Developing a tool to sustain desired plastic waste separation behavior in Dutch hospitals

Creative Technology Bachelor Thesis

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Abstract:

The plastic industry is the second largest and fastest-growing source of greenhouse gas emissions. 99% of what goes into plastic is derived from fossil fuels, such as oil and gas, and is therefore a key contributor to global warming. However, in healthcare, it is difficult to cut down on single-use plastics because of health and safety rules applied to medical devices and supplies.

A method is proposed to implement better plastic waste separation within a hospital environment, such that the waste streams can be used by other companies to recycle certain types of plastic. Through theory and state of the art analysis, requirements are set for the system and its functions. After brainstorm sessions and selection, a model is selected to further work out into a working prototype. The proposed method uses a screen and cameras, as well as a set of ultrasound sensors to detect, inform and improve people's waste separation behavior. Testing the proof of concept shows promising results towards a working system that could positively affect the waste separation within a hospital. Further developments would include a long-term test of the project and translation of the project into different sectors.

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1: Introduction

The century we live in has been characterized by an increasing interest in the negative impact our society has on the environment around us. Widespread media coverage is now surrounding global warming due to an increased greenhouse effect and numerous studies have been and still are under analysis to find solutions to limit this phenomenon. (Bostrom et al., 1994)

The plastic industry is the second largest and fastest-growing source of greenhouse gas emissions. 99% of what goes into plastic is derived from fossil fuels, such as oil and gas, and is therefore a key contributor to global warming (Hamilton et al., 2019)

Many studies have been carried out in the attempt of finding solutions to limit plastic production or reduce its greenhouse gas emissions and recycling is now crucial to this discussion. (Korkut, 2018)

1.1 Plastics recycling

Plastic recycling has significant greenhouse gas benefits compared to other waste disposal methods (incineration and landfill). It has been proven that making new products from recycled plastic packaging materials can save more than 75% of the greenhouse gas emissions in comparison to manufacturing from virgin raw materials. (Hamilton et al., 2019). According to the report written by CIEL (Centre for International Environmental Law), the energy savings arising from 3.17 Mt (Megaton = 1 billion kilogram) of plastic waste recycled in the US in 2014 equate to 3.2 million Mt of CO_2 savings according to EPA estimates. This is equivalent to 670,000 less cars on the road over the course of a year (Hamilton et al., 2019).

There are many sources of plastic waste, and one that has been becoming more relevant is the healthcare sector, which appears to be an increasingly significant contributor of plastic waste in the global landscape. A study carried out in Turkey over 18 years shows an increase in hospitals' waste of over 290%, going from generating 0.43 kg per bed-day of medical waste in 1999 to 1.68 kg per bed-day in 2017 (Korkut, 2018). Further proof of increasing plastic consumption in the medical sector is provided by another study carried out in South Korea which highlights the increasingly wide acceptance of single-use disposable items (Jang et al., 2006). In this study the management of medical waste is considered a topic of major concern due to its potential threats to human health and the environment. Figure 1 shows the global plastic packaging waste management.

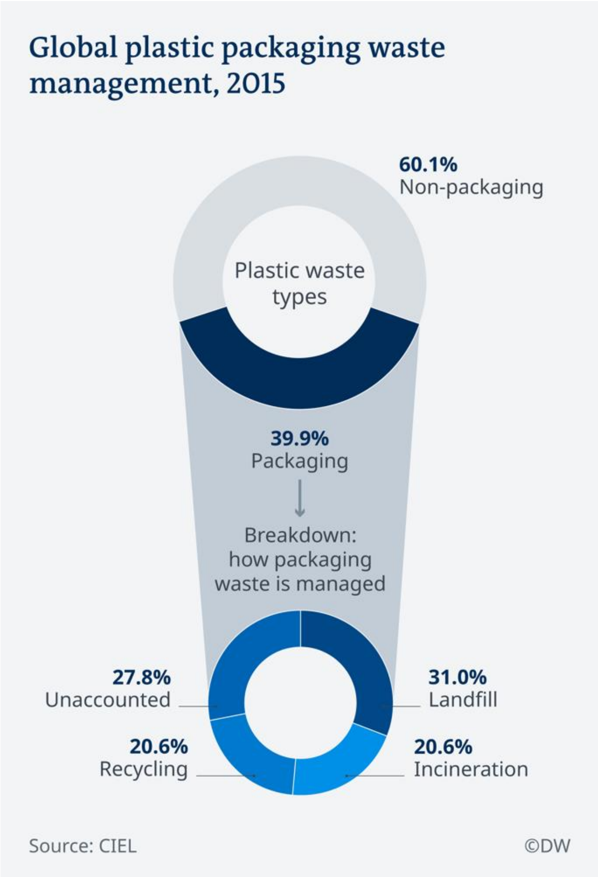


Figure 1. Global plastic packaging waste management

As of now, environmental responsibility is becoming a daily aspect of life. People recycle and reduce, for example, their usage of single-use plastics at home. However, in healthcare, it is difficult to cut down on single-use plastics because of health and safety rules applied to medical devices and supplies (e.g. syringe, bandage, clothing). After being used, hospitals will throw away their plastics and items and get new items to keep everything clean and sterile. Hospitals want to find a way to improve plastic waste collection to enable effective and efficient recycling of plastic waste by a waste processing organization via internal separation systems.

1.2 Goal and Research Questions

In this research, we ask the following question:

RQ How to develop a tool that stimulates desired plastic waste separation behavior of Dutch hospital employees?

The desired waste separation means that people on the working floor have to be informed and motivated to separate plastic waste correctly and act accordingly. Dutch hospitals believe that presenting options for plastic separation and possible reuse of plastic may contribute to improved plastic waste collection.

Sub-questions

The main research questions is split into a number of sub-questions:

- What is the current state of plastic waste behavior at Dutch hospitals?

This is the most logical sub-question to start off with, as it is the current situation and would provide a base data set for possible results.

After finding this base data, it becomes important to either activate or maintain the plastic waste behavior in the hospital, which leads us to the second sub-question:

- What are the contemporary theoretical frameworks to prevent behavior relapse?'

Concluding, we want to combine all of the other sub questions and make a tool out of all the information at hand, leading to our last sub-question

- What are the tool's key elements to stimulate desired behavior?

Only after answering all these sub questions and combining them, we can successfully answer the research question at hand.

1.3 Report outline

The outline of this report will be as follows. In Chapter 2, a theoretical analysis will be done, including state of the art analysis, in which previous research will be analyzed and main takeaways for this project will be found. In Chapter 3, the methods and techniques will be described over the course of the project. Chapter 4 will Identify stakeholders and their respective needs and requirements, after which prototype ideas will be made to be used in Chapter 5. Chapter 5 will be the specification chapter, which will further work out one of the concepts made in Chapter 4, specifying the functionality as well as the inner workings of the prototype. Chapter 6 will focus on the realization of the prototype, after which, in chapter 7, the prototype will be evaluated. Chapter 8 features the conclusion and recommendations for further projects.

2: Research

2.1: Plastic recycling in healthcare

Existing studies have shown that recycling wastes from hospitals is not only possible but it has great potential. Some measures, if adopted, can allow better waste management (Lee et al., 2002) (Sahni et al., 2018). It is clear that hospital plastic waste needs to be handled carefully as it could potentially be harmful, but this only applies to a minority of total waste produced by a hospital facility. The total waste stream is composed of hazardous waste such as the one produced in operating rooms and laboratories but also standard waste generated in cafeterias and facilities management (Lee et al., 2002). Studies estimated that around 75% to 90% of the total waste generated in the healthcare sector is non-hazardous waste (Sahni et al., 2018). However, it is argued that little infectious waste, if in contact with normal waste, make it all hazardous (Chaerul et al., 2008). For this purpose, the introduction of proper waste separation – one that separates on the basis of what type of waste is being handled – is crucial for recycling to be effective. It is very important to develop different processes for this purpose, and that this separation needs to happen at the initial stage of disposal in order for significant improvements to be made (Sahni et al., 2018).

To understand people's behavioral change towards waste recycling, the Transtheoretical Model of Planned Behavior (TPB) is applied (Prochaska & Velicer, 1997). This theoretical model focuses on the steps necessary in order to achieve behavioral change. With the implementation of this model, someone can predict the difference between intended behavior and actual actions.

This model has been used to analyze recycling behavior in healthcare, showing that behavioral changes are tightly linked with beliefs about the relevance of waste management and awareness regarding the benefits of recycling (T. L. Tudor et al., 2007). The same study also indicated several ways of enhancing these beliefs, one core element to success it to ensure people are aware and understand the relevance of the issue. Another crucial factor is to make staff feel empowered to make a difference with their own actions. Finally, posing tangible benefits, like showing that what they do actually has effect, can stimulate change. As a result, indicating a clear outcome to the recycling seems to be an essential feature of any improvement program. (Terry L. Tudor et al., 2007)

A later study focusing on recycling behavior shows that participation in recycling was low due to a range of factors including group norms, individual attitudes and beliefs. This suggests that to improve recycling behavior it is necessary to target both the individual attitudes and the culture of the organization.(Terry L. Tudor et al., 2007)

In practice there are two core factors fundamental to initiate behavior change which emerged in a study performed in Germany. The first element is the physical environment, focusing purely on the availability of recycling facilities and surroundings that encourage the individual to act as desired. Second element is the education and availability of information for staff at all levels (Vogt & Nunes, 2014). In one study, 57% of interviewed medical practitioners reported that they did now know which items from operating theaters are recyclable (Azouz et al., 2019). Moreover, 48% of those interviewed also reported that the greatest barrier for effective recycling was the lack of knowledge on recyclable items (Azouz et al., 2019).

Introducing effective recycling systems in hospitals could have a dual positive impact. Not only would it effect a reduction of waste, thus reducing emissions and lowering the environmental impact, but also hinders the potential for significant cost savings for the hospital itself. A pilot study carried out in the USA on sharps waste showed the opportunity of 10.3% savings (Azouz et al., 2019).

Conclusive, it is evident that for big organizations and their respective communities it would be possibly economically beneficial to inform their staff and employees more on the topic of sustainable waste management.

2.2 : Behavioral change

A big pillar in research on behavior change is the trans-theoretical model of behavior change. This model shows that (health) behavior change involves progress through six stages of change: precontemplation, contemplation, preparation, action, maintenance, and termination. Within this, ten processes of change have been identified for progress that comes with decisional balance, self-efficacy, and temptations. Furthermore, applied research has demonstrated dramatic improvements in recruitment, retention, and progress using stage matched interventions and proactive recruitment procedures (Prochaska & Velicer, 1997).

A big factor in the effectiveness of (health) behavior change is self-efficacy. Self-efficacy is the belief in capability to execute a certain task. A study focusing on self-efficacy in this context found that there is a positive relation between self-efficacy and behavioral change. It includes recommendations for enhancement of self-efficacy, such as breaking the change up into smaller pieces that can be mastered consecutively, ascending in complexity (start easy, work towards difficult). Progress should be made relative and encouraged, and Lapses should be treated as opportunities to analyze and control the factors (Strecher et al., 1986).

However, there are also problems in behavior change. Research looking into sustaining behavioral change found that learning a new behavior does not get rid of the old behavior. It also is very context dependent, which could lead to disruptions in the learnt behavior. Disruptions in behavior change are either forgetting about a learnt behavior, or forgetting to maintain said behavior. This makes disruptions very unfavorable, as these lead to lapses in the behavior, which could lead to returning to the old behavior. This means that new behaviors should be practiced in contexts where lapses are most likely to happen, so that the context will not make a difference after learning the new behavior. The same study also finds that behavioral change can be an unsteady and unstable process, in which relapse and lapse should be expected to occur, and in which case the lapse should be investigated and reflected on. (Bouton, 2014)

2.2.2 Nudge theory

Another big system within behavioral change is the nudge theory, which proposes positive feedback and indirect suggesting as a way to influence decision making and behavior (Thaler & Sunstein, 2008).

It is defined in the book as "*A nudge, as we will use the term, is any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting fruit at eye level counts as a nudge. Banning junk food does not.*" (Thaler & Sunstein, 2008)

A study using the nudge theory for pro-environmental behavior concluded that simple adjustments to decision settings can influence pro-environmental decisions, and that information about social norms and changes to decision context can encourage this behavior. The study however also notes that there are gaps in the evidence and current

knowledge, and that extra research is required to get a better understanding of how interventions can influence choice and behavior. (Byerly et al., 2018)
Examples of nudges that had significant influence include the fly in the male urinals the arrow changes to reduce traffic jams during rush hours and the piano stairs (Thaler & Sunstein, 2008).

2.2.3 Use of technology in behavior change

Currently, a lot of nudging is done through apps and text messaging. A study looking into behavior change interventions found that text messaging is a valid tool for behavior change, and leads to more monitoring of the behavior, which goes across age, minority status and nationality. However, the way in which a message is framed can affect the effect it has on the user and it's behavior change, which is a factor that should be taken into consideration (Cole-Lewis & Kershaw, 2010).
A study looking into pro-environmental behavior in combination with media use found that individuals rely on the media to acquire information, and that their attention and exposure to this have direct effects on their pro-environmental behavior. The study also shows that the exposed individuals show more interest in the topic, as well as promote it and proactively adopt pro-environmental behavior. This means that organizations, corporations and governments can use media as a tool to actively create more pro-environmental awareness and behavior (Huang, 2016).

2.2.4 In the context of environmental campaigns

A study using the theory of planned behavior in an environmental campaign showed that the theory of planned behavior is perfectly applicable on a set of high school students when it comes to pro-environmental behavior. The most notable thing found in this study is that the behavior that the parents and the family show is one of the more important things within the beliefs and norms that a high-school student takes (de Leeuw et al., 2015).

Another study confirms that knowledge increases the intention to act (Hsu, 2004), The researcher in question taught a full course on the environmental behavior of college students, which led to a significant rise in the intention to act, locus of control, and environmental responsibility. There was also a significant increase in perceived knowledge and skills in the action strategies related to the environmental behavior. The study also showed that there was no decrease in these values even 2 months after concluding the course (Hsu, 2004).

In the context of a company, a study focusing on making a conceptual model for voluntary pro-environmental behavior dissected it by working back from behavior to intention to motivational determinants and viewed it as a complete separate thing from prescribed behavior (e.g. company rules). They also found that supervisors are an important factor in active pro-environmental behavior as they set a norm for their employees and take more active responsibility for the campaign (Lülfs & Hahn, 2013).

For environmental campaigns following behavioral change, a study sending e-mails to managers of garages found that tailored messages had more accurate knowledge retention and pro-environmental behavior than non-tailored messages, which had zero to no effect (Daamen et al., 2001).

2.3: State of the art on Environmental campaigns

As for already existing environmental campaigns, the following campaigns were selected to look at for more information and can be divided these into two categories:
(1) Campaigns that focus on plastic recycling, and (2) Campaigns that are environmental campaigns but do not have the main focus on plastics. After ranking them from most to

least useful for the project, the homepage of the campaign will be shown, after which will be discussed what the campaign does and how it could be useful.

