blue bin is for paper, the green bin is for organic, the orange bin is for PD (plastic and drinking cartons), the gray bin is for the residual waste.

6.1.4 The Integration of the Hardware

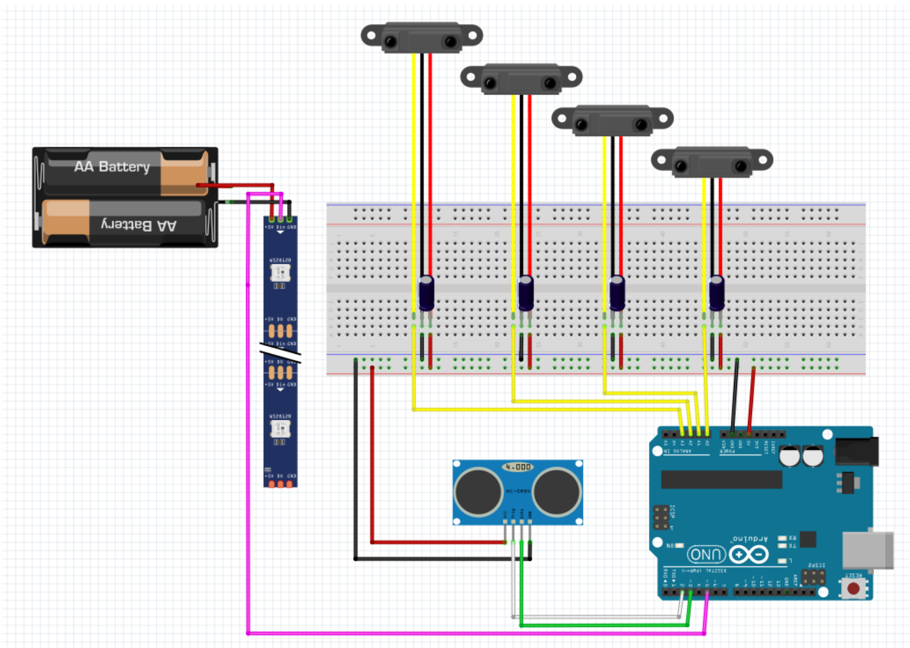


Figure 37: The integrated hardware

Now that the separate systems have been explained it is important to integrate them properly, see figure 37. For each of the bins there is a corresponding infrared sensor that can sense if waste is disposed into the bin. There is one ultrasonic sensor that can sense if a user is in a 1m proximity. Lastly, there is a LED strip that is powered by external batteries. All these parts are connected to and controlled by the Arduino, see figure 38.

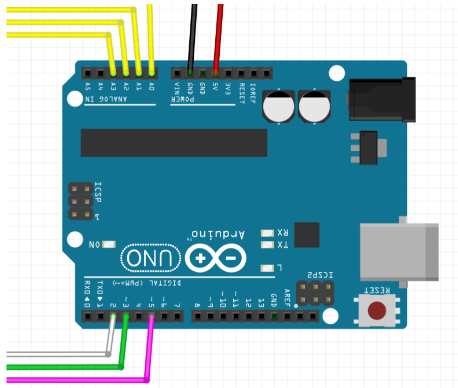


Figure 38: Arduino with used pins

The Sharp GPY0A21YK0F infrared sensors are powered by the Arduino and connected to analog pin 0 through 3. They are powered by the Arduino 5V pin and the voltage is directed to the ground pin after it goes through the sensors. The paper bin sensor is connected to the A0 pin, the organic to the A1 pin, the PD to the A2 pin, and the residual to the A3 pin. With these analog pins the Arduino can send out signals and receive the data from the sensors. The sensors are connected in a parallel circuit. For the output signals of the sensors to be as clear and clean as possible there are 10μF capacitors connected to them, see figure 39.

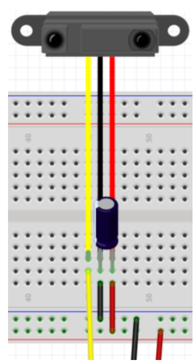


Figure 39: Infrared sensor with used pins

Then the HC-SR04 ultrasonic sensor is connected to the Arduino. This sensor has four pins. One pin is connected to the 5V (Vcc) and another pin is connected to the ground (Gnd) of the Arduino. The other two pins are for sending and receiving the signals. One of these pins is called the trigger pin (Trig) and the other pin is the echo pin (Echo). The trigger pin is connected to digital pin 2 and the echo pin is connected to digital pin 3 of the Arduino. Through one pin the Arduino can send out a signal and with the other it receives a signal. See figure 40 for the wires connected to the ultrasonic sensor.

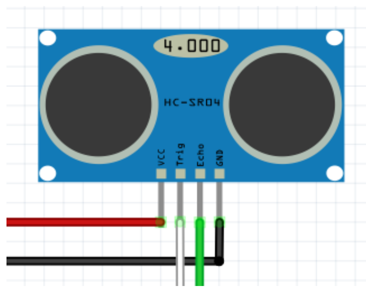


Figure 40: Ultrasonic sensor with used pins

The NeoPixel LED strip is powered by two extra batteries, see figure 41, since the Arduino is not capable of powering all the LEDs themselves. The current that the LED strip needs is too high for the Arduino to deliver. Therefore, an external current source is needed for the LED strip to work properly. The strip is connected to digital pin 5 of the Arduino. This way the LEDs can be controlled with the code. In the code it can be determined what color every single LED should be and what level of brightness.

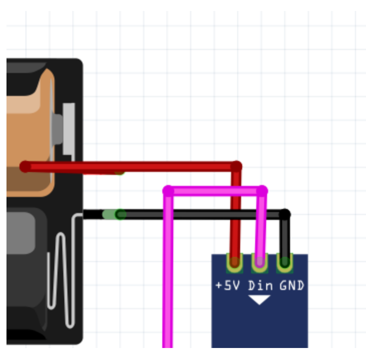


Figure 41: LEDs with used pins

Lastly, the Arduino is connected to the laptop which contains the software with the code that controls the whole system. They are connected with a USB cable.

6.2 The Software and the Coding

To be able to make these sensors and systems work they need to be programmed. For this two different software are used. For the programming of the Arduino and the sensors the Arduino computer software is used. For the programming of the visuals the PyCharm computer software is used.

6.2.1 Arduino

The Arduino software is used to code the electronics and how they work. This software can be downloaded for free on the internet. It uses C++ language to code the sensors. In the code for the integrated system there are multiple voids that control the different elements, see appendix B.1. The LEDs are controlled by 'for loops' that say which exact LEDs should be which colors. The infrared sensors are controlled by 'if statements'. If one of the sensors measures movement in a 14.5cm distance then that means that waste has been disposed into one of the bins. According to what bin it is disposed of, the code prints out the first letter of the bin that has been activated, which could be: P for paper, O for organic, PD for PD, and R for residual. By printing this in the serial monitor the Arduino code can communicate with the Python code, which makes the visuals appear on a screen.

6.2.2 Python

The communication between the Arduino code and the Python code goes through the serial monitor of the Arduino. Everything that is printed on the serial monitor of Arduino is taken and used in the Python program. The screen is made in Python using the Pygame library. This is an open source library that can be used by everyone. This library is used to program video games. This means that it is easy to build game situations in. In this case it can be useful to display the images for the BinBuddies and the video that shows the unknown items video. When the Python code receives the data from the Arduino serial monitor then it creates a counter for each of the bins. If the counter of one of the bins increases, that corresponding BinBuddy grows one step bigger. For the first two items the BinBuddy stays sad. When the counter is on the second till fifth item it depicts the neutral smiling BinBuddy. When there are more than five items in the bin the happy BinBuddy is shown. Once one of the counters is activated the code makes the 'Thank You' speech bubble show up and the confetti, see appendix B.2.