Non-Plastic

2.3.1 We Don't Have Time

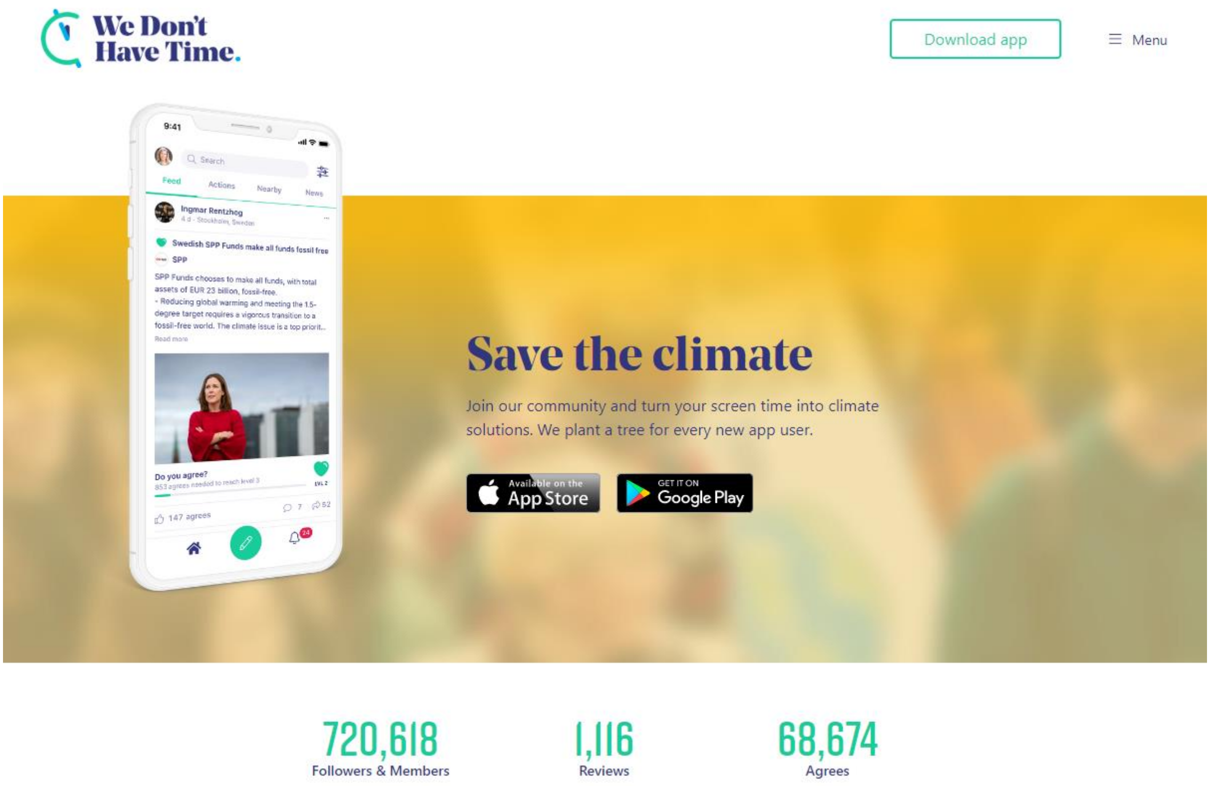


Figure 2: Home screen of the website 'We Don't Have Time'

We Don't Have Time is a social network for everyone who wants to find a solution to the climate crisis. It uses the power of social media and collaborative strength to have a big voice by combining small voices. This makes people have a goal, and believe that they can reach it together. Next to informing people about climate change and letting them have discussions, people can set goals and unite. Without it becoming a task, it takes just a simple "thumbs up" to sign a petition.
(*We Don't Have Time*, n.d.)

2.3.2 Surfers against Sewage

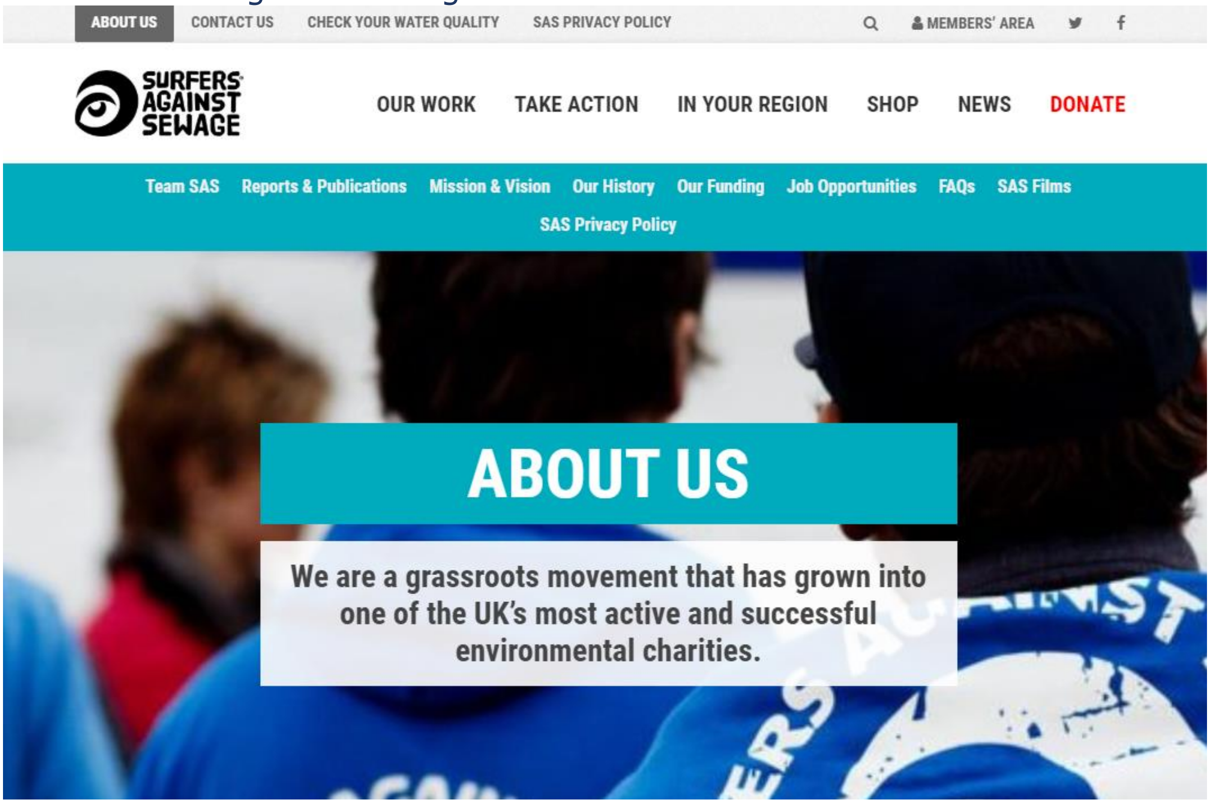


Figure 3: Home screen of the website 'Surfers Against Sewage'

Surfers Against Sewage is fighting for their oceans, waves, beaches and wildlife. They organize beach cleans, and after showing the problem right off the bat, they offer a lot of information with different ways how a person can help. This speaks to the diversity of people's interest, because if they don't want to give up one thing for the sake of the environment, the site has another thing readily available. This gives people a sense of purpose by firstly introducing the problem and immediately showing how you can prevent, or at least help preventing it.
("Surfers Against Sewage," n.d.)

2.3.3 Charity Water

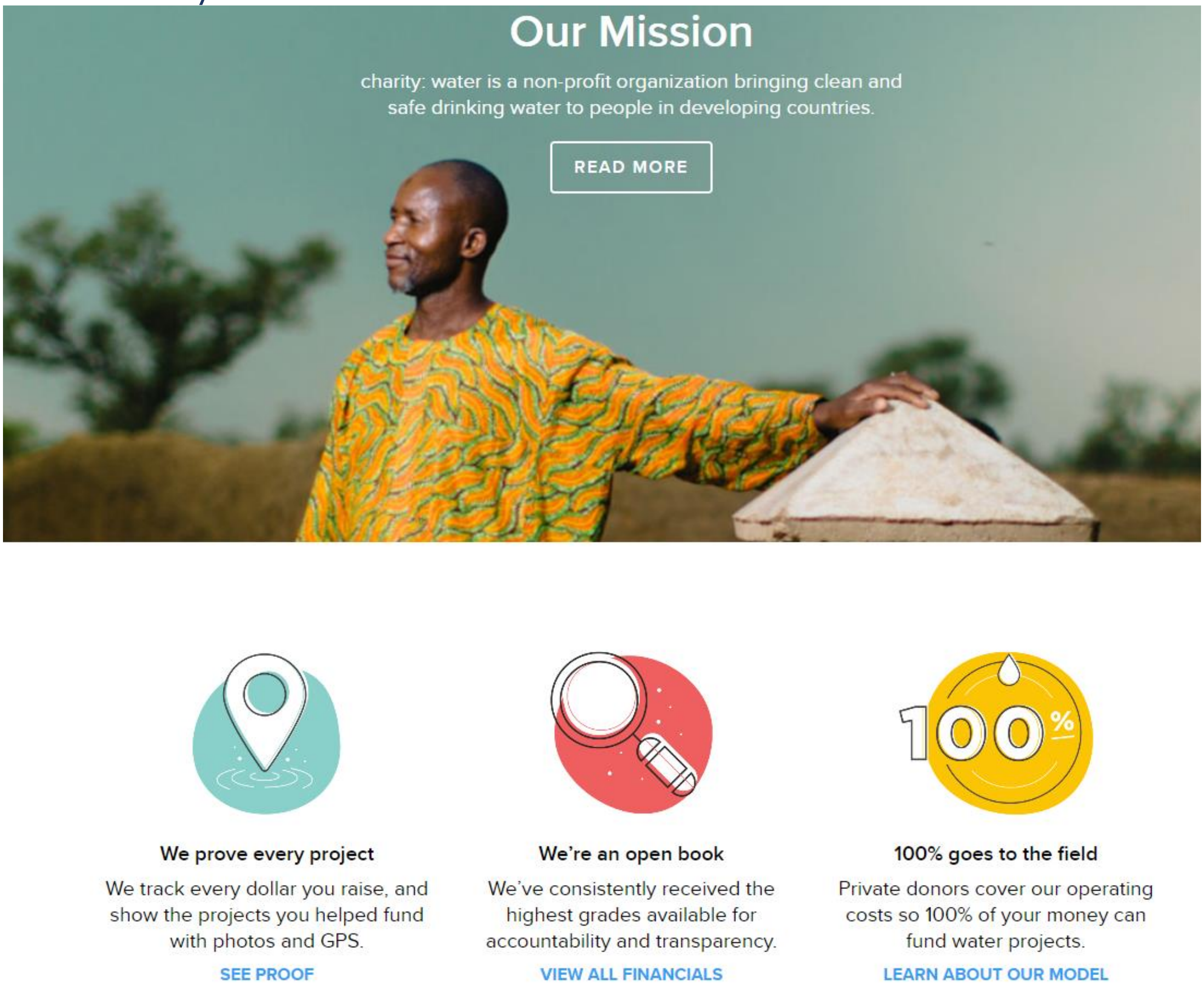


Figure 4: Home screen of the website 'Charity Water'

A charity organization aiming to help the 10% of the world that has no access to water. Though they only accept donations and brand partnerships, they claim to work with local partners, build sustainable projects and prove every project they build by giving GPS coordinates and remote sensors. This gives the people a feeling of accomplishment once they can actively see that they helped, and breaks the stigma of donations getting lost or used for other things.
("*Charity Water*", n.d.)

2.3.4 Ditch Disposable by Camelbak

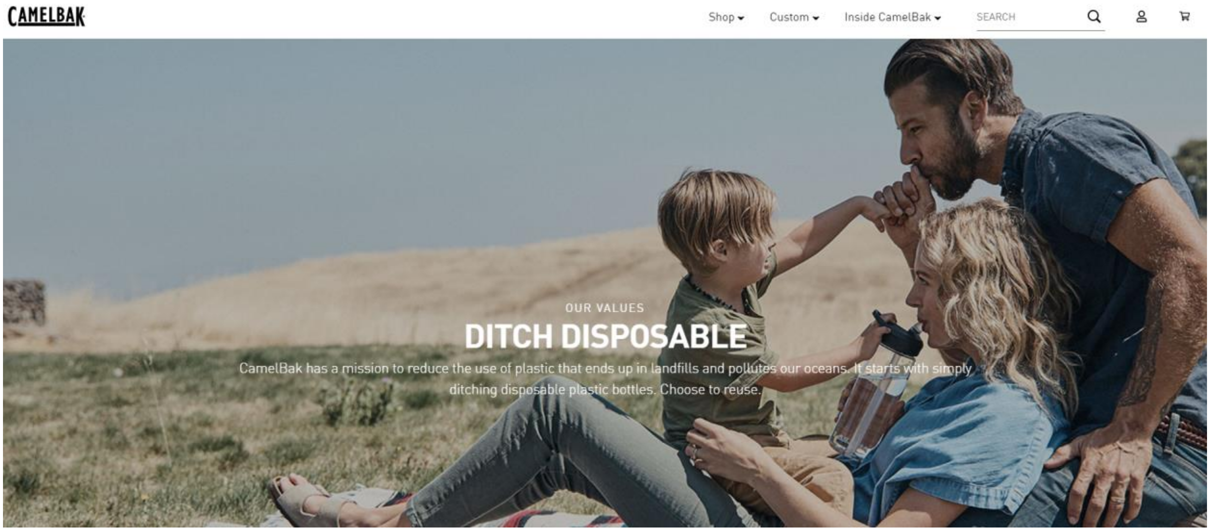


Figure 5: Home screen of the website 'Ditch Disposable'

Camelbak is a shop selling reusable water bottles, focusing mainly on the group effort strategy to get people to join. It has a live counter on how much is being done for the environment, and has information on how it helps both the user, and the world, by providing information that shows that it has both an economic and an environmental impact.
(*CamelBak*, n.d.)

2.3.5 ThinkEatSave

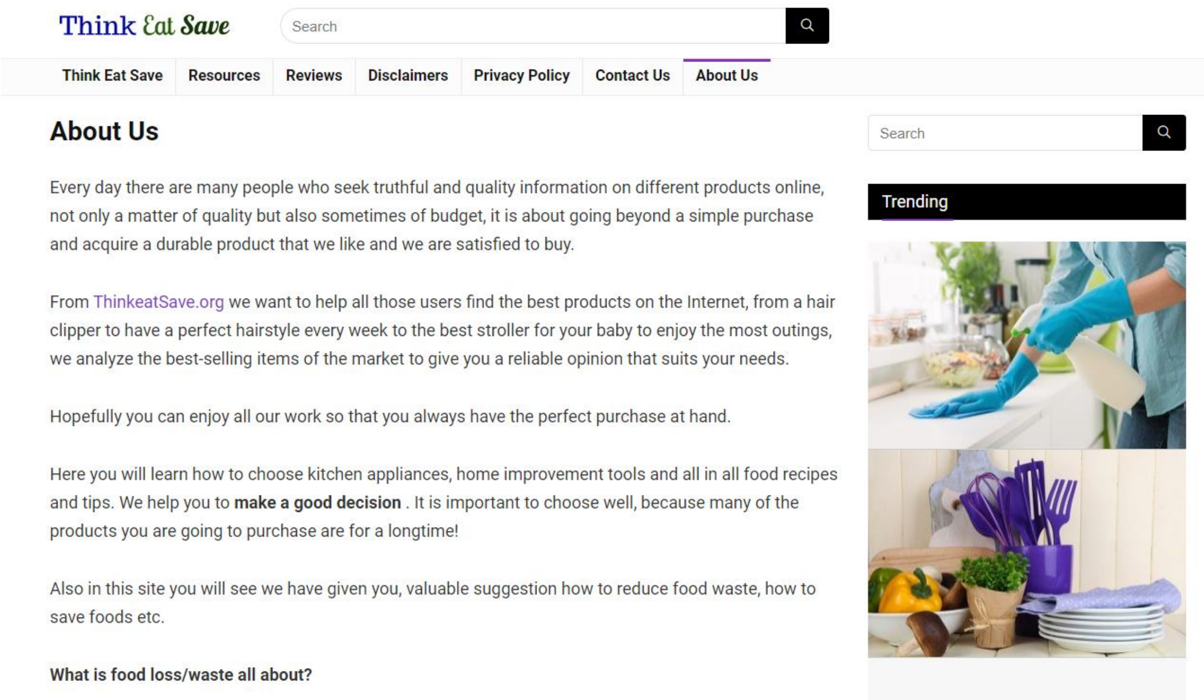


Figure 6: Home screen of the website 'ThinkEatSave'

ThinkEatSave attempts to battle food waste and bad products with having reviews and blogposts online, informing people about what they can do to help the world a little. Digging a little bit deeper into the campaign there is more information on how exactly you are helping and what you are doing, but it does not feel like that is the main goal of this initiative.
(*ThinkEatSave*, n.d.)

2.3.6 Trees for Cities

Figure 7: Home screen of the website 'Trees for Cities'

Trees for cities is an initiative to plant more trees in/around cities. The website starts off by showing that what they do is fun and possibly good for the environment, but mostly good for the people that help them. Then show their mission, and the impact they have. (*Trees for Cities*, n.d.)

Plastic

2.3.7 SchapenKoppieKoppie

Figure 8: Home screen of the website 'SchapenKoppieKoppie'

SchapenKoppieKoppie Dutch initiative aiming to inform and incentivize people to be interested in circular economy, they bring plastics into a pop-up lab and recycle it into 3d filament, which is then used to make a miniature artwork. This way they both show what can be done with the recycling of plastic as well as inform people that there is value in recycling itself.
(*Schapenkoppiekoppie*, n.d.)

2.3.8 Berecycled

Figure 9: Home screen of the website 'Berecycled'

Berecycled is a very informative site aiming to give knowledge about how to recycle better, which also shows this per type of material. It shows the top 5 impacts of recycling and then does not ask for money, but makes the user decide to pledge their help in becoming more environmentally friendly. They show what others have done, as well as that we can reach more if we get more people to join.
(*Berecycled*, n.d.)

2.3.9 Hospital Takes Aim at Plastic Recycling

Is an article about a campaign to increase recycling within hospitals. They started a campaign to end up with more recycling but ran into some problems along the way, including the problem of waste stream into the hospital, and the problem of it being a very large-scaled operation. Most of these being that the plastics used are complex plastics, that are unfit for recycling.
(Sookne, 2019)

2.4 Current state of Plastic waste behavior at a hospital

Due to the circumstances regarding COVID-19 and the rules made for the graduation project by the EEMCS, Hospitals were not called in order to not force them to respond. This lead to a couple of e-mails that ended in nothing. My client noted that currently in

the ASZ hospital, all the waste is just placed with other plastics which then goes to a trash company, which means that there is no selection of plastics whatsoever.
The only selection that is made regarding plastics is when it is contaminated plastics and/or plastics with sharps in it.

2.5 Conclusions for ideation

The biggest points to take from this contemporary research is that informing the public about the topic at hand and giving people a goal to work towards, this will increase the willingness of the people that have to change their behavior, as well as get higher-ups more invested in the projects. Giving them a purpose or a goal also increases willingness to do something for the environment.
Furthermore, the theory of planned behavior should be used, especially the use of the stages and their accompanying strategies to elevate people to the next stage.
The use of nudging, to unconsciously make people take correct choices and use of tailored media, in which the biggest take will be information dispersion from higher-ups and leaders are all big parts in behavior change that have to be incorporated, or at least considered in the ideation phase.
From the state of the art selections, it is planned to show the impact of recycling, and have a clear goal setting as that gives purpose to the tool, and makes people feel like they are actually working towards something.
Eventually, the hospital using the tool could connect to an external company to have things made of the plastic that is being selected, with which they can create art or useful tools. If these are shown in the hospital, this could add to the sense of purpose and goal, and adds a layer of transparency to the process.

3: Methods and design

3.1 Creative Technology design process

For this project, the "Creative technology Design Process" will be used (Mader & Eggink, 2014). This paper stresses the importance of User centered design and the development of prototypes, and proceeds to develop a design process consisting of four phases, which will be worked out in the rest of this chapter. Next to that, The MoSCoW method will be used, along with brainstorming.

3.2 Ideation

The Ideation phase revolves around the research question, and to go from research question and theory to a "vague" product idea.

After this, a stakeholder identification is done which will highlight the direct users, indirect users and their separate needs and wishes. For this, a semi-open interview will be held with my client to establish stakeholders, user needs and wishes.
It is important to use empathic design in this, to try to get a feeling of connection with the user and their needs so they are actively taken into consideration further into the project. Empathic design is a workflow that is achieved through four stages, and boils down to the following process: The researcher has to approach a user and must be willing and open to their view of things. Next, the researcher has to take knowledge and user data from the user by immersing himself in the view of the user's world. Then the Researcher should detach himself from the reality of the user and talk about their experience to establish an emotional connection with the user, after which the designer will have gained knowledge about the user's side of things, which can lead to a better requirement selection and user need understanding. (Koskinen et al., 2003)

The next step in the ideation phase asks for a brainstorm to be conducted. Within these, it is important to not limit yourself to ideas that seem unfeasible or impossible, as they can later be combined into other ideas that can become useful. The brainstorm is a diamond shaped brainstorm, and will from the start take into consideration all the "good" things that were collected from the state of the art, thus creating a varying roster of things. After making the roster, a combining phase takes place, making combinations out of things that are possible solutions. As combining things can make for very unfeasible applications, the next step is to take out the most feasible solutions, thus making a set of feasible preliminary ideas that can be worked out further than text based ideas. When looking for feasibility, the user needs should be taken into account again, and based on that, one idea needs to be selected to worked out. Consequently, a preliminary list of requirements should be set up and categorized using the MoSCoW method, and practical aspects should be addressed. To further elaborate on the user needs requirements, User scenarios should be made before moving on to the next phase.

3.2.2 MoSCoW method

The MoSCow method is a method that prioritizes the most important things over the least important things. This is very useful when it comes to user needs, as most of these can be set by a person. MoSCoW stands for four different categories of prioritization: Must have, Should have, Could have, Would like to have later (Haughey, n.d.)
Must requirements are a must have, and should be taken care of first. The should have requirements should be aimed to be completed, while could and would haves are not required for a successful project.

3.3 Specification

In the specification phase, we can go from a vague concept idea to a so called "paper model", this includes identifying and explaining the different functionalities of the system, including a system architecture and interaction diagrams

The first thing that needs to be done is to make a rough interaction diagram of a system, after which a second 'finalized' list of requirements can be made. When doing this, all the aspects and user needs from the ideation phase should be taken into account, as well as possible needs that emerged from the interaction diagram.
After this, a layer decomposition should be made, before heading into the realization stage.

3.4 Realization

In the realization phase, a working prototype of the envisioned product in the specification phase is made. It uses all the technical parts chosen in the ideation phase and explains why these are chosen and how it works. On top of that, a clear building instruction should be given, so that someone can recreate the system based off of the text, this includes adding appendices with code, and explanations on the functionality of the system. In case of failures with the prototype, changes can be made and should be documented here. This made prototype can then be used in the next phase.

3.5 Evaluation

After the system has been built, it is important to test this prototype. This is because no product is perfect in one go, and there will always be improvements or changes needed to improve the system. In the evaluation phase, there are two test phases. The functional test and the user test.
Functionality testing is done by the researcher. To do this properly, a functionality table should be constructed testing all functions of the prototype, to see if they work properly. This is important to do as this can make or break the user testing.
The user testing is done by an identified target group. It is important that the group tests this system as they are the ones that need to report if their needs are met, and if there is something in the installation that is impractical or unnecessary.
In this stage, user needs that were hidden can still be found. This is a totally normal phenomenon, as the user sometimes is not aware of user needs until the user needs are discovered.
In this stage, semi open interviews will also have to be conducted, to gather more information on specific improvements, overall mood and feel of the prototype.
After user testing is complete an analysis and a second prototype must be made. Whether this is a finalized prototype or not needs to be assessed with the feedback given and the possibilities of improvements.

4. Ideation

4.1 Stakeholder analysis

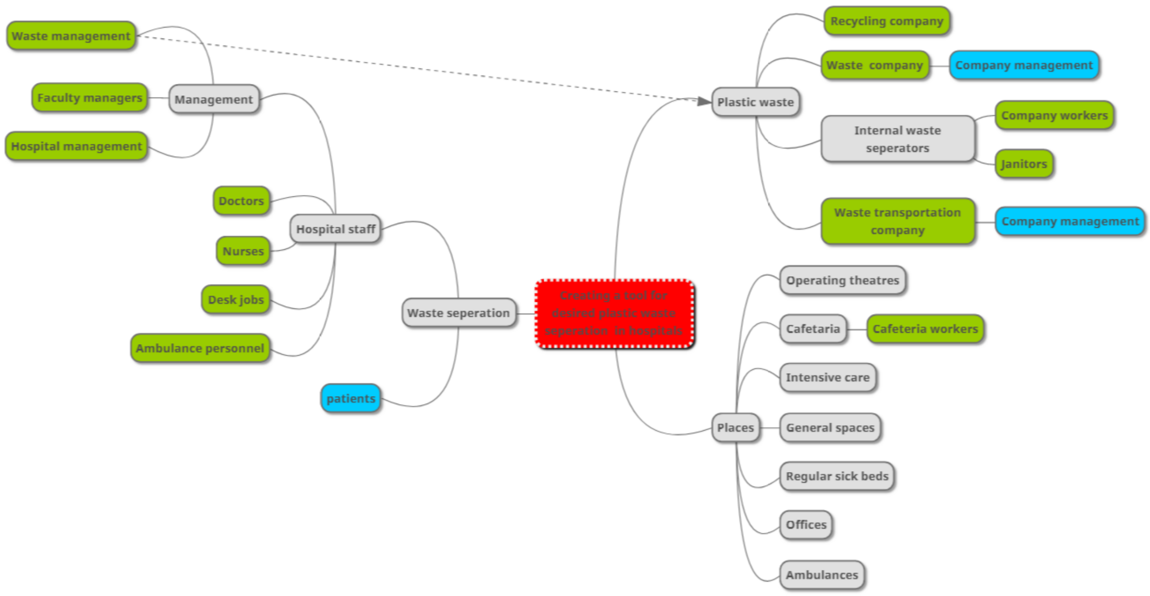


Figure 10: Stakeholder Identification

After conducting the initial study into theory, a first brainstorm into stakeholders led to the following figure with the direct stakeholders (in green) and indirect stakeholders (in blue). After a semi-open interview with the client on stakeholders and where they should go in a power matrix, which led to adding cafeteria workers, even though in the initial ideas, the cafeteria were not included in the mapping initially.

Listing all these People in power interest grid results in the following grid:

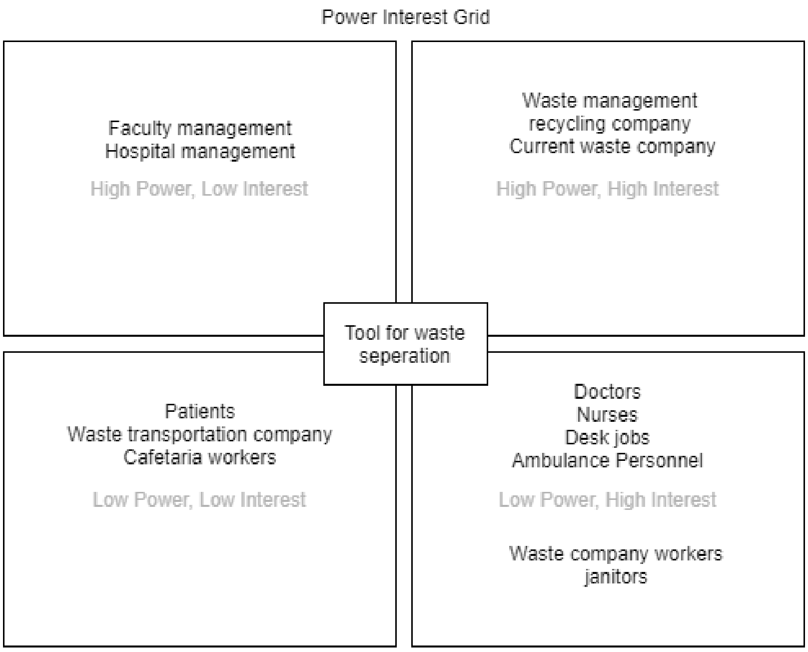


Figure 11: Stakeholder power matrix

4.1.2 Preliminary Idea

Because of the EEMCS rules regarding COVID-19, it was impossible to get a hold of the involved stakeholders, which made it impossible for me to interview them for functional and nonfunctional requirements. Because of this, a preliminary idea was created to merge all theory together. Following that, and a brainstorm for ideas, a requirement list was made.

The preliminary idea following the theory and the info gained from the brainstorm sessions is as follows: For the campaign to be an effective campaign that can be implemented across the whole hospital, both an informative session and a method of separation is needed, which should be not very different from the current situation. For this simple reason the informative session and a waste collection system need to be introduced one after the other, so the mental steps are logical, and following the Theory of Planned Behavior. After that, because it is currently impossible to automatically check the purity of the separation, a lot of feedback needs to be given on the separated plastics. To further reinforce the sense of purpose and self-efficacy, it seems helpful to both have collaboration with management, to give them responsibility, as well as to contact a recycling company to work together, and decide on a type of plastic (or multiple types) to collect.

To take pre-emptive measures against wrong separation, we can tell the doctors to not separate extra if they are unsure, but this should only be done if the first session of bin use leads to too much bad (or impure) separation, as the goal of the project is to get to the desired state of plastic separation.

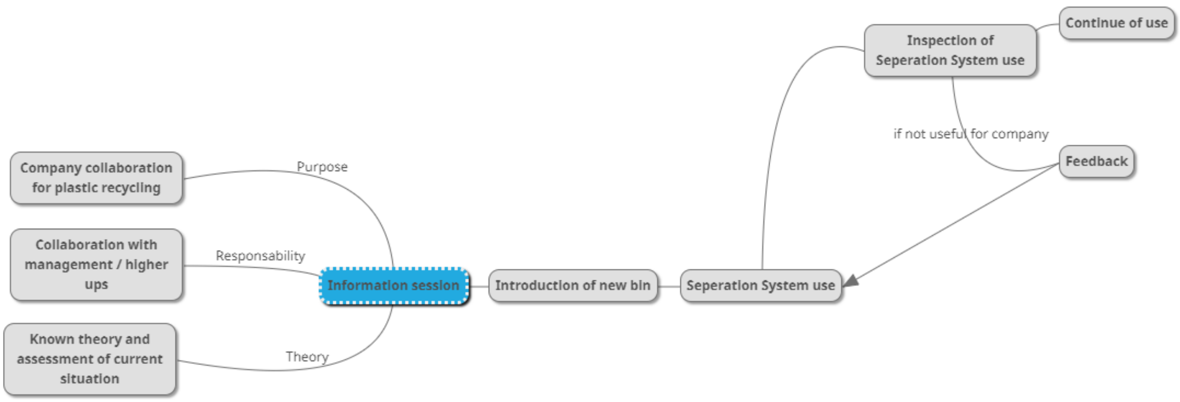


Figure 12: Standardized Theoretical model

4.2 Brainstorm on theoretical idea

After making this standard initial idea based on chapter 2, It was necessary to brainstorm on ideas for both the information session and the separation system to use. Since a seminar as information session would be boring and most certainly a burden on the medical field, this was eliminated early on. The information gain should always be there, instead of being given in one chunk.

This is the result of the brainstorm on the theoretical idea listing the information spread possibilities and the separation system possibilities.

Information spreading	Separation system
Lecture	Extra Trash bin
Design on separation system	Vending machine
On packaging	Trash collection robot
Poster	
Website	

Social media	
Podcasts	
Through higher-ups	
E-mails	

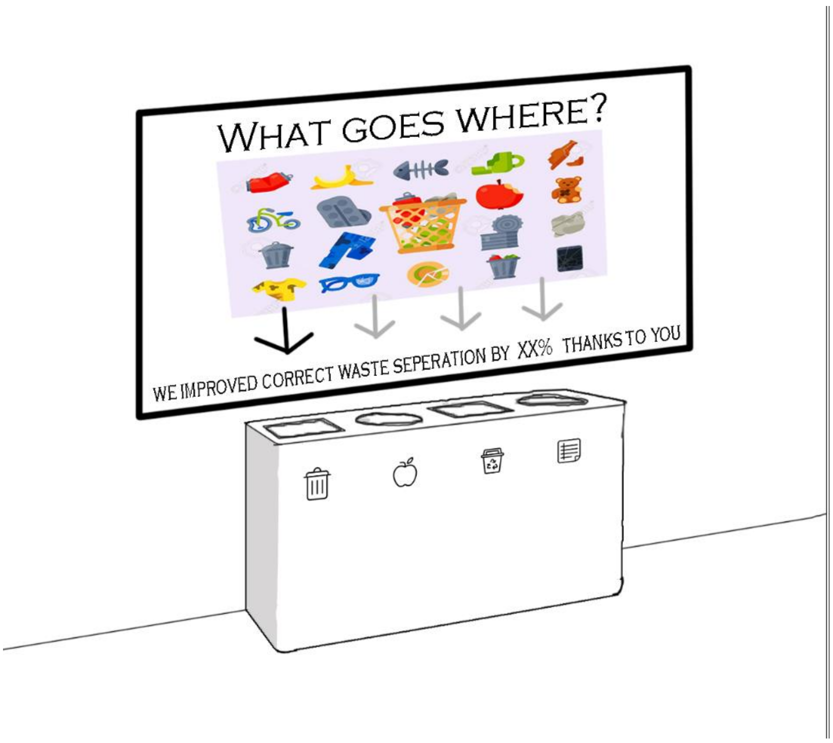
The next step in the process is to combine these ideas into 'main' ideas, of which a couple feasible ideas will be worked out and examined in further detail.