6.3 The Final Prototype

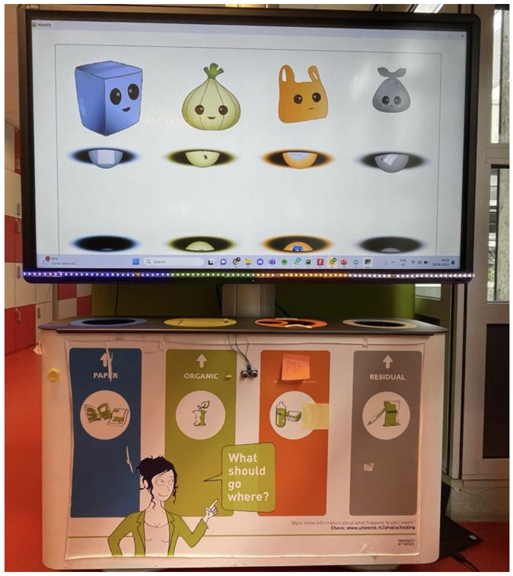


Figure 42: The Final Prototype

Image 42 shows the final prototype. All the sensors and wiring is hidden inside the waste island as much as possible. This way the prototype looks more clean and uncluttered. The wiring of the LEDs are hidden behind the display screen since the screen will be placed against a wall. The only electronics that can be seen from the front is the ultrasonic sensor.

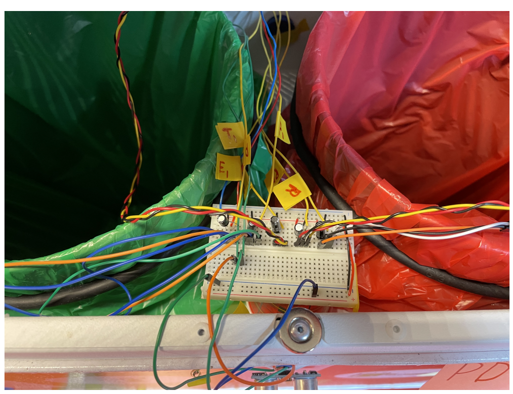


Figure 43: The wiring inside the waste island

The wires are all labeled to be able to keep track of which wire is from which sensor, see figure 43. The wires are also color coded. The red wires are for the 5V, while the black wires are the ground wires. The yellow wires are the analog pin wires from the infrared sensors and the yellow and green wires are the trigger and echo wires from the ultrasonic sensor.

Figure 44: The placing of the infrared sensors

The infrared sensors are placed at the most optimal position, see figure 44. This way the waste can be detected as fast as possible. Multiple positions have been tested during the realization of the prototype. The sensors are placed just under the roof of the waste island this way the waste gets recognized quickly and there is the least amount of obstacles nearby that could accidentally trigger the sensor. For example when the sensors are placed on the side of the waste island the sensor can sometimes be triggered by one of the waste bins or the bags that go inside the bins. The only downside to this placement is that the wires of the infrared sensors are hanging inside the bin. The waste items could potentially get stuck between the wires.

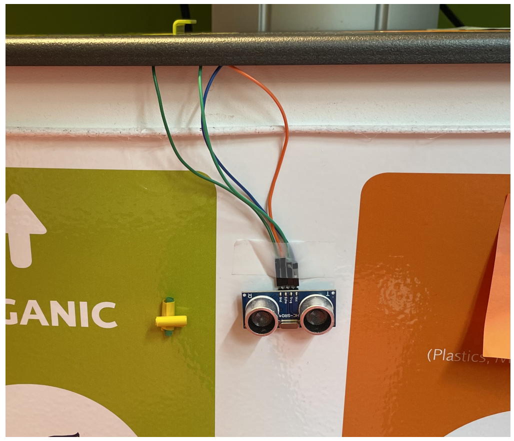


Figure 45: The ultrasonic sensor placed on the outside of the waste island

The ultrasonic sensor is placed at the front of the waste island, see figure 45 This sensor has to be placed at the front since this is the optimal position where it can sense the user. Since the ultrasonic sensor has an effective angle of 15° the sensor can also measure a user that is not directly in front of the waste island. Furthermore, the sensor is programmed to measure if a user is in a 1m proximity to the bin. It was tested with a 0.5m proximity however if the user moved a bit in this case the sensors would turn off too quickly. A distance of 1.2m was not that much different than a one meter distance so therefore, 1m was chosen.

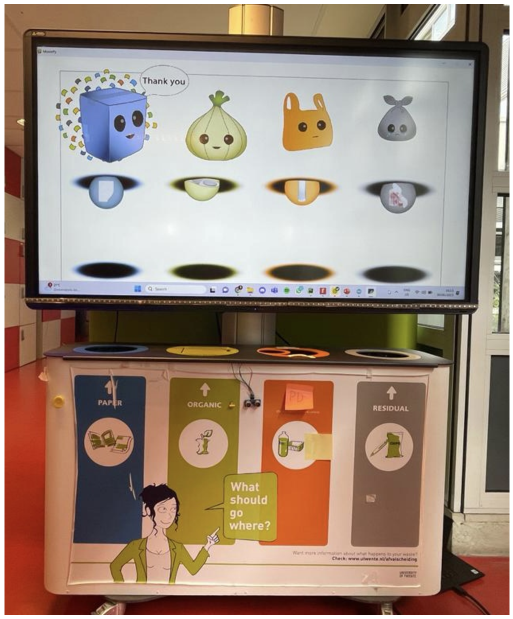


Figure 46: The paper BinBuddy activated after waste is disposed

When the BinBuddies are activated they thank the user and the screen displays confetti, see figure 46. The confetti emphasizes the fact that something happened. This way the eye of the user is caught and they tend to look more at the screen. Furthermore, the portals on the screen are located right above the bin for the corresponding BinBuddy. This way it looks like the unknown items are 'falling' into the bin.

6.4 Functional Requirements Review

After the integration it is time to revise back to the functional requirements and evaluate these. The *must* requirements are the most important requirements for the system to have.

Number	**Functional Requirement**	Implemented
1.	The waste island must sense when a user is in a proximity of one meter.	Yes
2.	The waste island must know what bin waste has been disposed of.	Yes
3.	The system must show the idle state when there is no user in the 1m proximity.	Yes
4.	The size of the BinBuddies *must* increase by 1.05 every time a waste item is thrown into the waste island.	Yes
5.	Each separate BinBuddy *must* thank the user when they dispose of waste by showing a speech bubble with the words "Thank You" once an item is thrown into one of the bins.	Yes
6.	User feedback *must* be given when the system is active through the use of colored LEDs, the colors of the LEDs represent each bin separately. Blue for paper, green for organic, orange for PD and gray for residual.	Yes
7.	The waste bin *must* detect two waste items for the facial expression of the BinBuddy to change from sad to neutral, and three items for it to change from neutral to happy.	Yes
8.	The maximal size of the BinBuddies *must* be 235 by 260 pixels to still fit properly onto the screen.	Yes
9.	The waste island *should* detect waste of any size in every waste bin.	Partially
10.	The waste bin *should* detect waste fast enough to detect the various waste items that are dropped into the bin from a 10cm height.	Partially

Table 5: Functional Requirements review

As shown in table 5 the functional requirements are achieved. Only functional requirements nine and ten are not completely satisfied. The system does measure most sizes of items, however, very small items are more difficult for the sensor to measure when thrown into the bin. This is where the sensitivity of the sensors come into place. A balance needs to be found between the ability to detect objects easier and the fact that if the sensitivity is too high the light that surrounds the sensor might influence the measurements. Therefore, the bins might not detect very small and fast falling objects.

7 Evaluation

This chapter will revolve around the prototype evaluation of the project. This is the final part of the Creative Technology design process. The evaluation is where the non-functional requirements are reviewed through user-testing. User-testing is where end users and important stakeholders of the project test the prototype. The users evaluate the system and the functions that it has. Thereafter, they identify positive attributes and points of improvement. This way the product can be iterated and improved upon for future use.

The user testing was done in the area of the Flex office which is located in the Zilverling in June 2023. There were 20 participants in total. All the participants were asked to do the same tasks. Right after the task was completed they were asked a few open questions, and asked to fill in a survey. In this chapter the setup and procedure of the user-testing is explained. Furthermore, the answers of the participants are analyzed and evaluated. Finally, the non-functional requirements are assessed.

7.1 User Testing

As mentioned before the system was analyzed and evaluated using user-testing. For this to work properly a well thought out setup was needed as well as clear and comprehensible tasks. There were two different days of testing with one day in between. On the first day 7 of the participants tested the prototype. From there on small alterations were made to the prototype. These were done during the day in between evaluations. Then the second testing day the next 13 participants evaluated the product. This way the new participants could test the altered product and observations could be done to see if the alterations positively or negatively changed their experience.