Trash bins with information shown over them
Trash bin with a touch screen to select what you are throwing away, and then it shows where it should go.
Trash bins that show how much they save per weight put in
A vending machine that shows a video on where your bought item should be recycled to
A vending machine that takes plastic trash as payment, with built-in hydraulic press to compress plastic on site.
A vending machine that takes back the trash immediately
Trash collection robot that lectures people on what they should throw in (think of Holle Bolle Gijs in the Efteling saying "papier hier" (Paper here!))
Trash collection robot that makes the rounds with info on it and a backpack for trash
an extra option taken from a different perspective entirely would be a Coffee dispenser that rewards people with X cents of reimbursement when they don't use a plastic cup but a mug.
Another idea was a trash man completely made out of plastic, except for the face that shows everything of plastics being used trudging a trashbag along.

4.3 Preliminary Concepts

Following this list of 10 different ideas for the project, six were worked out a little more and made into a concept on paper.

Concept 1: Help screen



- Possible Touchscreen or organised list
- Common items database with search
- Better separation
- Passive Information gain
- Feedback requested to trash company
- Arrows for which trash bin lights up according to the type of trash
- Encouraging words to keep going

Figure 13: Help screen

This trash bin has a touchscreen over it, and if you touch something that looks similar to your trash, it will light up an arrow that shows in which trash bin it should go. This is both informative and fun, but might be too big of an extra step to make, both physically and mentally, when you just want to throw something away.
Alternatively, rows could be made over each different trash bin, and a panel with a search bar in case people really want to know more about what they are throwing away. Even though this seems like a good idea, it needs a database to work properly, which requires updating.

At the bottom of the screen, the message: "We improved correct waste separation by __% thanks to you!" is shown, as this reassures people that they are doing good, and to keep them motivated to do better. This however, is a hard thing to realize efficiently without involving the inspection of trash.

Concept 2: Goal Screen

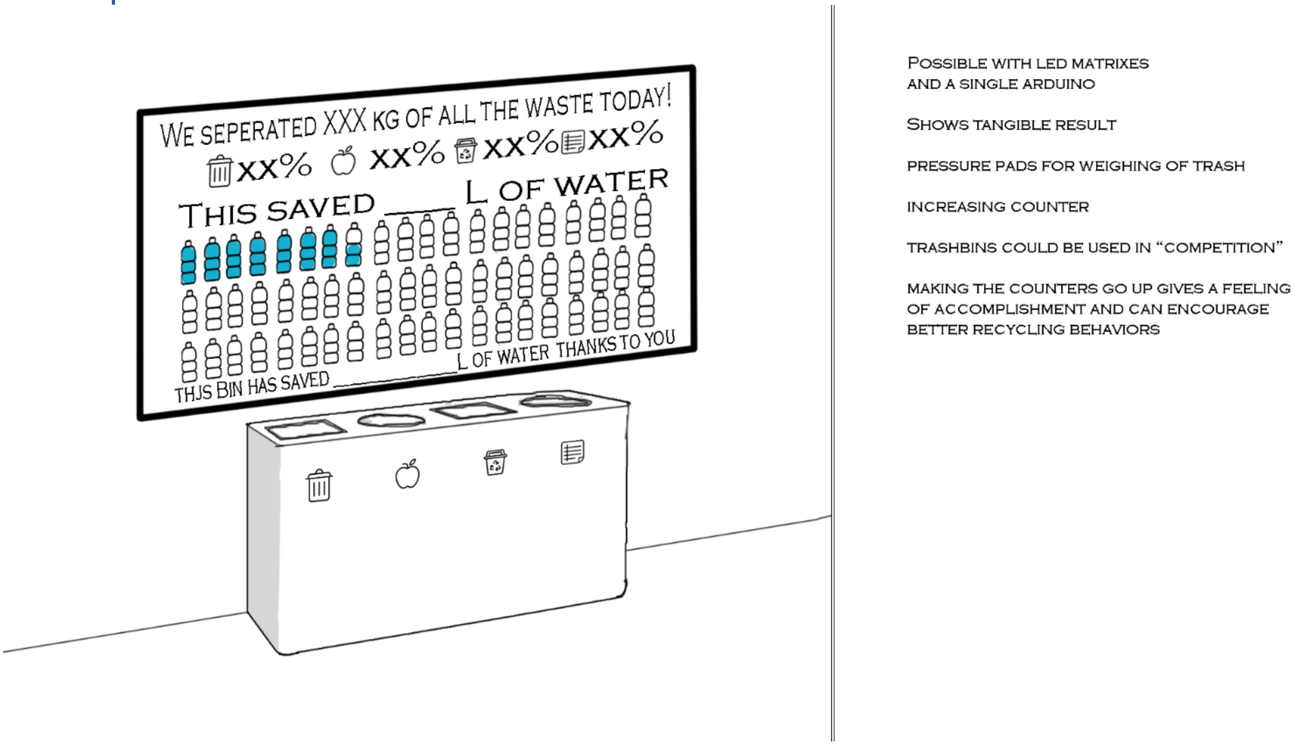


Figure 14: Goal screen

This trash bin has a board over it with led matrices in it. The weight of the separate trashcans is measured and makes a microcomputer compute how many kg of waste is separated, and how much liters of water that has saved in comparison to just throwing everything in a single bin. These give a tangible response to correct plastic separation, as the water bottles on the led matrix will be filled to show how much water is being saved, thus giving the user a feeling of accomplishment.
These can also be used by the hospital to fuel a competition between sections of the hospital as a fun way to get attention to the subject and to get more information across to more people. The downside is that it works with any given weight, so wrongly separated trash will not be filtered out of the equation. this could lead to a false sense of accomplishment, which is undesirable in this situation, as it could lead to a false positive feedback loop.

Concept 3: Vending machine with info

Figure 15: Vending machine with info

This vending machine shows on a screen where you should throw away your purchased item. This stimulates waste behavior by giving information about where to recycle, but does in worked out form, not seem very interesting.

Concept 4: Vending machine with a token system

Figure 16: Vending machine with a token system

This coffee machine has a button on it for “use own cup” and the text “ use your own mug, save 10 cents, and the planet, one cup per time” on it. This incentivizes the user to use their own mug, as it saves them money, and it isn't bad for the environment, so in the user's context, using a mug has both an economic benefit as well as an environmental benefit.

Concept 5: Trash Robot

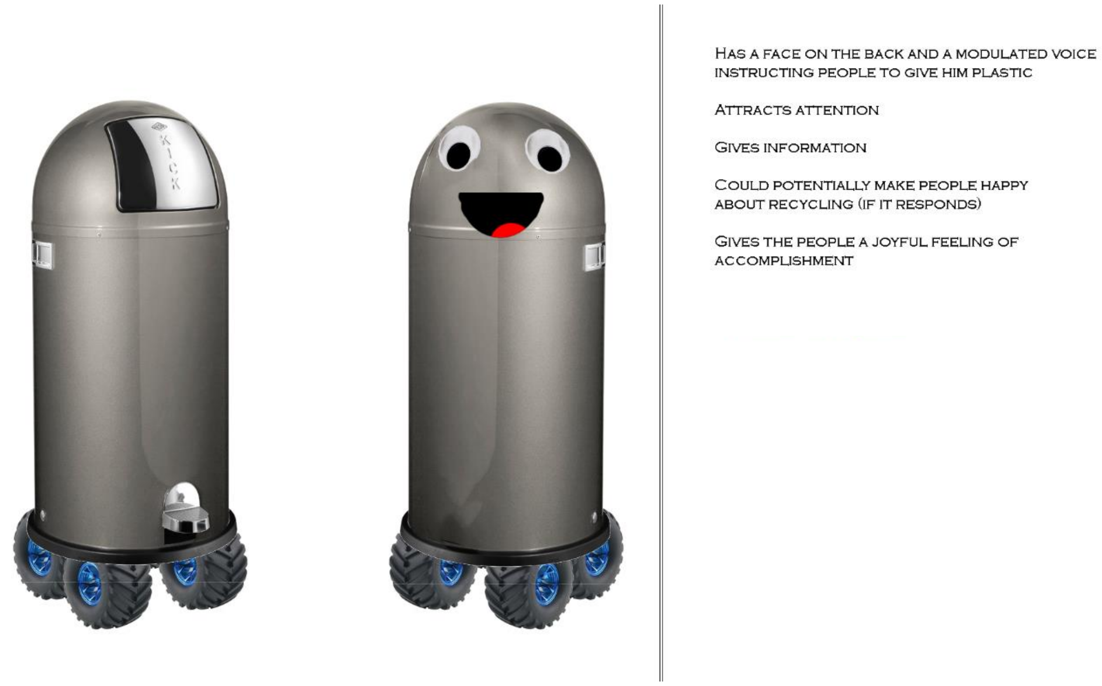


Figure 17: Trash robot

This driving little robot trashcan is a very happy robot, lecturing people on why you should recycle plastics, and why it is good to do so. His happy features and unique design attract a lot of people to look at him and listen. Next to giving information he doubles as a plastics trashcan, which can give people an immediate feeling of accomplishment after gaining more information about plastic recycling.
This, however, is aimed at a more public setting than the current user.

Concept 6: Trash Man

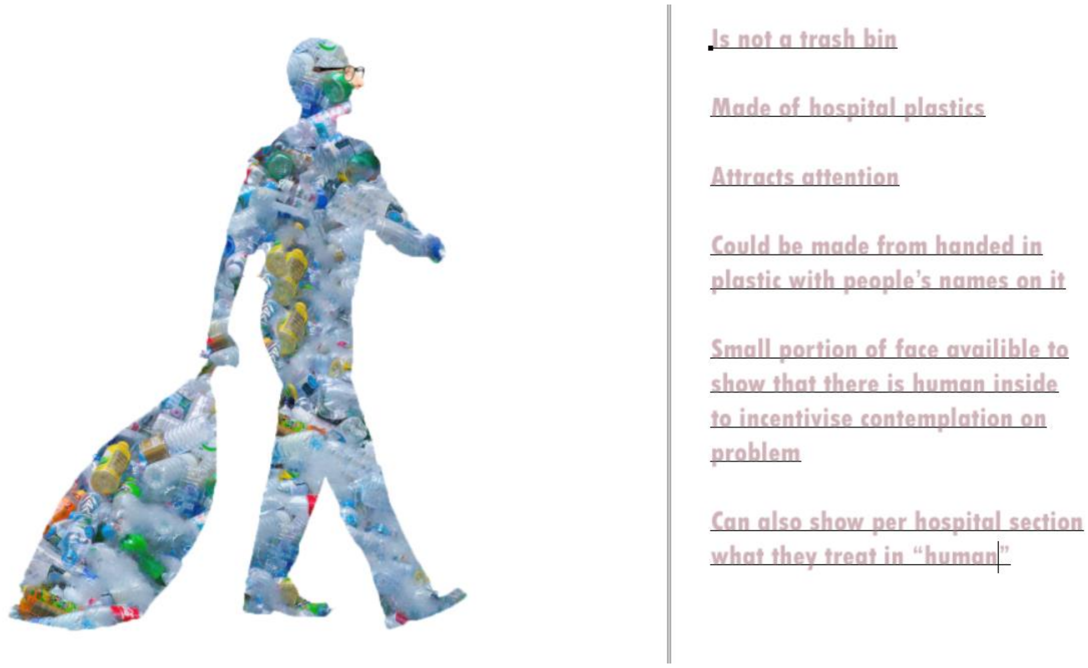


Figure 18: Trash Man

This Trash Man statue is entirely made out of hospital plastics, and can be placed anywhere. It reflects on the society of single use plastics we live in today, and shows a little bit of a face, like a man drowned in plastic, to incentivize contemplation on the problem. It also shows that we can be part of the solution, by holding his trash bag full of plastics.

Conclusion on Concepts

After thorough examination, it was decided to work out the first trashcan idea as final idea and project prototype. It's the only idea that can be made into an interactive informative tool, that is in line with the theory as discussed in chapter 2.
To work the idea into a prototype, a lot of things must first be done, this leads us to the requirements.

4.4 Preliminary Requirements

From previously discussed ideas and theory, a list of requirements was set up for the prototype. The requirements can be found in figure 19. The requirements are classified as general requirements that come with the theory, and prototype specific requirements.

No.		Prototype specific
1	The tool should inform people conform the TPB from Prochaska	
2	The tool should actively help people who are doubting	
3	The tool should actively give feedback on the separation	
4	The prototype should be able to run autonomously	**X**
5	The prototype should be installed close to a trash bin	**X**
6	The prototype should detect people standing in front of it	**X**
7	The prototype should detect the difference between a fast user and a slow user	**X**

Figure 19: Table of preliminary requirements

To further elaborate on these requirements, the MoSCoW method was applied to the prototype requirements.

Must have	Should have	Could have	Will not have
General anonymous person recognition	Non-intrusive design	Intention recognition	Internal trash bin
Information about what type of plastics go in which bin.	Different person recognition	A single plug for the wall.	A button for "are you sure"
Extra information on what items go in a certain bin after certain timeframe	Resetting timeframe on every person		
No loose wiring of sorts	A single frame or box that fits everything		
Be installed in close proximity of a trashbin			
Must give feedback			

Figure 20: Table of requirements sorted through MoSCoW

4.5 Scenarios

User scenarios can be used to further identify user needs and requirements for a system. For this reason, three user scenarios will be worked out to assess for more user needs.

Scenario 1: Experienced nurse Debby
Debby is a 36 year old nurse that is already educated on what plastics belong with which type, but she has been separating plastics before the new trash bin tools were implemented.

- Debby wants to throw away plastics
- Debby walks up to the trash bin
- Debby does not know exactly know where to put what type of plastic
- The screen of the prototype lights up and shows her where to put what type of plastic goes in which bin
- Debby knows what products are which type
- Debby throws away the plastic
- Debby walks away

This scenario builds upon the fact of self-efficacy and positive feedback. Seeing that the plastics indeed go in the bin you selected them from reinforces your feeling of self-efficacy, and shows that you've made the correct choice, which makes you feel good. the scenario also makes use of nudging, by showing the type of plastic. This way, the user gets nudged into re-evaluating their choice and making a good decision
All of this leads to relapse prevention in the Prochaska model, which is something needed for the maintenance of action.

Scenario 2: New nurse Jane
Jane is a 26 year old nurse that has recently come to work with the hospital, she is new to the types of plastics that are used in hospitals, and does only separate plastics at home.

- Jane wants to throw away plastics
- Jane walks up to the trash bin
- Jane does not know where to put what type of plastic
- The screen of the prototype lights up and shows her where to put what type
- Jane still isn't sure and hesitates for (x) seconds

- The screen of the prototype changes and shows Jane what items go in which bin
- Jane can now select which item goes in which trash bin
- Jane throws away the plastic
- Jane walks away

This scenario builds upon the theory of information gain and activation of a person. This is achieved by giving additional information on which items go where, thus giving them education without being intrusive.

Scenario 3: nurse Harry
Harry is a 29 year old nurse that has been working with the hospital for a couple of months, and knows about plastic recycling, but does not do it yet.

- Harry is on his way to the coffee room for a break
- Harry walks by the trashcan
- Harry reads the text on the "standby screen*"
- Harry is interested in the effects of the trash bin
- Harry goes on to the coffee room
- Harry researches the effects of trash recycling
- Harry starts using the trash bin whenever he gets the chance

This scenario builds on the aspect of needing a purpose or goal to be activated and/or motivated to take action or get more educated. This conforms Prochaska's TPB model and should help people in precontemplation and contemplation to move into contemplation or action respectively.

4.6 Preliminary concept of first product

This whole chapter and initial build lead to a very preliminary 3D sketch of what the prototype will do and how it will look. Please note that the image shown on the screen in figures 21,22 and 24 is not a final image, but merely a placeholder to give an idea.