7.1.1 Setup

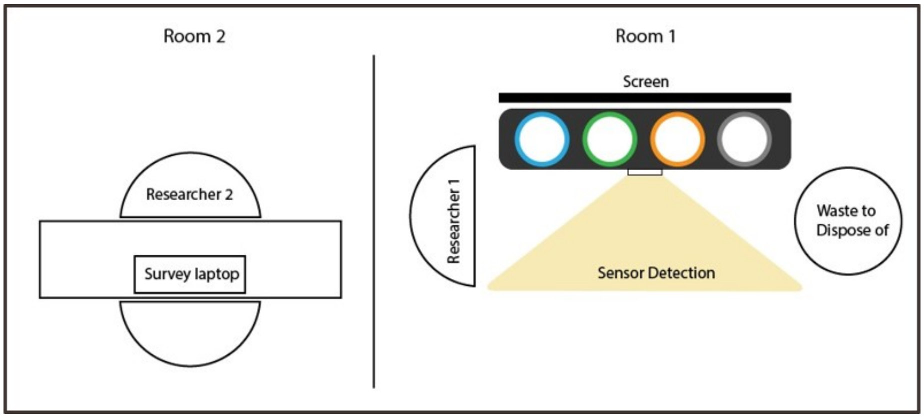


Figure 47: The setup of the evaluations

The user testing setup was divided into two different sections. The prototype section, and the interview section, see figure 47. The prototype was situated just outside the Flex office. This was where the participants fulfilled a task. During the task, one of the researchers sat next to the bin to observe how the participants reacted to the system. There was enough space for the user to walk up to the prototype and be able to dispose of their waste properly. Moreover, there was enough space for the participant to walk away from the bin to notice that the LEDs turned off. The consent form and the survey were filled in inside the Flex office, since there were comfortable chairs and a desk where the user could sit and fill in the forms. The other researcher was inside the Flex office to help the participant with any questions, and to conduct the interview.

7.1.2 The Task

The task that every participant had to complete was to dispose of 15 different items, see table 6. At least 3 items for every bin. They needed to separate these items into the bins that they thought would be correct. On some of the items was written if they were clean or not, this was either written on the object themselves or on a sticky note that was placed inside of the object. This would alter in which of the bins the waste belonged to. The items were not really dirty, since it was unethical to make the users touch items which were dirty and had food residue on them. The items from the organic bin were wrapped in a small transparent plastic bag. This way the participant did not have to touch the banana peel or the apple core. The waste items chosen were all items that are frequently discarded at the UT, for example: paper cups, napkins, drinking cartons and wooden cutlery. All the waste items were deposited into a plastic bag. This way the items were mixed up, to make it fair for all the participants.

Number	**Waste Item**	Waste bin
1.	Paper cup (used)	Residual
2.	Capri-Sun juice box (empty)	Residual
3.	Two napkins (used)	Residual
4.	Paper food container (dirty)	Residual
5.	Wooden cutlery (used)	Residual
6.	Metal can	Residual
7.	Paper food bag (dirty)	Residual
8.	Plastic cup (clean)	PD
9.	Drinking carton (empty)	PD
10.	Cookie wrapper	PD
11.	Apple core	Organic
12.	Banana peel	Organic
13.	Tea bag	Organic
14.	Cardboard box	Paper
15.	two Paper food bags (clean)	Paper

Table 6: Waste items used for the user-testing

7.1.3 The Interview

After the participant completed the task they were asked 3 questions in the style of a short interview. These questions were asked so that the participants could give answers in more detail. These open questions were useful for the analysis of the non-functional requirements. They covered the most important non-functional requirements for the prototype. These necessities were that the system must have motivated the user to separate waste and that the system must have educated the user on the unknown waste objects. The unknown objects were the waste items that were frequently thrown away in the wrong bin everywhere on the campus. The following three questions were asked:

1. How do you think the installation affects your motivation to separate waste?
2. How do you think it could affect your motivation in the long run?
3. How do you feel your knowledge is about waste separation after interacting with the installation?

7.1.4 The Survey

All the participants were asked to complete the same questionnaire. The survey was concluded after the interview was conducted. They were asked to fill in 20 different questions. These varied from asking for the user's age to asking if the prototype was motivating. The questions that were asked were based on the non-functional requirements that were set for this prototype. See appendix E to find all the questions. This way every non-functional requirement could be assessed separately if they were implemented correctly.

7.2 Steps of Procedure

1. The participant was invited into the Flex office, the information brochure and the ethical consent form were presented. The user was asked to read the brochure and to sign the consent form, see appendix C and appendix D.
2. The participant was taken outside the Flex office to where the prototype was placed. Clear instructions were given to the participant for what they need to do for the task.
3. The participant was given the plastic bag with the waste items inside. They were asked to separate the waste items and to put the items into the bins they thought was correct.
4. While disposing waste, one of the researchers observed the user to see what they were doing and what they were looking at while depositing the waste items into the bins.
5. When the user was finished, they were brought back inside the Flex office. Here they were interviewed by the other researcher, and then asked to complete a short survey.
6. After filling in the survey the participant was thanked for their participation and contribution to the research.
7. The researchers then got ready and prepared the set-up for the next participant.

7.3 Results

There were three sources of information when it came to the evaluation. There was data from the observations, interviews and from the survey. These were all looked at and evaluated to see if the non-functional requirements were achieved.

7.3.1 Interviews

The answers of all the interviews conducted on both days are summarized. The summaries focus on the three main objectives of the prototype: initial motivation, motivation in the long run, and knowledge on separating waste.

7.3.1.1 *First Day of Evaluations*

For the first evaluation day, most participants found the installation intriguing and captivating because it combined technology with a regular waste bin, making their daily task more engaging. The gamified interaction of the installation added to their curiosity and interest. When it comes to participant motivation, a bit more than half (58%) expressed that the gamification elements had a positive impact on their motivation and their first impression of the installation. They explicitly mentioned that the sound effects influenced their motivation in a positive way. Moreover, they mentioned that the LEDs did elevate their experience. Nevertheless, there were participants who didn't experience an initial sense of motivation from the installation. They expressed that the absence of feedback when it comes to the correctness of their item disposal made their actions feel identical compared to using a normal waste bin, with the only difference being a lengthier process. Therefore, when considering the short term motivation the integration of technology with a normal day to day task can be motivating however, in this case the lack of feedback for their waste separation behavior does not motivate them.

When regarding the motivational impact of the installation for the long run, a larger part of the participants assessed the installation as a good beginning venture. Nonetheless, the participants did mention that the installation would eventually get repetitive and thus diminishing motivation in the course of time. To address this problem a few suggestions were made. For example, implementing more animations or adding other attention grabbing functions to the system to keep the users attention over a longer period of time.

As to the knowledge of the participants after having interacted with the installation, 70% believed their separation behavior to be positively affected. This was due to the video containing the unknown items, that were frequently disposed of incorrectly. Though, it was brought up that the items shown in the video would eventually have to be updated once the UT community learns where the current displayed items go.

Furthermore, some small remarks were made. These would be that the system needed to be integrated more. Participants believed the system to be two separate parts, the screen and the waste island. The reason for this being that the participants tended to pay more attention to separating their waste than to look up at the display. Since the display was set at eye height, the users had more difficulty paying attention to both the waste island and the display at the same time. In addition, the LEDs that were placed right underneath the lid of the waste island were not visible enough according to the participants. They predicted that the function of the LEDs would become more clear once they became more visible.

7.3.1.2 *Second Day of Evaluations*

After receiving the feedback from the Monday evaluations. A few small alterations were made to the installation. The display was set to a lower position just above the waste island. This was the short term solution to the display and waste island not seeming like one integrated installation. The user could now see the waste island and the display at the same time. In addition, the LEDs were attached to the frame of the display, making them more visible. Besides these changes there was also a confetti animation added to the situation in which the BinBuddies are activated. When a BinBuddy said 'Thank you' to the user, confetti would appear behind the activated BinBuddy. This was executed so that there would be more emphasis on the BinBuddies and their emotions. Lastly, the growing steps of the BinBuddies were increased. They grew bigger at a faster rate so that the user would clearly see the changes in the BinBuddies. These changes were made so that observations could be made on the second evaluation day to see if the changes positively affected the participants' experience.

Just like on the first testing day, on the second day the participants liked the combination of technology and the waste island to increase the separation behavior of the UT community. 62% of the participants expressed that the overall installation did positively affect their motivation to separate waste. Some mentioned that the change in expression and size of the BinBuddies did prompt them to throw away more waste. The visuals of the installation were effective in stimulating participants to engage with the installation. The participants enjoyed the way that the BinBuddies gave positive feedback using sound and the confetti. The gamification element and the immediate feedback was positively welcomed.

Similarly to the first evaluation day when looking at the motivation in the long run, the participants thought that the system would get repetitive over time. As a solution for this, participants explained that more interaction would provoke them to keep their attention on the system. Some of the participants mentioned that the system only provoked them to dispose of waste and not focus on separating their waste. Again, it was also mentioned that the images would have to be updated once in a while.

When looking at the improvement of knowledge on the unknown items, 69% of the participants agreed that the video of the waste items did help their separation. However, a minority of the participants felt that their knowledge of waste separation was already advanced, and therefore did not feel that the installation had a significant impact on their behavior.

7.3.2 Surveys

The survey was conducted to be able to see the statistics of the BinBuddy experience. Questions were asked about the system to see to what extent the non-functional requirements were completed.

7.3.2.1 BinBuddy Experience

Thirteen of the survey questions were multiple choice questions with five possible answers: strongly disagree, disagree, neutral, agree, and strongly agree.

This scale can also be called the Likert scale. [38] The answers are set into a graph with one being strongly disagree and five being strongly agree. These 13 questions are formed into points of criteria. The average is taken from all the questions and plotted into a graph, see figure 48.

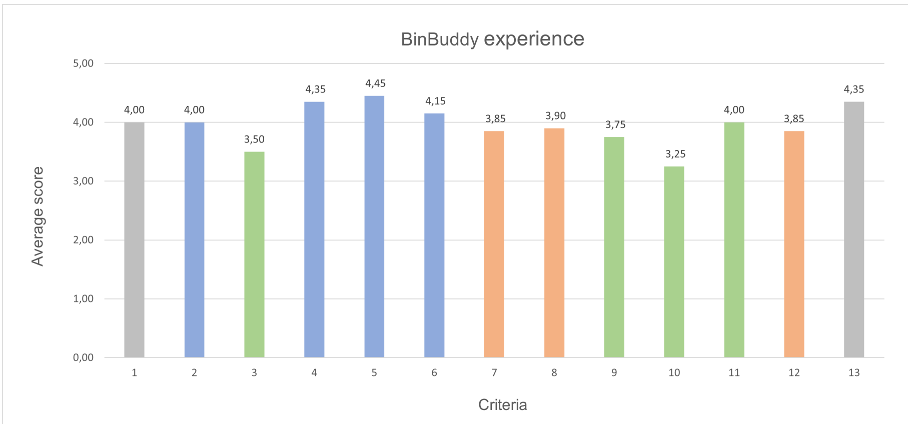


Figure 48: The respective 13 criteria points from the survey

The following 13 statements were the criteria points rated by the participants:

1. The screen is easy to understand.
2. The screen looks appealing.
3. The screen gave informative feedback.
4. The items in the bubbles were easy to recognize.
5. The items in the bubbles looked realistic.
6. The text on the screen was readable.
7. The video of the waste items was clear.
8. The video of the waste items helped separate waste.
9. The goal of the BinBuddies is understood.
10. Sympathy is felt for the BinBuddies.
11. The installation engaged and captured attention.
12. The installation taught how to separate waste better.
13. The installation was easy to interact with.

The criteria can be separated into four categories: aesthetics (blue), motivation (green), knowledge (orange), and convenience (gray), see figure 49. When looking at the rating of the four different aspects it can be seen that the aesthetics of the BinBuddy installation has been given a high average rating of 4.24 out of 5. While the motivation is scored relatively low for the prototype. The participants gave a low score for the fact that they did not have sympathy for the BinBuddies and that the system did not give enough informative feedback. Moreover, the goal of the BinBuddies was not clear enough according to the participants. The knowledge criteria of the system got a rating of 3.88. This is the criteria that focuses on the visibility and understand-ability of the video with the unknown items. The convenience of the system is rated high as well with a 4.18. The screen is easy to understand and the installation is easy to interact with. Even though the score of the motivation and the knowledge aspect of the system got rated relatively low the prototype got a total average rating of 3.98. Which signifies that the system has a high rating out of 5. When looking at the separate criteria points, in general, they received a relatively high score. Criteria point number ten being the lowest scored criteria with an average of 3.25. This is where the participants were asked if they felt sympathy for the BinBuddies. With number five being the highest, for the realistic images in the bubbles.

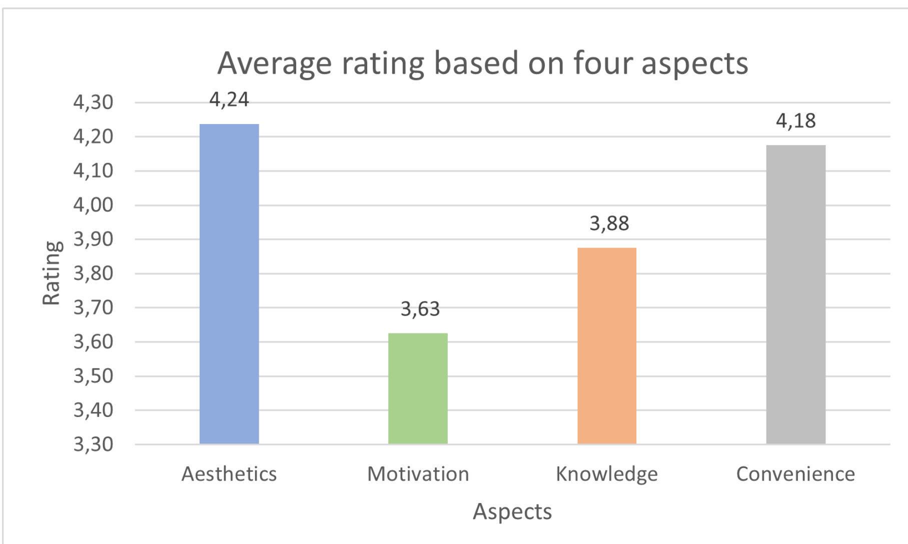


Figure 49: The average of the four aspects

7.3.2.2 Survey Remarks

Other than the multiple choice questions that rated the system there was one question where the participant could give their opinion on the BinBuddies. Most of the participants thought they were cute. The survey also covered one open question. This question asked if the participant had any other remarks and comments. The main comments were that the sound was more inviting than the BinBuddies themselves. However, this did create confusion due to the sound always being positive even when disposing of waste incorrectly. In addition to that the users remarked on the display and waste island needing to be integrated better.

7.3.3 Observations

When conducting the evaluations some observations were made. These observations were made either during the disposing of waste or were small comments given by the participants while testing the prototype. It was observed that the participants were confused about what the emotions of the BinBuddies represented. Furthermore, it was observed that the speed of the video was too slow. The participants ran out of patience when disposing of all the waste items. However, it was also observed that while the system was up and running people that were sitting in the surrounding area did pay attention to the items in the bubbles while not having to dispose of waste. This means that the installation does attract attention and in some cases can teach people what items go where.

7.4 Concluding Remarks

Number	**Non-functional Requirement**	Implemented
1.	The system must be easy to interact with.	Yes
2.	The system must educate on improper separated waste items.	Yes
3.	There must be no alterations to the existing waste islands.	Yes
4.	The system should be interesting to use.	Partially
5.	The user should be motivated by the installation.	Partially

Table 7: Non-functional Requirements review

In conclusion, although most participants found the gamified elements of the installation captivating and motivating, a subset of individuals felt less motivated due to the lack of immediate feedback on the correctness of their waste separation behavior. They also believed that over a longer period of time the installation would get repetitive and lose its usefulness. Therefore needing more interaction, in addition to, replacing the items in the video once in a while. Furthermore, the installation was focused more on disposing of waste instead of separating waste. The motivational and knowledge aspects of the system could be improved upon. Nonetheless, the overall rating of the system was comparatively high. Even though the evaluation made clear that there was a lot to change, the overall system did achieve what it was meant to achieve.