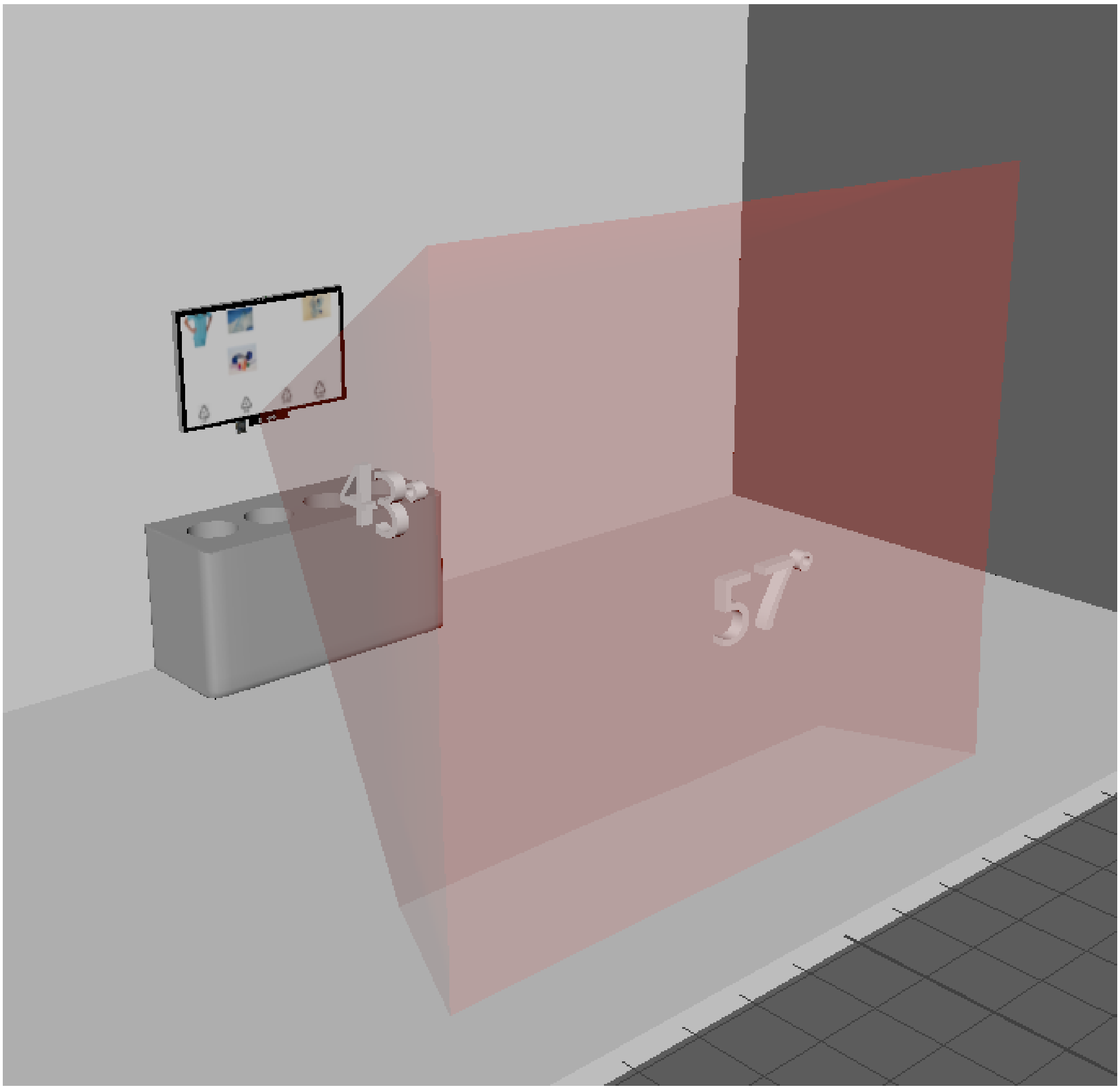


Figure 21: 3D render of the envisioned idea

After analysis of the camera on an Xbox Kinect, a viewing angle of 43° was found vertically, while horizontally this was 57°, this was implemented in the 3D model to show the viewing angle of the camera and its importance.
The XBOX Kinect was assumed to be used for this project as it is readily available to prototype with.

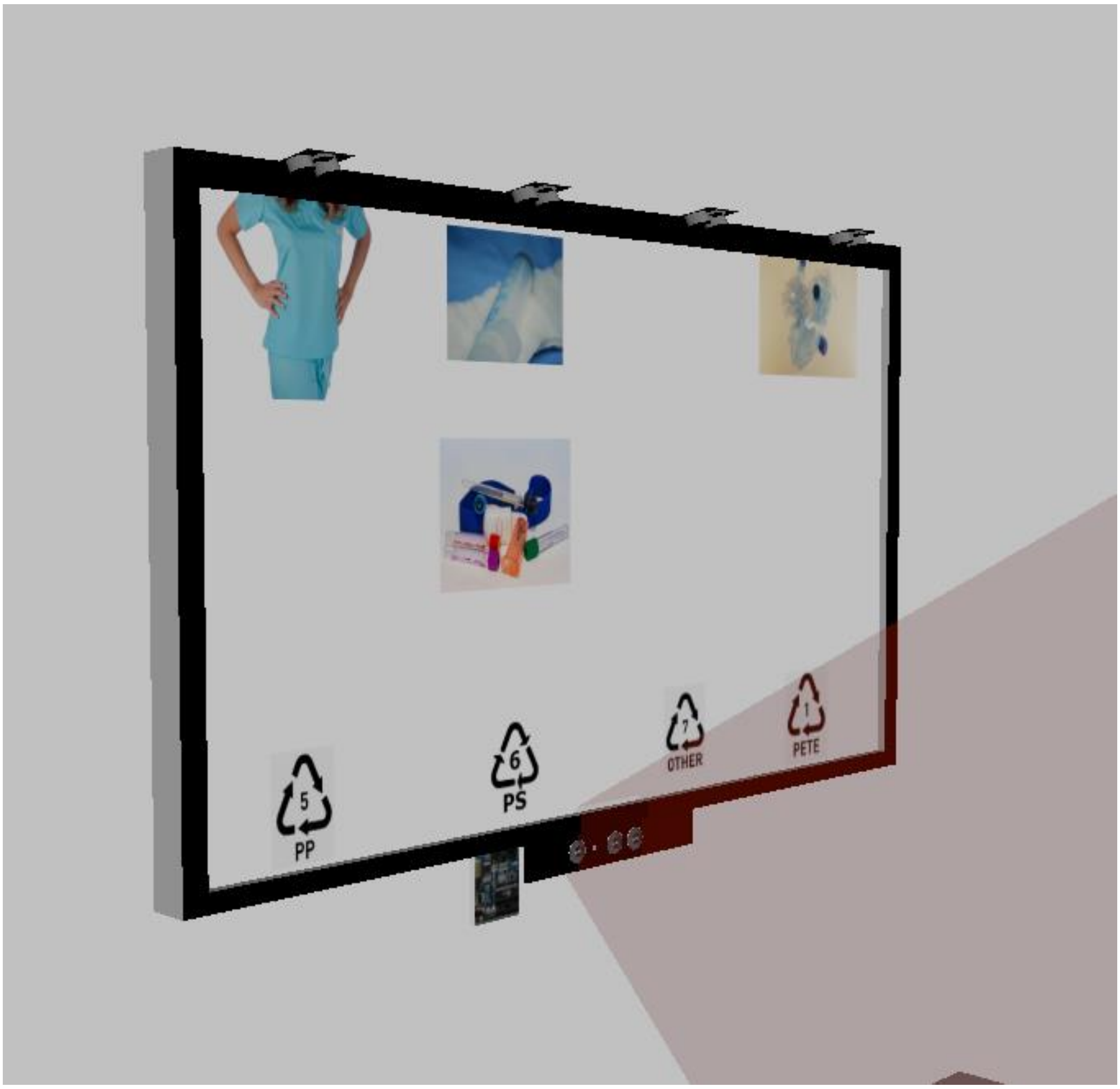


Figure 22: 3D render of the screen and components

This picture shows the screen and the setup a little closer. An Arduino and an XBOX Kinect at the bottom of the screen, and on top 4 ultrasound sensors detecting what goes in which bin.

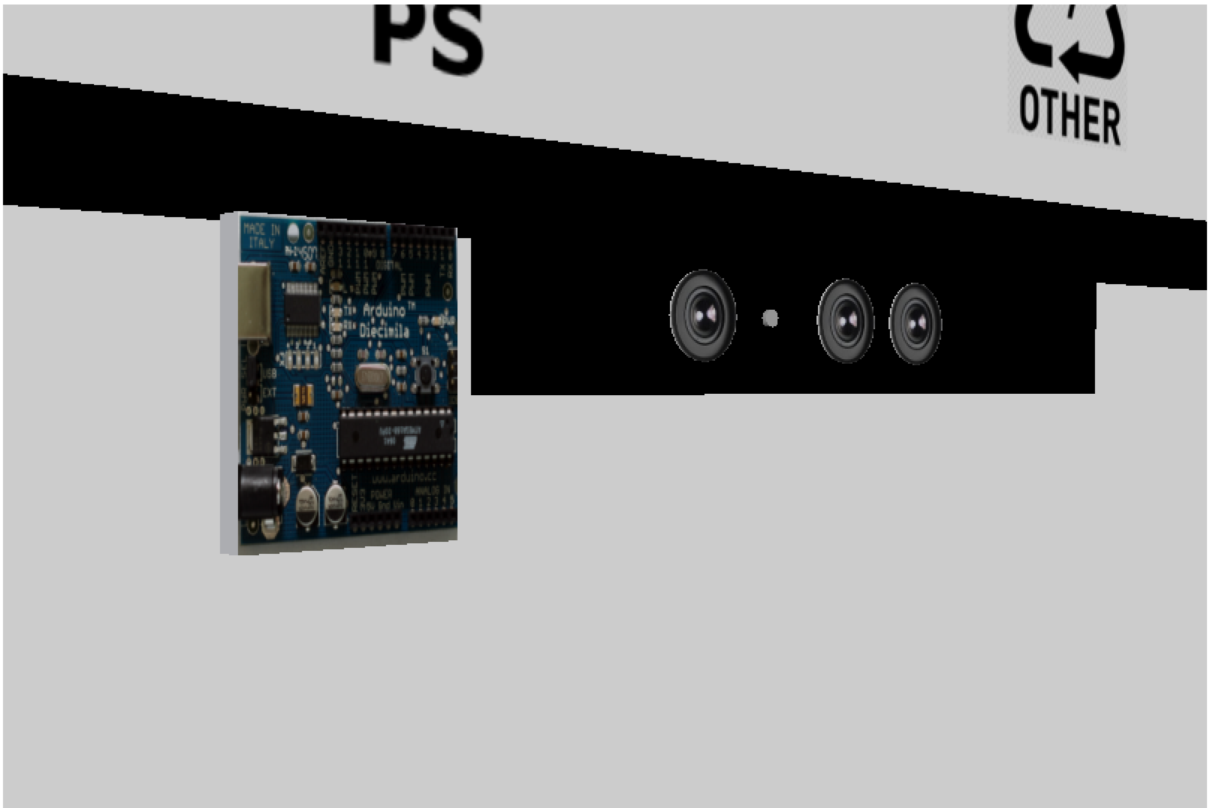


Figure 23: 3D render of the Arduino and Kinect sensor

The Arduino and the Kinect sensor detecting a person and doing the computing part

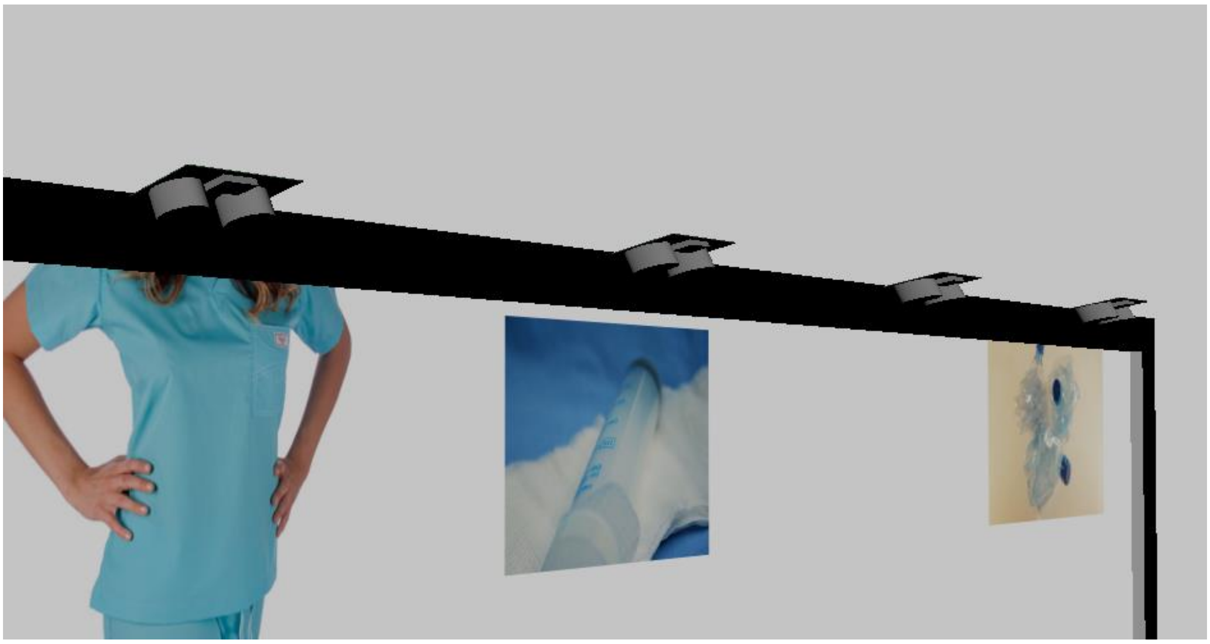


Figure 24: 3D render of ultrasound sensors

4 ultrasound sensors registering what is thrown in which trash bin

5. Specification

In this chapter we will be focusing on the system architecture and requirements that the Information screen should have. Based on this chapter it should become possible for a system engineer to create a version of this information screen prototype.

From previous ideas and ideation, a list of detailed requirements was made for the prototype, which are shown in the table below.

5.1 Requirements

No.	Requirement
1	The system must be installed above a trash bin.
2	The screen used should be big enough to be read from 60cm away from the trash bin
3	The system must be intuitive to use
4	The system must use anonymous person recognition
5	The system must respond within 250ms of an action happening
6	The system must detect people within 60cm in front of the trash bin
7	The system should be closed off system (e.g. no loose cables except for power)
8	The system must not be intrusive
9	The system must have a detection system for when something is thrown away in a certain bin
11	The system must give information about what type of plastics go in which bin.
12	The system must give extra information on what items go in a certain bin after X seconds*
13	The system must give feedback on what type of plastic is thrown away in the bin that is used.
14	The System must have a standby screen giving a goal/reason to separate plastics.

Figure 25: Requirements

* to be determined after testing.

5.1.2 Detailed User interaction.

After making a second iteration of requirements, a more extended version of a user interaction can be made, most of the interactions shall be named in a more extensive way as opposed to the user scenario's as presented in chapter 4.5, to fully show the interaction and system response for User 1, Debby.

Debby wants to throw away plastics in the trash bin; Walking up to the bin she sees the screen above the trash bin, which shows her the products being made from the recycled plastics*. Just before she arrives at the bin (60cm from the bin) the screen suddenly switches to a screen showing different items with their respective bin it should go in. Debby hesitates, for she isn't completely sure which bin she needs to throw it in. After a small timeframe, the screen switches to a list-form, in which she easily finds in what bin the plastics have to go. Debby then throws away the plastic in the correct bin. As soon as she throws something in the bin, the screen switches again, showing her what is being made from the type of plastic she just threw away. Debby feels happy about her small do-good moment, and feels like she has learnt that the plastic she threw away goes in that specific bin. Debby walks away from the trash can, and the screen jumps back to its goal-screen.

*used as example, but could be any goal/reason

5.2 System Architecture

The prototype will be described in four composition levels, namely 0, 1, 2 and 3.
Level 0 – system as a whole
Level 1 – Inner working of Plastic Separation System
Level 2 – Inner working of Item detector
Level 3 – Inner working of Proximity detector

5.2.1 Level 0: System as a whole

This level will provide a clear overview of the system as a whole, showing input and output from the user’s point of view.

Figure 26 is a black box overview of the system. Even though the plastic item(s) depicted aren’t used within the prototype, they are used to measure data and will therefore be included in the system decomposition. The plastic seperation system has 2 inputs from the outside world, which is the user proximity and the plastic items that end up in the trash bin. The only output is the visual feedback.