8 Conclusion & Discussion

8.1 Conclusion

The research question: “How can a smart technology based intervention be used to influence the motivation of the UT community towards proper waste separation at the UT campus?” can be answered. An interactive waste island with the BinBuddies system is a good starting point for motivating the UT community, however, major alterations and improvements need to be made for the system to work well enough to keep motivating them over a longer period of time. The results from the prototype evaluations established that the short term motivation was indeed increased. With 55% of all the participants combined who agreed with that. When asking about the motivation in the long run, although, it was not as positively reviewed. 35% of the total participants said the installation lacked interaction, and therefore believed it would lose their interest in the long run. Furthermore, 70% of the participants presumed that their knowledge of waste separation did improve while using the system. Overall, the non-functional requirements were mostly satisfied. Moreover, the functional requirements were predominantly satisfied as well. This signifies that the research has been proven useful. The BinBuddies solution helps with motivation in the short run and the knowledge aspect. The long run motivation of the BinBuddies can be enhanced for an optimal working intervention that uses smart technology.

8.2 Discussion

8.2.1 Prototype Performance

The results from the evaluation chapter indicate that the prototype enhances the short term motivation for the UT community. In the long run, however, improvements need to be made. The participants mentioned that more interactivity is needed for the system to be more effective and more appealing to use. The knowledge aspect of the waste island did improve when interacting with the installation. One problem with the system was that the objective of the BinBuddies was not really clear according to the users. The users observed that the BinBuddies started small and sad. They did observe that they eventually got happier and bigger. However, not all participants knew what was meant with this. Some thought that they were disposing of their waste wrong because the BinBuddies were sad. The confusing part was that most participants expected the system to give feedback about wrongly separated waste, which was not done by the system. In addition, the video of the unknown items went a bit slow for most of the participants. They seemed to lose interest and patience while waiting for their unknown item to show up on the screen. Overall, the participants did mention the system to be a good start when it comes to motivating the UT.

8.2.2 Limitations

There were a few limitations when it came to the installation and the research. The accuracy of the sensors was one of the substantial problems concerning the BinBuddies system. For the user detection, an ultrasonic sensor was placed on the front side of the waste island exactly in the middle. This way the sensor would detect if a user would be standing directly in front of the bin. With an effectual angle of 15 (degrees) the sensor was thought to be good enough to sense users that walked up to the system at an angle. The sensor did occasionally measure users at an angle, nonetheless, it did not have a very broad and accurate range. Sometimes the sensor would work at an angle and other times not so much. Moreover, the ultrasonic sensor seemed to have a difficult time sensing when the user was moving in and out of the proximity.

Furthermore, the infrared sensors were also strained. The balance between the accuracy and the influence of outside light was problematic. The sensors would have to be calibrated to sense small and fast objects. Once the sensitivity of the sensors was set too high, outside light would alter the effectiveness of the sensors. The sensors would sense the light from the hallway and the system would falsely be activated.

Another limitation that is mentionable is that it was not permitted to change the waste island in any way. Some creative additions could have been made if this was possible. For example, more interactivity with the waste island itself. Buttons or smaller displays could have been inserted into the waste island to be able to interact with the BinBuddies. Then the BinBuddies would move if a button was pressed or more information would be given to the user about updated statistics of waste separation at the UT. Being able to alter the waste island would have increased the possibility of interaction with the installation.

9 Future Work

Though the prototype is a good start to motivate the UT community, there is still room for improvement. During the realization and evaluation phases there were observations and recommendations for future research.

As mentioned before, the participants missed more interaction with the waste island. One participant mentioned that an interaction with the waste island to see the current statistics of waste separation at the UT would be an agreeable and meaningful addition to the installation.

A few alterations could be made to the visuals of the system. One example of this could be the image resolution of the BinBuddies. By having to transform the pictures in the Python code for the BinBuddies to increase in size, the resolution of the images decreased. Once the BinBuddies grew a few times they became pixelated. Another alteration could be to change the speed of the looped video of unknown items. The participants of the evaluations lost patience to see if their unknown item would show up. A way to fix this would be to create a way to keep the unknowns visible at all times. For example, use displays on the waste island where the unknown items could stack up. Or make the unknown float around on the screen instead of disappearing.

Since some participants found it difficult to understand that the system did not see if the items thrown away were correct or not, this could be implemented in the future. A bar code system could be applied that checks where the waste item should be placed in and the system would indicate this. This would be useful in the short run and long run due to the fact that the UT community will eventually learn where what waste would go, and if not they could keep scanning the bar-code of all items.

Furthermore, some improvements could be made to the evaluation of the system. When the participants were testing the system the ultrasonic sensor did not always detect the user. Therefore an indication of where they could stand, would improve the user testing. The system would detect more of the waste items disposed of into the system. Another solution for this would be to add more ultrasonic sensors to the waste island. This way the user could throw away their waste from all around the waste bin, including the sides. This could also be used to adjust the problem with the infrared sensors that do not detect small waste items. There could possibly be more infrared sensors implemented into each bin. An alternative would be to use more accurate sensors. This would be the more expensive option, however, probably the most secure option as well.

Evidently there are numerous improvements that could be made to the installation to make the system more efficient, intriguing, and motivating for the UT community. This research can be used to influence and motivate the UT community to improve on its waste separation, and help University of Twente achieve the waste plan.

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A Appendix data waste analysis

PD			Residual			Paper			GFT		
items:	Amount:	Should be in:	items:	Amount:	Should be in:	items:	Amount:	Should be in:	items:	Amount:	Should be in:
paper cups	43		paper napkins	73		paper napkin	139	res	wooden cutlerty	4	res
bubble wrap	1		wooden cutlery	60		paper cups	20	res	napkins	3	res
PET bottles	9		paper cups	15	pd	wooden cutlery	28	res	paper food bags	1	res
6 cans	6	res	plastic bags	6	pd	paper food bags	16	res	portions of rice	2	
wooden cutlery	9	res	paper food bags	13		plastic wrapper	3	res	banana peels	3	
plastic contsiners	10		paper bowls	4		sandwich bag	1	res	tangirines	3	
paper napkins	17	res	paper food containers	9		paper food containers (waaier	3	res	apples	2	
plastic container lids	2		paper trays	15		paper tray	7	res	egg shells	2	
aluminium container lids	4	res	condiment packets empty	3	pd	cigaret bud	1	res	ginger slices	10	
paper tray	5	res	salt&pepper packages	16					grape vine	1	
paper bags	2	res	aluminium foil	1							
paper bowls	1	res	metal key chain lock thingy	1							
condiment packets	6	res	plastic containers	2	pd						
condiment packets empty	3		plastic lids	3	pd						
drinking cartons	4		aluminium container lids	9							
metal bottle cap	1	res									
plastic food bags	15										
aluminium foil	1	res									
snack wrappers	5										
caprisun	1										
	Total amount:			Total amount:			Total amount:			Total amount:	
	145			230			218			31	
	Total good:	%:		Total good:	%:		Total good:	%:		Total good:	%:
	93	0.6413793103		185	0.8043478261		0	0		23	0.7419354839
	Total faulty:			Total faulty:			Total faulty:			Total faulty:	
	52	0.3586206897		45	0.1956521739		218	1		8	0.2580645161
	Overall total:										
	624										
	Overall good:	%:									
	301	0.4823717949									
	Overall faulty:										
	323	0.5176282051									