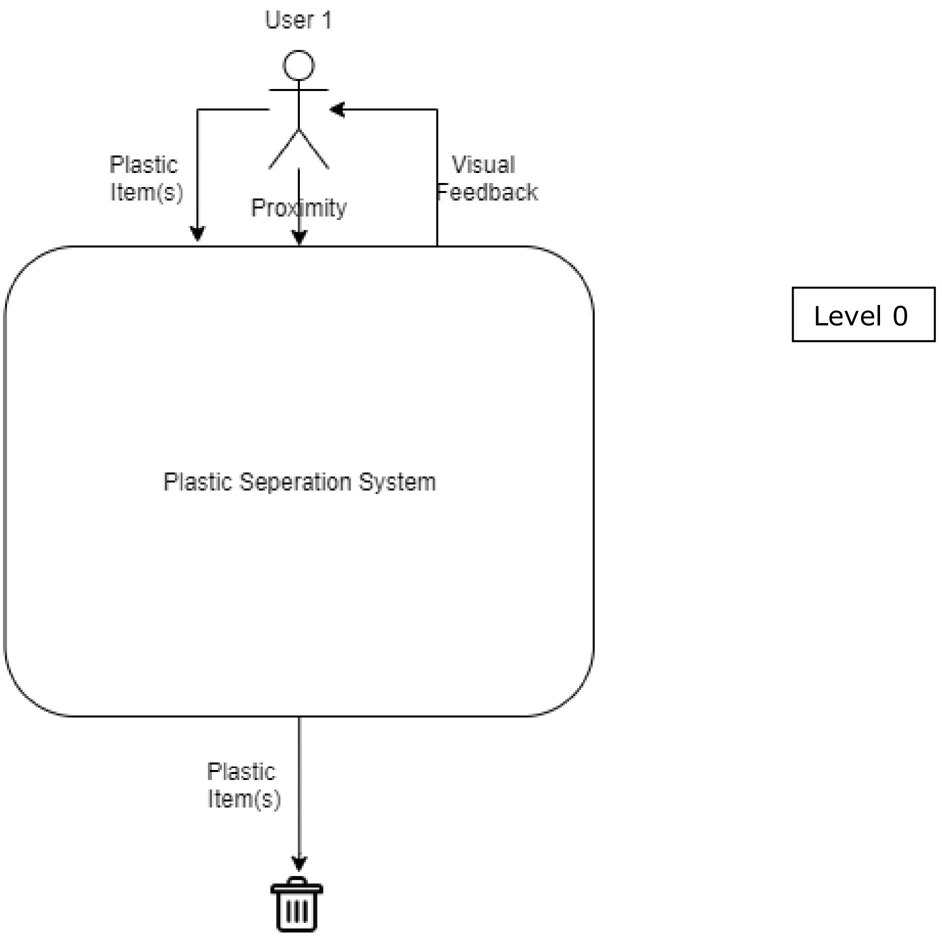


Figure 26: System diagram Level 0

5.2.2 Level 1: Combined functions

The system on level 1 contains three main components; a proximity detector, a feedback generator and an item detector. The system is active by default, giving feedback in the form of a goal screen. To wake the system out of this, a user has to walk within the proximity of the proximity detector. When they move into this field, the proximity detector sends a signal to the feedback generator, which switches feedback to a screen that shows where to put what type of plastic, and the most common items in picture form.

When a user hesitates and spends an X amount of seconds in front of the trash bin while still being detected (staying in range of the proximity sensor), another message is sent to the feedback generator, which will then output a new screen, showing what item to put where in text form.

Once the user has "chosen" a bin to throw his trash away and does so, item detectors will detect the trash being thrown away, and will make the feedback generator show a new screen with what can be made out of that type of plastic.

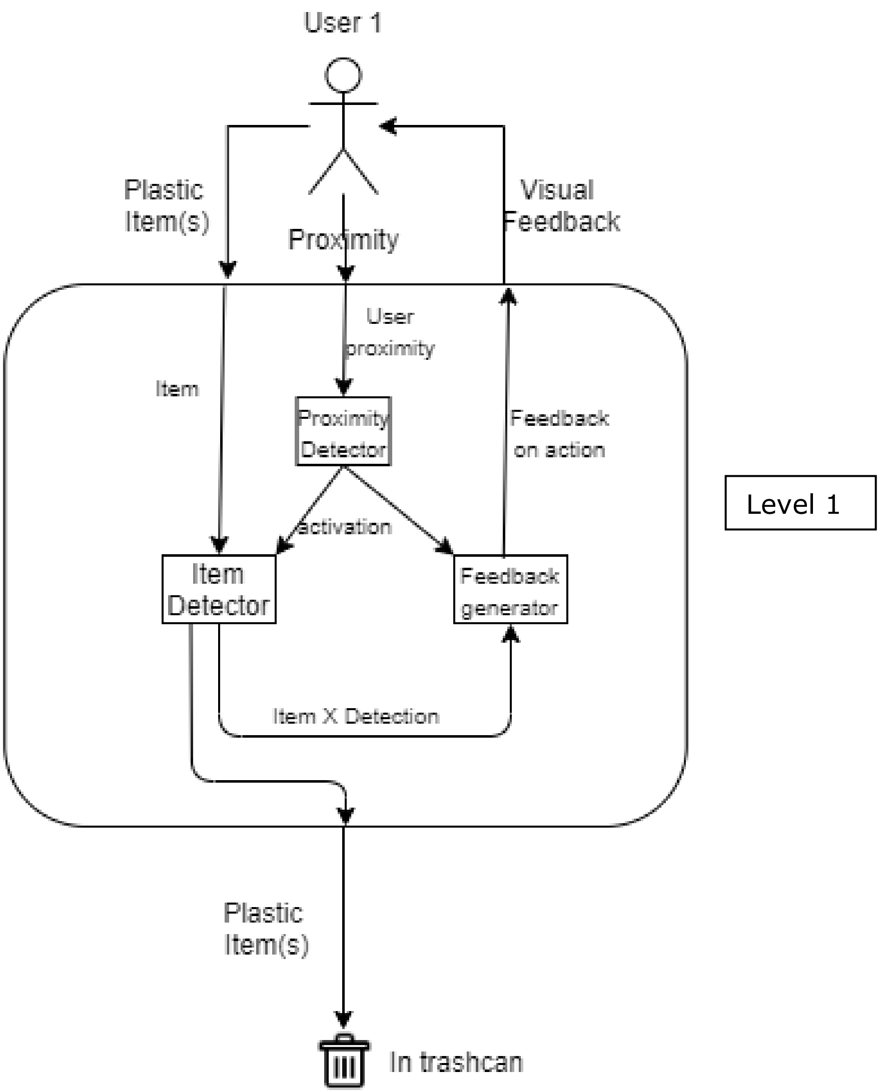


Figure 27: System diagram Level 1

5.2.2 Level 2: Proximity detection

Whenever a user gets within range of the system, the system sends a detection response and activates the item detector.

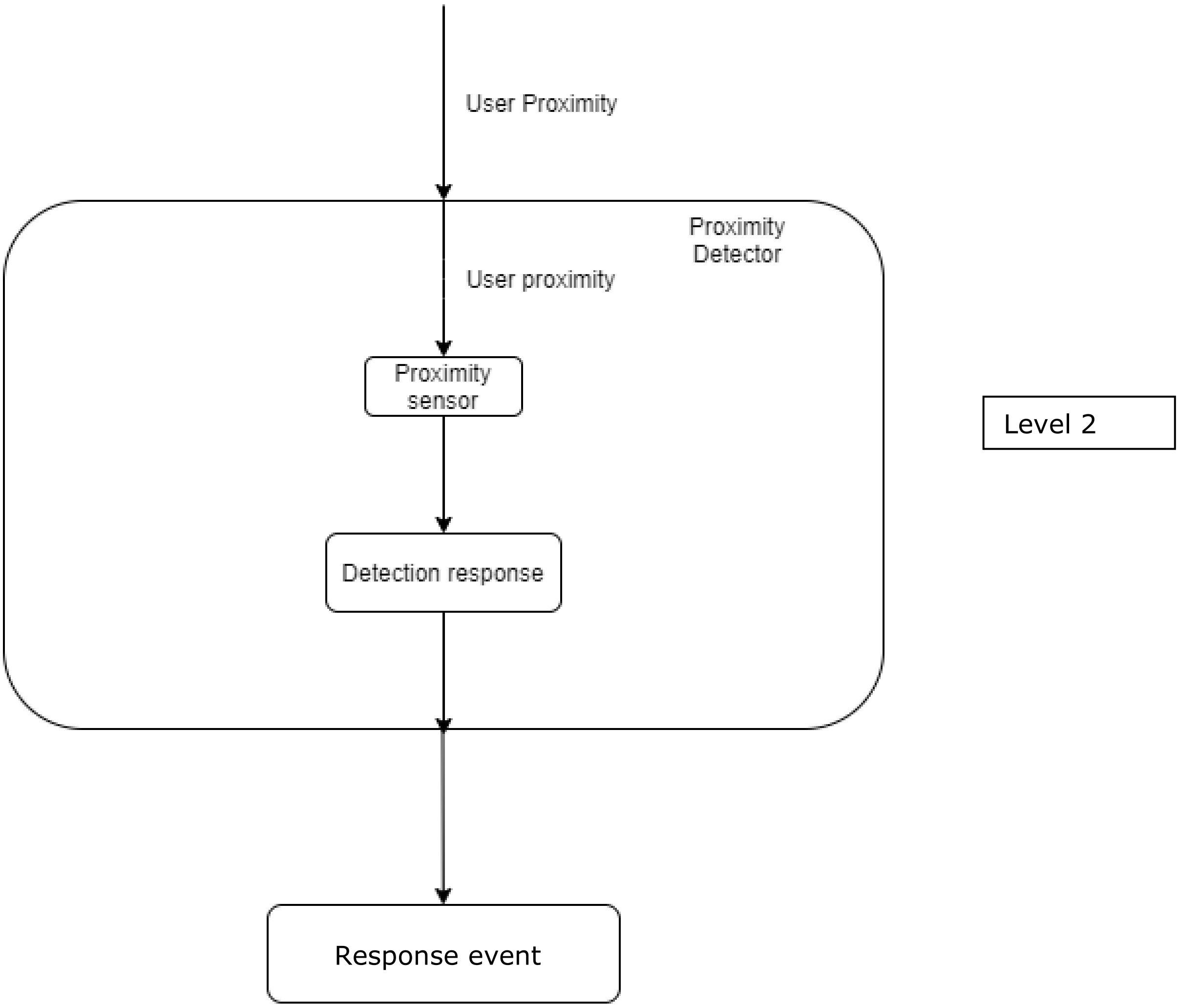


Figure 28: System diagram Level 2

5.2.2 Level 3: Item detection

The item detector senses when there is trash thrown away by a user and sends a detection response. Here a safety check for the proximity detector is triggered, in case bugs or other weird phenomenon disrupt the system. After this check, the feedback is shown in according to which bin something is thrown into.

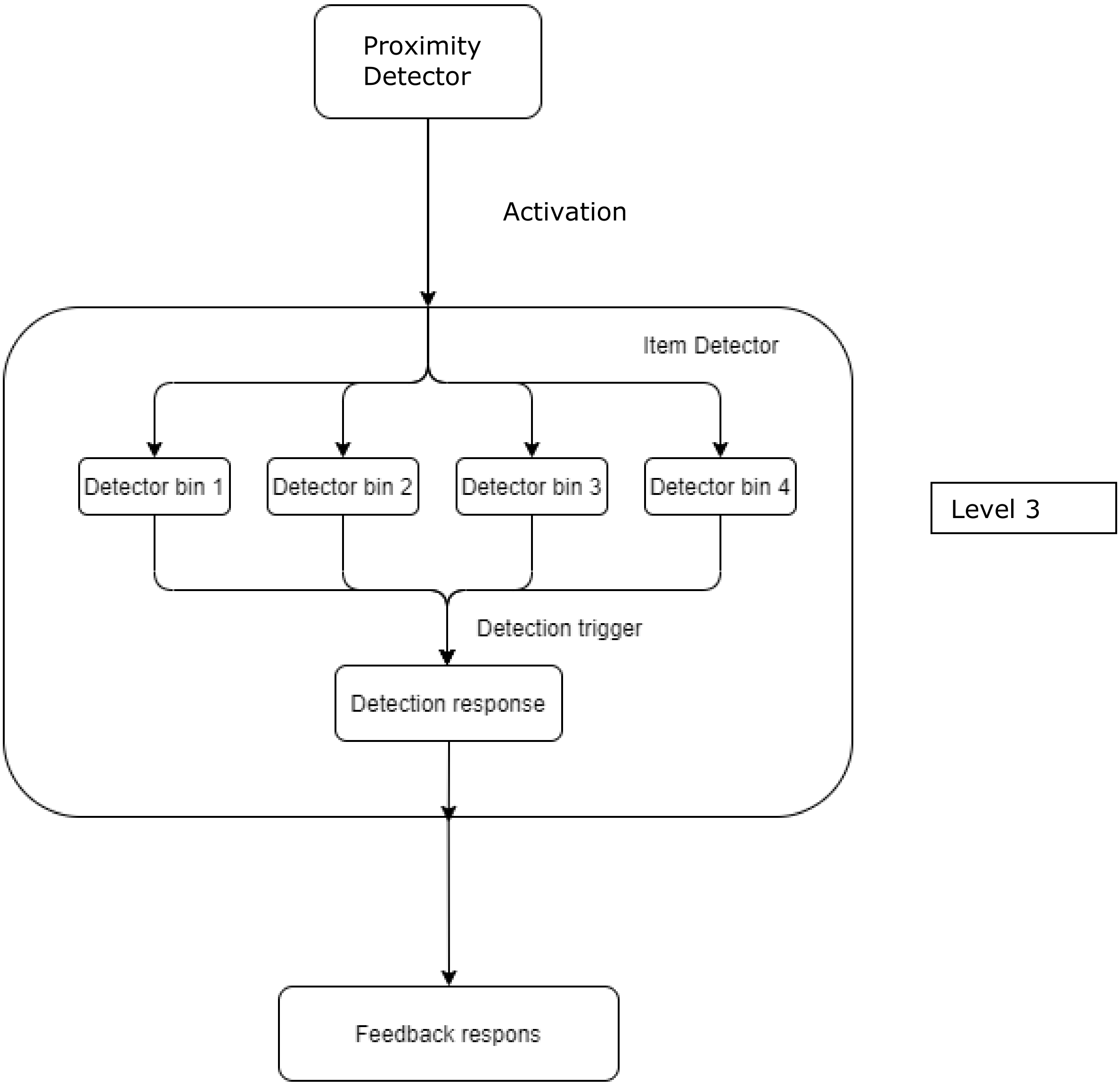


Figure 29: System diagram Level 3

5.3 System interaction diagrams

5.3.1 Level 0: System as a whole

This interaction diagram shows a user interacting with the system as envisioned by the engineer.

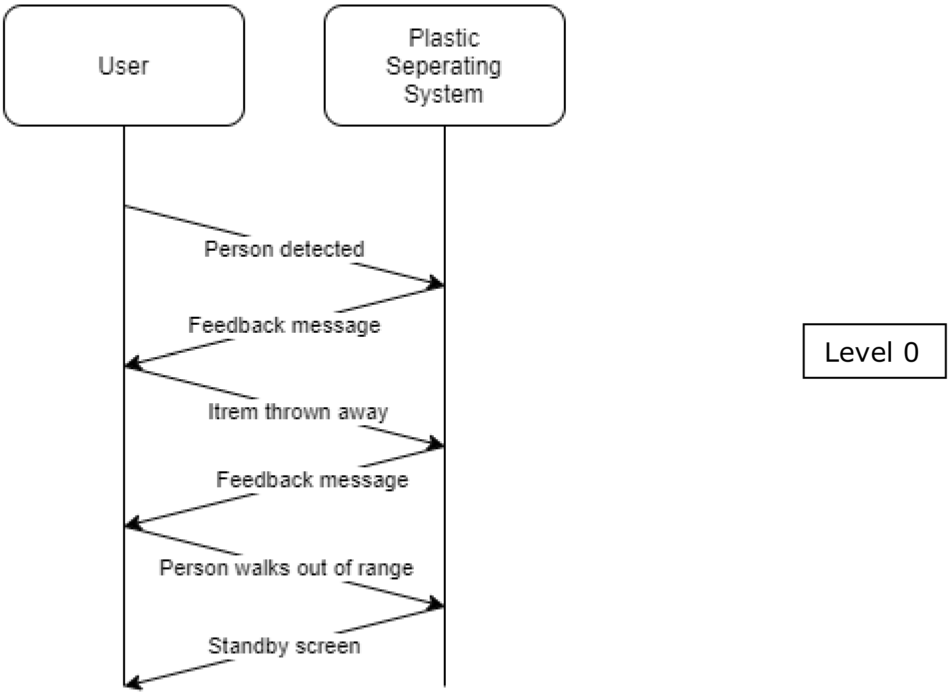


Figure 30: Interaction diagram Level 0

5.3.2 Level 1: combined functions

This interaction diagram shows how different functions behave within the prototype whenever a user interacts with it.