Figure 50: The data on the waste analysis done May 17th 2023

B Appendix Code

B.1 Arduino code

```
#include <FastLED.h>

// LED configuration
#define LED_PIN           5
#define NUM_LEDS          102
#define BRIGHTNESS        64
#define LED_TYPE          WS2811
#define COLOR_ORDER       GRB
CRGB leds[NUM_LEDS];

// Ultrasonic sensor configuration
const int trigPin1 = 2;
const int echoPin1 = 3;

// IR sensor configuration
const int analogPin1 = A0;
const int analogPin2 = A1;
const int analogPin3 = A2;
const int analogPin4 = A3;
const int analogPin5 = A4;

// Sensor distance thresholds
const float DISTANCE_THRESHOLD = 14.5;

// Sensor activation counters
```

```
int pCounter = 0;
int oCounter = 0;
int pdCounter = 0;
int rCounter = 0;

// Sensor activation timestamps
unsigned long lastActivationTimeP = 0;
unsigned long lastActivationTimeO = 0;
unsigned long lastActivationTimePD = 0;
unsigned long lastActivationTimeR = 0;

// Full print timestamps
unsigned long lastFullPPrintTime = 0;
unsigned long lastFullOPrintTime = 0;
unsigned long lastFullPDPrintTime = 0;
unsigned long lastFullRPrintTime = 0;

// Filtered voltage variables
float filteredVolts1 = 0;
float filteredVolts2 = 0;
float filteredVolts3 = 0;
float filteredVolts4 = 0;
float filteredVolts5 = 0;

// Sensor activation flags
bool papActivated = false;
bool orgActivated = false;
bool pdActivated = false;
bool resActivated = false;
bool irSensorsActivated = false;

// Function prototypes
void setup();
void loop();
void turnOnLEDs();
void turnOffLEDs();
void turnOnIRSensors();
void turnOffIRSensors();
long microsecondsToCentimeters(long microseconds);

void setup() {
  // Initialize serial communication
  Serial.begin(9600);

  // LED strip setup
  delay(3000); // Power-up safety delay
  FastLED.addLeds<LED_TYPE, LED_PIN,
  COLOR_ORDER>(leds, NUM_LEDS).setCorrection(TypicalLEDStrip);
  FastLED.setBrightness(BRIGHTNESS);
  FastLED.clear();
  FastLED.show();
}

void loop() {
  // Ultrasonic sensor code
  long duration, cm;
```

```
  pinMode(trigPin1, OUTPUT);
  digitalWrite(trigPin1, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin1, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin1, LOW);
  pinMode(echoPin1, INPUT);
  duration = pulseIn(echoPin1, HIGH);
  cm = microsecondsToCentimeters(duration);

  if (cm < 100) {
    turnOnLEDs();
    turnOnIRSensors();
  } else {
    turnOffLEDs();
    turnOffIRSensors();
  }

  delay(50);
}

void turnOnLEDs() {
  for (int i = 0; i < 31; i++) {
    leds[i] = CRGB::Blue;
  }
  for (int i = 31; i < 48; i++) {
    leds[i] = CRGB::Green;
  }
  for (int i = 48; i < 66; i++) {
    leds[i] = CRGB(255, 80, 0);
  }
  for (int i = 66; i < NUM_LEDS; i++) {
    leds[i] = CRGB::Gray;
  }
  FastLED.show();
}

void turnOffLEDs() {
  FastLED.clear();
  FastLED.show();
}

void turnOnIRSensors() {
  irSensorsActivated = true;

  if (irSensorsActivated) {
    // Read the analog input voltages from the sensors
    float volts1 = analogRead(analogPin1);
    float volts2 = analogRead(analogPin2);
    float volts3 = analogRead(analogPin3);
    float volts4 = analogRead(analogPin4);
    float volts5 = analogRead(analogPin5);

    // Low-pass filter
    filteredVolts1 = filteredVolts1 * (1 - 0.02) + volts1 * 0.02;
    filteredVolts2 = filteredVolts2 * (1 - 0.2) + volts2 * 0.2;
    filteredVolts3 = filteredVolts3 * (1 - 0.15) + volts3 * 0.15;
```

```
filteredVolts4 = filteredVolts4 * (1 - 0.15) + volts4 * 0.10;
filteredVolts5 = filteredVolts5 * (1 - 0.05) + volts5 * 0.05;

// Distance calculations
float dist1F = (6762 / (filteredVolts1 - 9)) - 4;
float dist2F = (6762 / (filteredVolts2 - 9)) - 4;
float dist3F = (6762 / (filteredVolts3 - 9)) - 4;
float dist4F = (6762 / (filteredVolts4 - 9)) - 4;
float dist5F = (6762 / (filteredVolts5 - 9)) - 4;

// Check the conditions for each sensor and print the corresponding number
if (dist1F < DISTANCE_THRESHOLD || dist5F < DISTANCE_THRESHOLD) {
  papActivated = true;
  if (papActivated && millis() - lastFullPPrintTime >= 2000) {
    pCounter++;
    if (pCounter >= 1 && pCounter <= 7) {
      Serial.println("P");
      Serial.println("Paper");
      lastFullPPrintTime = millis();
      pCounter = 0;
      papActivated = false;
    }
  } else {
    lastActivationTimeP = millis();
  }
  activationCounterP++;
} else {
  papActivated = false;
}

if (dist2F < DISTANCE_THRESHOLD) {
  orgActivated = true;
  if (orgActivated && millis() - lastFullOPrintTime >= 2000) {
    oCounter++;
    if (oCounter >= 1 && oCounter <= 5) {
      Serial.println("O");
      Serial.println("Organic");
      lastFullOPrintTime = millis();
      oCounter = 0;
    }
  } else {
    lastActivationTimeO = millis();
  }
  activationCounterO++;
} else {
  orgActivated = false;
}

if (dist3F < DISTANCE_THRESHOLD) {
  pdActivated = true;
  if (pdActivated && millis() - lastFullPDPrintTime >= 2000) {
    pdCounter++;
    if (pdCounter >= 1 && pdCounter <= 5) {
      Serial.println("PD");
      Serial.println("Plastic");
      lastFullPDPrintTime = millis();
      pdCounter = 0;
```

```
          pdActivated = false;
        }
      } else {
        lastActivationTimePD = millis();
           activationCounterPD++;
    } else {
      pdActivated = false;
    }

    if (dist4F < DISTANCE_THRESHOLD) {
      resActivated = true;
      if (resActivated && millis() - lastFullRPrintTime >= 2000) {
        rCounter++;
        if (rCounter >= 1 && rCounter <= 2) {
          Serial.println("R");
          Serial.println("Residual");
          lastFullRPrintTime = millis();
          rCounter = 0;
        }
      } else {
        lastActivationTimeR = millis();
      }
      activationCounterR++;
    } else {
      resActivated = false;
    }
  }
}

void turnOffIRSensors() {
  irSensorsActivated = false;
}

long microsecondsToCentimeters(long microseconds) {
  return microseconds / 29 / 2;
}
```

B.2 Python code

I still have to clean up the python code :)

```
import serial
import pygame
import moviepy.editor
import pygame.mixer

# Establish serial communication with Arduino
arduino_port = 'COM6'  # Replace with the appropriate port
arduino_baudrate = 9600  # Make sure to match the baud rate in your Arduino code
arduino_serial = serial.Serial(arduino_port, arduino_baudrate)

counterPap = 0
counterOrg = 0
counterPD = 0
counterRes = 0
```

```
# Variables for timer
show_imagePapY = False

imagePap_timer = 0
imageOrg_timer = 0
imagePD_timer = 0
imageRes_timer = 0

pygame.mixer.init()
pygame.init()

# Get the dimensions of the screen
screen_width = pygame.display.Info().current_w
screen_height = pygame.display.Info().current_h

# Create the Pygame display
screen = pygame.display.set_mode((screen_width, screen_height), pygame.FULLSCREEN)
screen = pygame.display.set_mode((1550 , 780))
clock = pygame.time.Clock()

counter_up_sound = pygame.mixer.Sound('Achievement.mp3')
sound_played = False
# Load the paper images
imagePapH = pygame.image.load('P_Happy.png')
imagePapN = pygame.image.load('P_Neutral.png')
imagePapS = pygame.image.load('P_Sad.png')


# Load the organic images
imageOrgH = pygame.image.load('O_Happy.png')
imageOrgN = pygame.image.load('O_Neutral.png')
imageOrgS = pygame.image.load('O_Sad.png')
#imageOrgY = pygame.image.load('')

# Load the PD images
imagePDH = pygame.image.load('PD_Happy.png')
imagePDN = pygame.image.load('PD_Neutral.png')
imagePDS = pygame.image.load('PD_Sad.png')
#imagePDY = pygame.image.load('')

#load the residual images
imageResH = pygame.image.load('R_Happy.png')
imageResN = pygame.image.load('R_Neutral.png')
imageResS = pygame.image.load('R_Sad.png')
#imageResY = pygame.image.load('')

#Thankyou speech bubbles
imageThankYouL = pygame.image.load('Thank_You_R.png')
imageThankYouR = pygame.image.load('Thank_You_L.png')

# Confetti celebration
imageConfettiS = pygame.image.load('Confetti_RCN_Small_1.png')
imageConfettiM = pygame.image.load('Confetti_RCN_Medium_1.png')
imageConfettiB = pygame.image.load('Confetti_RCN_Big_1.png')
imageConfettiE = pygame.image.load('Confetti_RCN_Extra_1.png')

# Set the initial width and height for each image
```

```
widthH, heightH = 160, 180
widthN, heightN = 150, 170
widthS, heightS = 140, 160

# Scale the paper images to the initial size
imagePapH = pygame.transform.scale(imagePapH, (widthH, heightH))
imagePapN = pygame.transform.scale(imagePapN, (widthN, heightN))
imagePapS = pygame.transform.scale(imagePapS, (widthS, heightS))

imageOrgH = pygame.transform.scale(imageOrgH, (widthH, heightH))
imageOrgN = pygame.transform.scale(imageOrgN, (widthN, heightN))
imageOrgS = pygame.transform.scale(imageOrgS, (widthS, heightS))

imagePDH = pygame.transform.scale(imagePDH, (widthH, heightH))
imagePDN = pygame.transform.scale(imagePDN, (widthN, heightN))
imagePDS = pygame.transform.scale(imagePDS, (widthS, heightS))

imageResH = pygame.transform.scale(imageResH, (widthH, heightH))
imageResN = pygame.transform.scale(imageResN, (widthN, heightN))
imageResS = pygame.transform.scale(imageResS, (widthS, heightS))

# transform speech bubbles
imageThankYouL = pygame.transform.scale(imageThankYouL, (180, 120))
imageThankYouR = pygame.transform.scale(imageThankYouR, (180, 120))

# Load the video
video = moviepy.editor.VideoFileClip("Portals_Final.avi")
video_surface = pygame.Surface(video.size).convert()

# Function for video playback
def play_video():
    video_x = (screen_width - video_surface.get_width()) // 2
    video_y = (screen_height - video_surface.get_height()) // 2
    video_frame = video.get_frame(pygame.time.get_ticks() / 1000 % video.duration)
# Get the frame at the current time
    frame_surface = pygame.surfarray.make_surface(video_frame)
    rotated_surface = pygame.transform.rotate(frame_surface, -90)
    flipped_surface = pygame.transform.flip(rotated_surface,True, False)
    video_surface.blit(flipped_surface, (0, 0))
    screen.blit(video_surface, (video_x, video_y))



statePap = pygame.Surface((0, 0))  # Initialize the state variables
stateOrg = pygame.Surface((0, 0))
statePD = pygame.Surface((0, 0))
stateRes = pygame.Surface((0, 0))

prev_counterPap = 0
prev_counterOrg = 0
prev_counterPD = 0
prev_counterRes = 0

while True:

    current_time = pygame.time.get_ticks()  # Get the current time in milliseconds
   # Read a line of data from Arduino
```

```
arduino_data = arduino_serial.readline().decode().strip()

# Increment the counters based on the Arduino data
if arduino_data == 'P':
    counterPap += 1
elif arduino_data == 'O':
    counterOrg += 1
elif arduino_data == 'PD':
    counterPD += 1
elif arduino_data == 'R':
    counterRes += 1

# If the counter increases the thank you image is
# blitted and the sound is played.
if counterPap > prev_counterPap and not sound_played:
    imagePap_timer = pygame.time.get_ticks()  # Start the timer
    sound_played = True
    counter_up_sound.play()
else:
    sound_played = False

if counterOrg > prev_counterOrg and not sound_played:
    imageOrg_timer = pygame.time.get_ticks()
    sound_played = True
    counter_up_sound.play()
else:
    sound_played = False

if counterPD > prev_counterPD:
    imagePD_timer = pygame.time.get_ticks()
    sound_played = True
    counter_up_sound.play()
else:
    sound_played = False

if counterRes > prev_counterRes:
    imageRes_timer = pygame.time.get_ticks()
    sound_played = True
    counter_up_sound.play()
else:
    sound_played = False


scale_factorPap = 1 + (counterPap * 0.05)
scale_factorOrg = 1 + (counterOrg * 0.05)
scale_factorPD = 1 + (counterPD * 0.05)
scale_factorRes = 1 + (counterRes * 0.05)
max_width = 235
max_height = 260

# Determine the current emotional state based on the counter value
# The paper BinBuddy grows
if counterPap <= 2:
    statePap = pygame.transform.scale(imagePapS, (widthS, heightS))
    statePap = pygame.transform.scale
    (statePap, (int(widthS * scale_factorPap), int(heightS * scale_factorPap)))
elif counterPap <= 5:
```

```
        statePap = pygame.transform.scale(imagePapN, (widthN, heightN))
        statePap = pygame.transform.scale
        (statePap, (int(widthN * scale_factorPap), int(heightN * scale_factorPap)))
    else:
        statePap = pygame.transform.scale(imagePapH, (widthH, heightH))
        statePap = pygame.transform.scale
        (statePap, (int(widthH * scale_factorPap), int(heightH * scale_factorPap)))
        widthPap = int(widthH * scale_factorPap)
        heightPap = int(heightH * scale_factorPap)
        if widthPap > max_width:
            widthPap = max_width
        if heightPap > max_height:
            heightPap = max_height
            statePap = pygame.transform.scale(statePap, (widthPap, heightPap))

    # The organic BinBuddy grows
    if counterOrg <= 2:
        stateOrg = pygame.transform.scale(imageOrgS, (widthS, heightS))
        stateOrg = pygame.transform.scale
        (stateOrg, (int(widthS * scale_factorOrg), int(heightS * scale_factorOrg)))
    elif counterOrg <= 5:
        stateOrg = pygame.transform.scale(imageOrgN, (widthN, heightN))
        stateOrg = pygame.transform.scale
        (stateOrg, (int(widthN * scale_factorOrg), int(heightN * scale_factorOrg)))
    else:
        stateOrg = pygame.transform.scale(imageOrgH, (widthH, heightH))
        stateOrg = pygame.transform.scale
        (stateOrg, (int(widthH * scale_factorOrg), int(heightH * scale_factorOrg)))
        widthOrg = int(widthH * scale_factorOrg)
        heightOrg = int(heightH * scale_factorOrg)
        if widthOrg > max_width:
            widthOrg = max_width
        if heightOrg > max_height:
            heightOrg = max_height
            stateOrg = pygame.transform.scale(stateOrg, (widthOrg, heightOrg))

    # The PD BinBuddy grows
    if counterPD <= 2:
        statePD = pygame.transform.scale(imagePDS, (widthS, heightS))
        statePD = pygame.transform.scale
        (statePD, (int(widthS * scale_factorPD), int(heightS * scale_factorPD)))
    elif counterPD <= 5:
        statePD = pygame.transform.scale(imagePDN, (widthN, heightN))
        statePD = pygame.transform.scale
        (statePD, (int(widthN * scale_factorPD), int(heightN * scale_factorPD)))
    else:
        statePD = pygame.transform.scale(imagePDH, (widthH, heightH))
        statePD = pygame.transform.scale
        (statePD, (int(widthH * scale_factorPD), int(heightH * scale_factorPD)))
        widthPD = int(widthH * scale_factorPD)
        heightPD = int(heightH * scale_factorPD)
        if widthPD > max_width:
            widthPD = max_width
        if heightPD > max_height:
            heightPD = max_height
            statePD = pygame.transform.scale(statePD, (widthPD, heightPD))
```

```
# The residual BinBuddy grows
if counterRes <= 2:
    stateRes = pygame.transform.scale(imageResS, (widthS, heightS))
    stateRes = pygame.transform.scale
    (stateRes, (int(widthS * scale_factorRes), int(heightS * scale_factorRes)))
elif counterRes <= 5:
    stateRes = pygame.transform.scale(imageResN, (widthN, heightN))
    stateRes = pygame.transform.scale
    (stateRes, (int(widthN * scale_factorRes), int(heightN * scale_factorRes)))
else:
    stateRes = pygame.transform.scale(imageResH, (widthH, heightH))
    stateRes = pygame.transform.scale
    (stateRes, (int(widthH * scale_factorRes), int(heightH * scale_factorRes)))
    widthRes = int(widthH * scale_factorRes)
    heightRes = int(heightH * scale_factorRes)
    if widthRes > max_width:
        widthRes = max_width
    if heightRes > max_height:
        heightRes = max_height
        stateRes = pygame.transform.scale(stateRes, (widthRes, heightRes))

# Clear the screen
screen.fill((255, 255, 255))

# Play the video
play_video()

# Blit the paper confetti images and the speech bubble
if 0 <= pygame.time.get_ticks() - imagePap_timer < 250:
    screen.blit(imageConfettiS,(70, 40))
if 250 <= pygame.time.get_ticks() - imagePap_timer < 500:
    screen.blit(imageConfettiM, (70, 40))
if 500 <= pygame.time.get_ticks() - imagePap_timer < 750:
    screen.blit(imageConfettiB, (70, 40))
if 750 <= pygame.time.get_ticks() - imagePap_timer < 2000:
    screen.blit(imageConfettiE, (70, 40))
if pygame.time.get_ticks() - imagePap_timer < 2000:
    screen.blit(imageThankYouL, (350, 20))

# Blit the organic confetti images and the speech bubble
if 0 <= pygame.time.get_ticks() - imageOrg_timer < 250:
    screen.blit(imageConfettiS,(420, 40))
if 250 <= pygame.time.get_ticks() - imageOrg_timer < 500:
    screen.blit(imageConfettiM, (420, 40))
if 500 <= pygame.time.get_ticks() - imageOrg_timer < 750:
    screen.blit(imageConfettiB, (420, 40))
if 750 <= pygame.time.get_ticks() - imageOrg_timer < 2000:
    screen.blit(imageConfettiE, (420, 40))
if pygame.time.get_ticks() - imageOrg_timer < 2000:
    screen.blit(imageThankYouL, (650, 20))

# Blit the PD confetti images and the speech bubble
if 0 <= pygame.time.get_ticks() - imagePD_timer < 250:
    screen.blit(imageConfettiS, (750, 40))
if 250 <= pygame.time.get_ticks() - imagePD_timer < 500:
    screen.blit(imageConfettiM, (750, 40))
if 500 <= pygame.time.get_ticks() - imagePD_timer < 750:
```

```
    screen.blit(imageConfettiB, (750, 40))
if 750 <= pygame.time.get_ticks() - imagePD_timer < 2000:
    screen.blit(imageConfettiE, (750, 40))
if pygame.time.get_ticks() - imagePD_timer < 2000:
    screen.blit(imageThankYouR, (650, 20))

# Blit the residual confetti images and the speech bubble
if 0 <= pygame.time.get_ticks() - imageRes_timer < 250:
    screen.blit(imageConfettiS,(1100, 40))
if 250 <= pygame.time.get_ticks() - imageRes_timer < 500:
    screen.blit(imageConfettiM, (1100, 40))
if 500 <= pygame.time.get_ticks() - imageRes_timer < 750:
    screen.blit(imageConfettiB, (1100, 40))
if 750 <= pygame.time.get_ticks() - imageRes_timer < 2000:
    screen.blit(imageConfettiE, (1100, 40))
if pygame.time.get_ticks() - imageRes_timer < 2000:
    screen.blit(imageThankYouR, (1000, 20))

# Blit the Binbuddies
screen.blit(statePap, (150, 100))
screen.blit(stateOrg, (520, 100))
screen.blit(statePD, (860, 100))
screen.blit(stateRes, (1200, 100))

# Update the display
pygame.display.flip()

prev_counterPap = counterPap
prev_counterOrg = counterOrg
prev_counterPD = counterPD
prev_counterRes = counterRes

#Limit the frame rate
clock.tick(60)

# Handle events
for event in pygame.event.get():
    if event.type == pygame.QUIT:
        # Close the serial communication and quit Pygame
        arduino_serial.close()
        pygame.quit()
        exit()
```