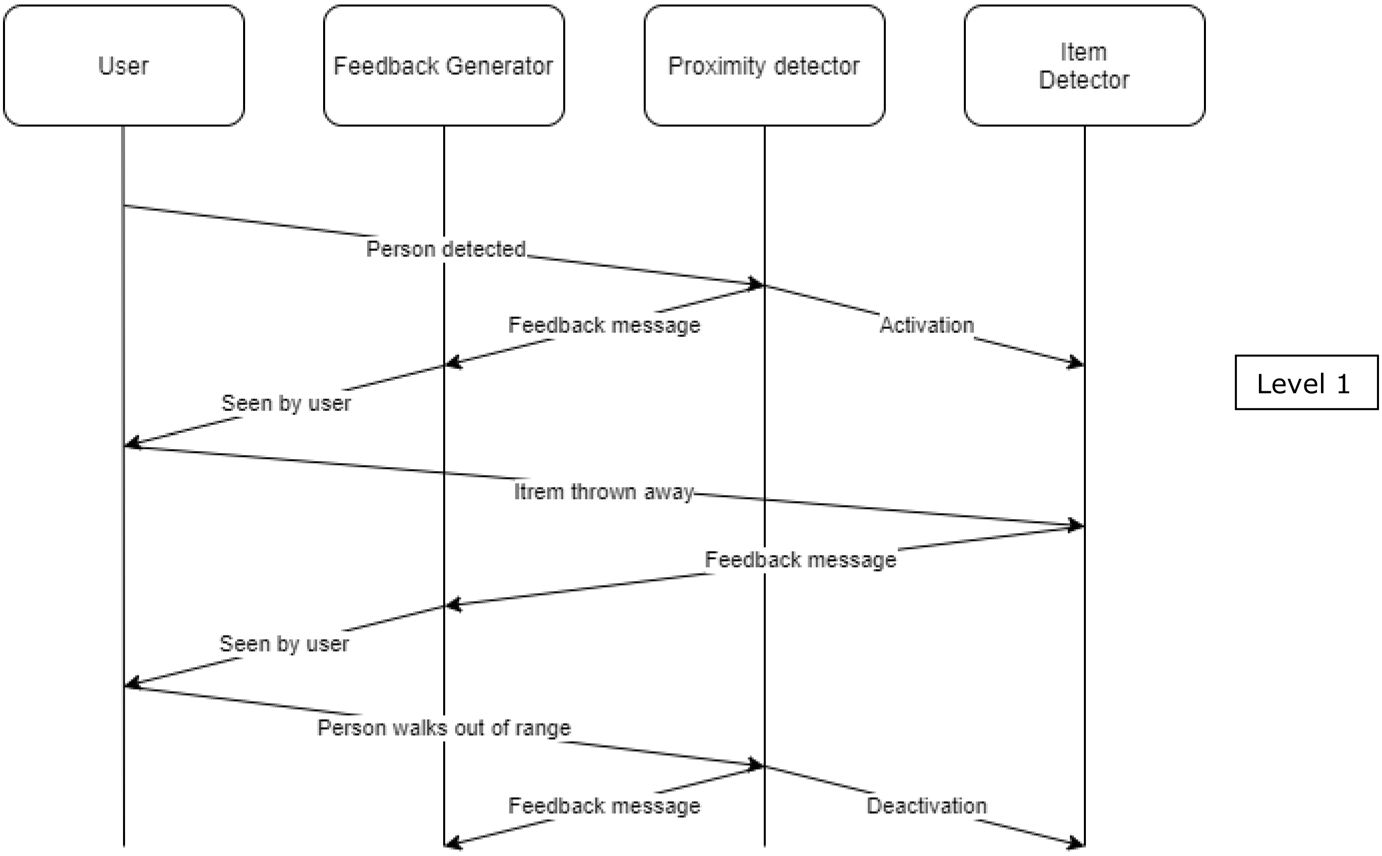


Figure 31: Interaction diagram Level 1

6. Realization

6.1 Practical Aspects

To detect if a person is in front of a trash bin, a lot of devices can be used. The first and most easy being two distance sensors used to measure if someone is "in" the trash bin area, or a single distance sensor sensing the distance in front, and a second one off to the side to see if the person is "close enough". However, the problem with this is that if the placement is in a busy hallway, the distance sensors won't be able to keep up with the people passing or just detect people inside the area all the time, thus triggering the "extra information after certain timeframe"-screen.

The next best thing is an infrared obstacle avoidance sensor, these are commonly found in robots that need to avoid things, by sending a signal once an obstacle gets too close. The problems in using these is that their maximum range is about 30 cm, which is not nearly enough if you place the sensor on a wall, as the trash bin itself also takes up a lot of this depth. Placing it on the trash bin (or under) adds a lot of logistics to the problem, and would likely make it so that the whole trash bin has to be modified.

The easiest solution is using a camera with sensor, such as a Kinect to sense if people are coming closer. This solves both the problem of people having to be in a range and different people being within this range. The best thing is that if "person recognition" can be added, a timer can be added to the triggering. The only problem that arises there is when people move behind each other, it might confuse the two. This, however, is not that big of a problem since we are working with general timeframes, and it might just give the extra information a little earlier or later.

The biggest problem about the Kinect sensor is that it is currently not being sold anymore – Which makes it so that it cannot be brought up as a solution. For that reason I've looked into 3d camera options that function the same and seem promising.
The top alternative for a Kinect at the moment is an Astra pro, which is made by a company called ORBBEC (*Orbbec*, n.d.).

6.2 Hardware

6.2.1 Xbox Kinect

The Xbox Kinect is a motion sensing input device made by Microsoft and released in 2010. It has three cameras, a normal camera, an infrared camera and a sensor for it. For this project it will only be using its two outer cameras to sense depth and trigger if someone is in the range of the depth sensor, which means that for ethical reasons the RGB camera *could* be closed off to not be able to leak anything other than contours and shapes.

The Kinect has a set boundary for people detection through its depth sensor, which will set in the code, if someone comes within this threshold, it will paint those pixels (on the Kinect output) white and set the person detected to true. If there is a certain amount of white pixels on the screen, the timer will be triggered. There is a little buffer on the timer, in case someone just walks by. This way it doesn't trigger. After a certain threshold the first screen shows up, which has pictures of "most common items". After a longer threshold a new screen will pop up, which will have items listed by name.

6.2.2 Arduino

The Arduino is a microcontroller that uses an open source software kit, And is able to read inputs from different sensors and inputs. This makes it a good base for a system like these that completely works on sensors. Its own software is based off of the processing software. In case of this project, the Arduino is connected to 4 ultrasonic sensors that can sense distance.

Ultrasonic sensors use ultrasonic sound pulses to determine the distance between the sensor and an object. This is done by measuring the time between sending a sound and receiving it, for which the distance can then be calculated through the following formula: Millimeters = PulseWidth * 34 / 100 / 2.
(*Arduino Official Store | Boards Shields Kits Accessories*, n.d.)

6.2.3 Operating Hardware
For the initial testing, a screen and a laptop will be used. This could eventually be replaced by a microcomputer such as a Raspberry pi to save space and make the whole setup autonomous and compact, but that is unnecessary for the current project and testing, as this is more a proof of concept rather than a finalized product. This is however something that can be considered in a future prototype.

6.3 Software
The prototype uses two pieces of software to both use the distance sensors and the Kinect, Processing and Arduino IDE;
Processing is an open source software sketchbook that has a main focus on visual arts, and is able to connect to an Xbox Kinect system and read it's data. From here, you can set a limit on the depth meter, and paint everything that comes within the range white, and the rest black. The processing code then searches for white spots that are in the output picture of the Kinect and, when detected, wakes the tool up from it's standby mode. The code has some safeguards in place for people that just casually walk by, so it doesn't turn on for people that do not intend to use it.
It is also linked to the Arduino and receives Arduino data regarding the ultrasonic sensors to trigger the other images.
The code used within processing can be found in Appendix A

The Arduino IDE is a software package based off of Processing and works similar to Processing, except for the fact that this uses physical hardware to make things work instead of outputting software/visual art. In this project it is connected to four ultrasonic sensors which, when something comes in range (like a hand moving towards a trash bin) will send a signal to processing.
How to connect the Arduino to the ultrasonic sensors can be found in figure 32 below.
The code used within Arduino IDE can be found in Appendix B

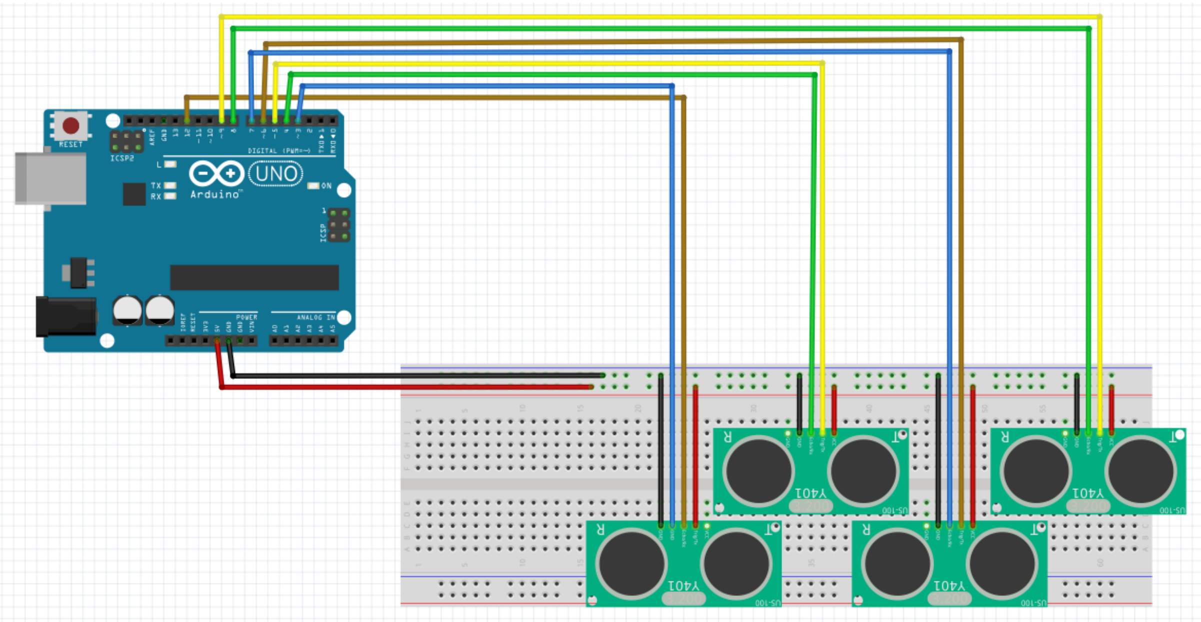


Figure 32: Fritzing scheme of the Arduino setup

Figure 33: Picture showing setup of the prototype

Figure 34: Picture showing ultrasound sensors used in prototype

7. Evaluation

7.1 Functional test

Before the prototype can be tested with the users selected for the test, a functional test needs to be performed to test all the functionalities implemented and to see where there are errors or bugs in the system. A table is constructed to test on a set of things and a percentage is calculated after a random amount of tests on the accuracy and functionality of the tool

Description of action -> consequence	Percentage on 40 tests
Subject in range -> switch scene	100%
Subject lingers -> switch scene	100%
Subject throws away trash A -> switch scene	92.5%
Subject throws away trash B -> switch scene	87.5%
Subject throws away trash C -> switch scene	90%
Subject throws away trash D -> switch scene	92.5%
Subject walks away -> reset	100%

Figure 35: Results functional testing

While there are still some small errors in the detection of trash thrown away, the detection system works perfectly and flawlessly. The trash detection system had at most 5 problems with trash bin B where it either did not pick up at all, or another sensor picked it up. When another sensor picks up the signal, the wrong scene gets switched to. This means that the information does not correspond with the users action and could lead to confusion. However, because the rate is so low, testing can continue normally.

7.2.1 User test

Important to note that during the user test is being tested with random users that have experience with throwing away plastics, and not nurses and their equipment.
This is due to the EEMCS rules regarding COVID-19, which states that the researcher cannot put pressure on the medical field. This means the testing is a proof of concept test, and not an actual user test, and cannot be shown as such.

7.2.2 Testing procedure

User tests were conducted as follows:
The user was welcomed into the room which had the prototype in it and a table with plastic trash on it, the plastic should have been sorted as can be seen in table X.X

Plastic type 2	Plastic type 4	Plastic type 5	Plastic type 7
Shopping bag	Trash bag	Hard food container	Food plastic
Small bags	Squeeze bottle	Milk container	PET bottle
Small food wrapper	Straws		Can

Figure 36: Table of plastics used in testing procedure

After seeing the trash and the tool, they were asked to throw away the trash into the bins. For the first testing round, they are not shown what they have to do, or how the prototype works. This is to test if the prototype is useful without giving information to a user beforehand, and to see if the user will take any information from the prototype.

After this first test, the Users were shown how the prototype works and asked to look at the lists of items on what goes where. These screens can be found in appendix C

Now, the user will enter a second round, in which they have to throw away the same set of plastics again.

After this process, the participants are asked what they think of the prototype, and what they would improve.

7.3 Test Results

The test results were put into table X.X as can be seen below.

#	Test 1	Mistakes	Test 2	Mistakes	Test *	Mistakes
1	5:28	8	4:37	2	6:34	9
2	4:36	8	2:44	6	2:46	9
3	3:26	6	3:06	5		
4	4:24	6	2:59	3		
5	4:37	4	1:24	1		

Figure 37: Table of results from testing procedure

Note that for these test results, there are two test *'s

Test subject 1 had No screen at the first test , and then got a screen for test 1 and 2, to see if the message of the screen had any impact on her choices.

Test subject 2 started sorting everything by the color they knew from their real life experiences, even though the names were taped off, which lead to a fast, and unverifiable outcome, which was then stored in test*

Between test subjects 4 and 5, there was a 20 minute window, in which small changes to the "list" screen was made, adding all the things to the lists that were in the trash group that had to be thrown away. This was done to see whether or not the time and accuracy of a user would be improved if the lists would have every single thing on it.

The participants feedback lead to the following observations:

The pictures that are used in the image screen can be deceiving and lead to mistakes made in the separation. This means that the pictures that are shown have to be very precise depictions of the items, and cannot be items that can have another type of plastic if it looks the same but isn't. A perfect example in the user test is for example that a generalized "squeeze bottle" belongs in bin B, but the garlic sauce condiment bottle, that is normally squeezed to be used, belongs in bin C.

The same goes for the text- The text lines need to be specific and include all possibilities of trash that can be thrown away.

The last observation made is that the system has a hard learning curve. It immediately gives you a lot of information, which was a lot to take in for some of the users. After the first round however, this knowledge was known, and lead to the use of the image screen more.

8. Conclusion and Recommendations

8.1 Conclusion

This graduation project presents the development of a tool to sustain plastic waste separation behavior in Dutch hospitals. The project starts out with a research question and a couple of sub-questions, which have all been answered within the graduation report. The first sub-question asked could very easily be answered. Currently, the plastics are separated like every other plastic would be separated, thrown with all the other plastics, and the only distinction currently made is between contaminated and non-contaminated plastics.

The project then moved on to a literature study and state of the art research, which lead to the conclusion that there are a couple of theoretical frameworks to prevent behavior relapse, but also that there should be looked in to how to maintain current behavior, which is done through the Theory of Planned behavior and nudging.
However, an important limitation of this contemporary research is that the scope of literature used is just a fraction of all existing literature on the subject of recycling. Additionally, most papers used are healthcare related, and sometimes only briefly come to the topic of recycling. On top of that, most behavioral change programs and studies are aimed at health- or social behavior change, instead of better plastics recycling. While this is still improving behavior change, it has nothing to do with for example addictions or social disruption. This could mean that the findings in this study could be different, as is assumed that nobody is actively addicted to throwing trash in the wrong bin.

Following this, stakeholders were assessed through brainstorming. Due to rules regarding COVID-19, stakeholder interviews and stakeholder requirements could not be made, requiring a preliminary idea of the system. A brainstorm was conducted on possibilities, and mixing and matching the basic parts of the project gave room for a few feasible prototypes, of which one was chosen. This prototype was worked out using theory and earlier findings.

next, the system was decomposed into parts, interaction diagrams were made and a prototype was made using an Arduino, Xbox Kinect and ultrasound sensors, after which it was tested for bugs. An important note to make is the 87.5% score on the detection of trash thrown in bin B, which could have led to skewed results.