C Appendix Information Brochure

Information Brochure for Graduation Project on Waste Separation

Institution: University of Twente

Researcher information: Marina Stefanova: m.t.stefanova@student.utwente.nl & Eva Barten: e.d.f.barten@student.utwente.nl

Supervisors: Kasia Zalewska: k.zalewskakurek@utwente.nl & Richard Bults: r.g.a.bults@utwente.nl

This research has been **approved/not approved** by the EEMCS Ethics Committee ethicscommittee-cis@utwente.nl.

Title: Improving Waste Separation at the University of Twente Campus

Purpose: The purpose of this research is to observe the waste separation behaviour of the UT community members.

Procedures: You will be asked to participate in a user test, where you are asked to test the prototype created for the final product of the Graduation Project of the researchers. You will be given a task to separate several different waste items (such as a plastic bottle, a coffee cup, an empty chips bag, a piece of paper, a napkin, empty salad box, empty sandwich bags, a banana peel, a tea bag etc.). The waste items will be cleaned prior to the user testing. To fully simulate day to day waste, clean items will be labelled "dirty" with a posted note. For those items you are asked to imagine them as being dirty and separate accordingly. Afterwards a small unstructured interview will be performed, where we will ask several questions regarding your experience with the installation. The interview will be **Audio recorder** and **transcribed** into text afterwards. After the transcription the audio file will be deleted. For this research there will be **no personal** data used and all the recorded data will be anonymised. During the user testing, the researchers may take notes on how the participants interact with the installation and dispose of their waste, as well as perceived easiness or difficulties with separating the provided trash. You can withdraw from the research at any moment, as well as request for your data to not be used in the research. If at any point you feel uncomfortable during the research, please inform on of the researchers and the session will be stopped.

Duration: Approximately 15-20 minutes

Risks: Participants must attend the user testing session in person at the University of Twente. During the user testing we will prioritize the health and safety of all participants.

Confidentiality: Participants are not obligated to provide any personal information. The research findings will be reported in a thesis using anonymized and aggregated data. If you wish for your data to be excluded from the research, you can request at any time during the research. The contact information to make such a request is provided in this brochure, as well as in the consent form.

Figure 51: The information brochure given to participants

D Appendix Ethical consent form

Consent Form for Improving Waste Separation at the UT

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	O	O
I consent voluntarily to be a participant in this study and understand that I can refuse to take part in the user testing, interview and I can withdraw from the study at any time, without having to give a reason.	O	O
I understand that taking part in the study involves working with a physical prototype and taking part in an interview. I also understand that for the choice of the interview, it will be recorded and transcribed to text after which the recordings are destroyed, and that the data which will be collected is saved for research purposes.	O	O
Use of the information in the study		
I understand that information I provide will be used for research into the waste habits of the community members of the UT, which will be translated into a report. This report will be published online and might be used for further research.	O	O
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	O	O
I agree that my information can be quoted in research outputs	O	O
Future use and reuse of the information by others		
I give permission for the data that I provide will be saved in the archive. The data will be saved in the form of a report. The deposited data will be anonymised. Participants will be referred to as "participants" and no names, or any other personal identifiable information will be published.	O	O

Signatures

____________________ ____________________ ________

Name of participant [printed] Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_______________________ __________________ ________

Researcher name [printed] Signature Date

Study contact details for further information:

Marina Stefanova

m.t.stefanova@student.utwente.nl

Figure 52: The ethical consent form given to participants page 1

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

Figure 53: The ethical consent form given to participants page 2

E Appendix Survey questions

1. What is your age?
    - Under 18
    - 18 - 24
    - 25 - 34
    - 35 - 44
    - 45 - 54
    - 55 - 64
    - 65+
2. What is your Gender?
    - Male
    - Female
    - Other
    - Prefer not to say
3. I am a:
    - Bachelor student
    - Master student
    - UT employee
    - Other
4. I think my current waste separation knowledge is:
    - Very bad
    - Bad
    - Neutral
    - Good
    - Very good
5. The screen was easy to understand.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

6. The screen was appealing to me.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

7. The screen gave me informative feedback.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

8. I was able to easily recognize the items displayed in the images.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

9. The items displayed in the images looked realistic.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

10. The text displayed on the screen was clearly readable.
    - Strongly disagree
    - Disagree

- Neutral
- Agree
- Strongly agree

11. The Video (the loop of items) of the waste items was clear to me.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

12. The Video (the loop of items) of the waste items helped me separate my waste.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

13. I understood the goal of the BinBuddies (the 4 different creatures).
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

14. The BinBuddies (The 4 different creatures) made me feel sympathetic.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

15. I think the creatures are:
    - Cute
    - Creepy
    - Uncanny
    - Engaging

- Quirky
- Other

16. The installation effectively engaged me and managed to capture my attention.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree
17. The installation taught me how to better separate my waste.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree
18. It was easy to interact with the installation.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree
19. General Remarks and comments