Then, a user test took place, but was tested with random users that have experience with throwing away plastics, instead of my users. This is due to the EEMCS rules regarding COVID-19, which states that the researcher cannot put pressure on the medical field. Another very big discussion point of this research is that the window of time to test the device was 2 hours, which made it impossible to do a large scale or long-time test which could have skewed the test results.

However, the evaluation of the system showed that the proof of concept is true and that a system like this can be worked out and adopted into the medical field to sustain the current plastic waste behavior.

8.2 Recommendation

Multiple recommendations can be given on the research and development of this project into a better and more ready prototype.
For this, first of all, testing needs to be done in the user field, and a user study needs to be conducted. Next to this, a long-term study needs to be conducted to find better data and understanding of how and why is interacted with the system. This will all lead to a better understanding and a better implementation of the system. After this, testing for

specification in other fields will require good listing of every possible item that is used in this other field.
The possibilities of AI and machine learning in making a device that recognizes trash instead of having humans decide what type of trash goes in which bin would be a very interesting project to see come to life, but with the current standings of our technology, should be very well possible.

9. References

Arduino Official Store | Boards Shields Kits Accessories. (n.d.). Retrieved June 15, 2020, from https://store.arduino.cc/

Azouz, S., Boyll, P., Swanson, M., Castel, N., Maffi, T., & Rebecca, A. M. (2019). Managing barriers to recycling in the operating room. *American Journal of Surgery*, *217*(4), 634–638. https://doi.org/10.1016/j.amjsurg.2018.06.020

Berecycled. (n.d.). I Want To Be Recycled. Retrieved May 27, 2020, from https://berecycled.org/

Bostrom, A., Morgan, M. G., Fischhoff, B., & Read, D. (1994). What do People Know About Global Climate Change? 1. Mental Models. *Risk Analysis*, *14*(6), 959–970.

Bouton, M. E. (2014). Why behavior change is difficult to sustain. *Preventive Medicine*, *68*, 29–36. https://doi.org/10.1016/j.ypmed.2014.06.010

Byerly, H., Balmford, A., Ferraro, P. J., Wagner, C. H., Palchak, E., Polasky, S., Ricketts, T. H., Schwartz, A. J., & Fisher, B. (2018). Nudging pro-environmental behavior: Evidence and opportunities. *Frontiers in Ecology and the Environment*, *16*(3), 159–168. https://doi.org/10.1002/fee.1777

CamelBak. (n.d.). Retrieved July 16, 2020, from https://www.camelbak.com/en/our-values/ditch-disposable

Chaerul, M., Tanaka, M., & Shekdar, A. V. (2008). A system dynamics approach for hospital waste management. *Waste Management (New York, N.Y.)*, *28*(2), 442–449. https://doi.org/10.1016/j.wasman.2007.01.007

Charity Water. (n.d.). Charity: Water. Retrieved July 16, 2020, from https://www.charitywater.org/

Cole-Lewis, H., & Kershaw, T. (2010). Text Messaging as a Tool for Behavior Change in Disease Prevention and Management. *Epidemiologic Reviews*, *32*(1), 56–69. https://doi.org/10.1093/epirev/mxq004

Daamen, D. D. L., Staats, H., Wilke, H. A. M., & Engelen, M. (2001). Improving Environmental Behavior in Companies: The Effectiveness of Tailored Versus Nontailored Interventions. *Environment and Behavior*, *33*(2), 229–248. https://doi.org/10.1177/00139160121972963

de Leeuw, A., Valois, P., Ajzen, I., & Schmidt, P. (2015). Using the theory of planned behavior to identify key beliefs underlying pro-environmental behavior in high-school students: Implications for educational interventions. *Journal of Environmental Psychology*, *42*, 128–138. https://doi.org/10.1016/j.jenvp.2015.03.005

Hamilton, L. A., Feit, S., Kelso, M., Rubright, S. M., Bernhardt, C., Schaeffer, E., Moon, D., Morris, J., & Labbé-Bellas, R. (2019). *Plastics & Climate: The hidden costs of a plastic planet* (p. 108). CIEL: Center for International Environment Law. https://www.ciel.org/wp-content/uploads/2019/05/Plastic-and-Climate-FINAL-2019.pdf

Haughey, D. (n.d.). *MoSCoW Method*. Retrieved July 16, 2020, from https://www.projectsmart.co.uk/moscow-method.php

Hsu, S.-J. (2004). The Effects of an Environmental Education Program on Responsible Environmental Behavior and Associated Environmental Literacy Variables in Taiwanese College Students. *The Journal of Environmental Education*, *35*(2), 37–48. https://doi.org/10.3200/JOEE.35.2.37-48

Huang, H. (2016). Media use, environmental beliefs, self-efficacy, and pro-environmental behavior. *Journal of Business Research*, *69*(6), 2206–2212. https://doi.org/10.1016/j.jbusres.2015.12.031

Jang, Y.-C., Lee, C., Yoon, O.-S., & Kim, H. (2006). Medical waste management in Korea. *Journal of Environmental Management*, *80*(2), 107–115. https://doi.org/10.1016/j.jenvman.2005.08.018

Korkut, E. N. (2018). Estimations and analysis of medical waste amounts in the city of Istanbul and proposing a new approach for the estimation of future medical waste amounts. *Waste Management*, *81*, 168–176. https://doi.org/10.1016/j.wasman.2018.10.004

Koskinen, I., Mattelmäki, T., & Battarbee, K. (2003). *Empathic Design*.

Lee, B.-K., Ellenbecker, M. J., & Moure-Eraso, R. (2002). Analyses of the recycling potential of medical plastic wastes. *Waste Management*, *22*(5), 461–470. https://doi.org/10.1016/S0956-053X(02)00006-5

Lülfs, R., & Hahn, R. (2013). Corporate Greening beyond Formal Programs, Initiatives, and Systems: A Conceptual Model for Voluntary Pro-environmental Behavior of Employees. *European Management Review*, *10*(2), 83–98. https://doi.org/10.1111/emre.12008

Mader, A. H., & Eggink, W. (2014). A Design Process for Creative Technology. *Proceedings of the 16th International conference on Engineering and Product Design, E&PDE 2014*, 568–573. https://research.utwente.nl/en/publications/a-design-process-for-creative-technology

Orbbec. (n.d.). Retrieved July 17, 2020, from https://orbbec3d.com/

Prochaska, J., & Velicer, W. (1997). The Transtheoretical Model of Health Behavior Change. *American Journal of Health Promotion : AJHP*, *12*, 38–48. https://doi.org/10.4278/0890-1171-12.1.38

Sahni, P., Arora, G., & Dubey, A. K. (2018). Healthcare Waste Management and Application Through Big Data Analytics. In B. Panda, S. Sharma, & N. R. Roy (Eds.), *Data Science and Analytics* (Vol. 799, pp. 72–79). Springer Singapore. https://doi.org/10.1007/978-981-10-8527-7_7

Schapenkoppiekoppie. (n.d.). Schapenkoppiekoppie. Retrieved July 16, 2020, from http://schapenkoppiekoppie.nl/

Sookne, K. (2019, January 31). *Hospital Takes Aim at Plastic Recycling*. Healthcare Packaging. https://www.healthcarepackaging.com/issues/sustainability/article/13294459/hospital-takes-aim-at-plastic-recycling

Strecher, V. J., McEvoy DeVellis, B., Becker, M. H., & Rosenstock, I. M. (1986). The Role of Self-Efficacy in Achieving Health Behavior Change. *Health Education Quarterly*, *13*(1), 73–92. https://doi.org/10.1177/109019818601300108

Surfers Against Sewage. (n.d.). *Surfers Against Sewage*. Retrieved May 27, 2020, from https://www.sas.org.uk/about-us/

Thaler, R. H., & Sunstein, C. R. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. Yale University Press.

ThinkEatSave. (n.d.). Retrieved July 16, 2020, from https://www.thinkeatsave.org/about/

Trees for Cities. (n.d.). Retrieved July 16, 2020, from https://www.treesforcities.org/

Tudor, T. L., Barr, S. W., & Gilg, A. W. (2007). Linking intended behaviour and actions: A case study of healthcare waste management in the Cornwall NHS. *Resources, Conservation and Recycling*, *51*(1), 1–23. https://doi.org/10.1016/j.resconrec.2006.06.009

Tudor, Terry L., Barr, S. W., & Gilg, A. W. (2007). Strategies for improving recycling behaviour within the Cornwall National Health Service (NHS) in the UK: *Waste Management & Research*. https://doi.org/10.1177/0734242X07082030

Vogt, J., & Nunes, K. R. A. (2014). Recycling behaviour in healthcare: Waste handling at work. *Ergonomics*, *57*(4), 525–535. https://doi.org/10.1080/00140139.2014.887786

We Don't Have Time. (n.d.). Retrieved July 16, 2020, from https://www.wedonthavetime.org/

10. Appendices

Appendix A: Processing Code

```
/* Base code taken from an example by Elie Zananiri
 Adapted by Lucas van Ovost to fit his Graduation Project
 made on June 10th, 2020 */

import org.openkinect.freenect.*;
import org.openkinect.processing.*; //import the kinect libraries used to read data
import processing.serial.*; //Construct a connection between arduino and processing using the serial library
Serial myPort;
Kinect kinect;
PImage img = loadImage("1.jpg"); //load in the images used for the different screens
PImage img2 = loadImage("2.jpg"); //These images must be in the folder of the processing code
PImage img3 = loadImage("3.jpg");
PImage img4 = loadImage("4.jpg");
PImage img5 = loadImage("5.jpg");
PImage img6 = loadImage("6.jpg");
PImage img7 = loadImage("7.jpg");
boolean pd; //person detected
boolean nt; //No trash detected
int timer = 0;
int diff = 0;
PImage depthImg;    //depth image
int minDepth =  0;  //boundaries for the depth image on a kinect
int maxDepth = 600; //change this if you want more "range" on the detection

void setup() {
  size(1920, 1080);  //paint a canvas
  kinect = new Kinect(this); //set up the kinect
  kinect.initDepth();
  depthImg = new PImage(kinect.width, kinect.height); // Blank image
  String portName = Serial.list()[1]; //set up communications with the arduino.
  myPort = new Serial(this, portName, 9600);
}

void draw() {
  // Threshold the depth image
  int[] rawDepth = kinect.getRawDepth();
  for (int i=0; i < rawDepth.length; i++) {
    if (rawDepth[i] >= minDepth && rawDepth[i] <= maxDepth) { // if the pixels are within the range, paint them white
      depthImg.pixels[i] = color(255);
    } else {                                        // all the others are black
      depthImg.pixels[i] = color(0);
    }  }

  for (int x = 0; x < kinect.width-1; x++) {
    for (int y = 0; y < kinect.height; y++) {  //going over all pixels vertically
      int loc1 = x + y*kinect.width;
      int loc2 = (x+1) + y*kinect.width;
      float b1 = depthImg.pixels[loc1];
      float b2 = depthImg.pixels[loc2];
      float diff = abs(b1-b2);                 //if there is a white pixel next to another white pixel
      if (diff>200) {
        pd = true;                             //set Person Detection on
      }   }  }
  fill(0);

  if (pd == true) {                            // If person detection is on
    timer +=1;                                 // timer +1
    pd = false;                                // set person detection off
  } else {
    nt = true;                                 // no trash detected
    timer = 0;                                 // timer is 0
    image (img, 0, 0);                         // show base screen  }

  if (timer >= 20 && nt == true) {             // if the timer reaches 20
    image (img2, 0, 0);                        // show first screen  }

  if (timer >= 300 && nt == true) {            // if timer exceeds threshold time and nothing has been thrown away
    image (img3, 0, 0);                        // show second screen  }

  if ( myPort.available() > 0)  // If there is data from the Arduino
  {
    char inByte = myPort.readChar();  //Gets the input from arduino and makes it a Char.
    if (timer>=20 && inByte == 'a') { //If arduino sends "a"
      image (img4, 0, 0);             //show trash type screen
      delay(2000);                    //wait for two seconds
      nt =false;                      //set NoTrash false    }
    if (timer>=20 && inByte == 'b') {
      image (img5, 0, 0);
      delay(2000);
      nt =false;    }
    if (timer>=20 && inByte == 'c') {
      image (img6, 0, 0);
      delay(2000);
      nt =false;    }
    if (timer>=20 && inByte == 'd') {
      image (img7, 0, 0);
      delay(2000);
      nt =false;
    } } }
```

Appendix B: Arduino Code

```
// Made by Lucas van Ovost on 23-06-2020 for his Graduation Project
// Uses 4 Ultrasound sensors with a range Dist, and sends a ping over sertialport (a,b,c,d) for processing to receive.
int EchoPin1 = 3;   // Rename the pin on the arduino to the number of the port used for the ultrasound sensors
int TrigPin1 = 12;  // every ULTRASOUND SENSOR has an Echo and a Trig pin.
int EchoPin2 = 4;
int TrigPin2 = 5;
int EchoPin3 = 7;
int TrigPin3 = 6;
int EchoPin4 = 9;
int TrigPin4 = 8;

long Time_Echo_us1 = 0; //these will be used to calculate the distance for every single ultrasound sensor
long Time_Echo_us2 = 0;
long Time_Echo_us3 = 0;
long Time_Echo_us4 = 0;

long Len_mm1  = 0; //this will be used as distance in mms
long Len_mm2  = 0;
long Len_mm3  = 0;
long Len_mm4  = 0;

int dist = 580; // used to set the distance for trigger zones. Adjust this to adjust the range of the sensors

void setup() {
  Serial.begin(9600);         //  The measurement results through the serial output to the serial port on the PC monitor

  pinMode(EchoPin1, INPUT);    //  The set EchoPin input mode.
  pinMode(TrigPin1, OUTPUT);   //  The set TrigPin output mode.
  pinMode(EchoPin2, INPUT);
  pinMode(TrigPin2, OUTPUT);
  pinMode(EchoPin3, INPUT);
  pinMode(TrigPin3, OUTPUT);
  pinMode(EchoPin4, INPUT);
  pinMode(TrigPin4, OUTPUT);
}

void loop() {
  digitalWrite(TrigPin1, HIGH);                  // Send pulses begin by Trig / Pin
  delayMicroseconds(20);                         // Set the pulse width of 50us (> 10us)
  digitalWrite(TrigPin1, LOW);                   // The end of the pulse
  Time_Echo_us1 = pulseIn(EchoPin1, HIGH);           // open up receiving end
  if ((Time_Echo_us1 < 60000) && (Time_Echo_us1 > 1)) { // Pulse effective range (1, 60000).
    Len_mm1 = (Time_Echo_us1 * 34 / 100) / 2;          // Calculating the distance by a pulse width using physics.
    if (Len_mm1 < dist) {                          // if the active distance is smaller than the trigger distance send message
      Serial.println("a");
    }
  }

  digitalWrite(TrigPin3, HIGH);                  //Repeat for third ultrasound sensor
  delayMicroseconds(20);
  digitalWrite(TrigPin3, LOW);
  Time_Echo_us3 = pulseIn(EchoPin3, HIGH);
  if ((Time_Echo_us3 < 60000) && (Time_Echo_us3 > 1)) {
    Len_mm3 = (Time_Echo_us3 * 34 / 100) / 2;
    if (Len_mm3 < 560) {
      Serial.println("c");
    }
  }

  digitalWrite(TrigPin2, HIGH);                  //Repeat for second ultrasound sensor
  delayMicroseconds(50);
  digitalWrite(TrigPin2, LOW);
  Time_Echo_us2 = pulseIn(EchoPin2, HIGH);
  if ((Time_Echo_us2 < 60000) && (Time_Echo_us2 > 1)) {
    Len_mm2 = (Time_Echo_us2 * 34 / 100) / 2;
    if (Len_mm2 < dist) {
      Serial.println("b");
    }
  }

  digitalWrite(TrigPin4, HIGH);                  //Repeat for fourth ultrasound sensor
  delayMicroseconds(20);
  digitalWrite(TrigPin4, LOW);
  Time_Echo_us4 = pulseIn(EchoPin4, HIGH);
  if ((Time_Echo_us4 < 60000) && (Time_Echo_us4 > 1)) {
    Len_mm4 = (Time_Echo_us4 * 34 / 100) / 2;
    if (Len_mm4 < dist) {
      Serial.println("d");
    }
  }
  delay (50);
}
```

Appendix C: Evaluation Screens

Figure 38: Standby screen

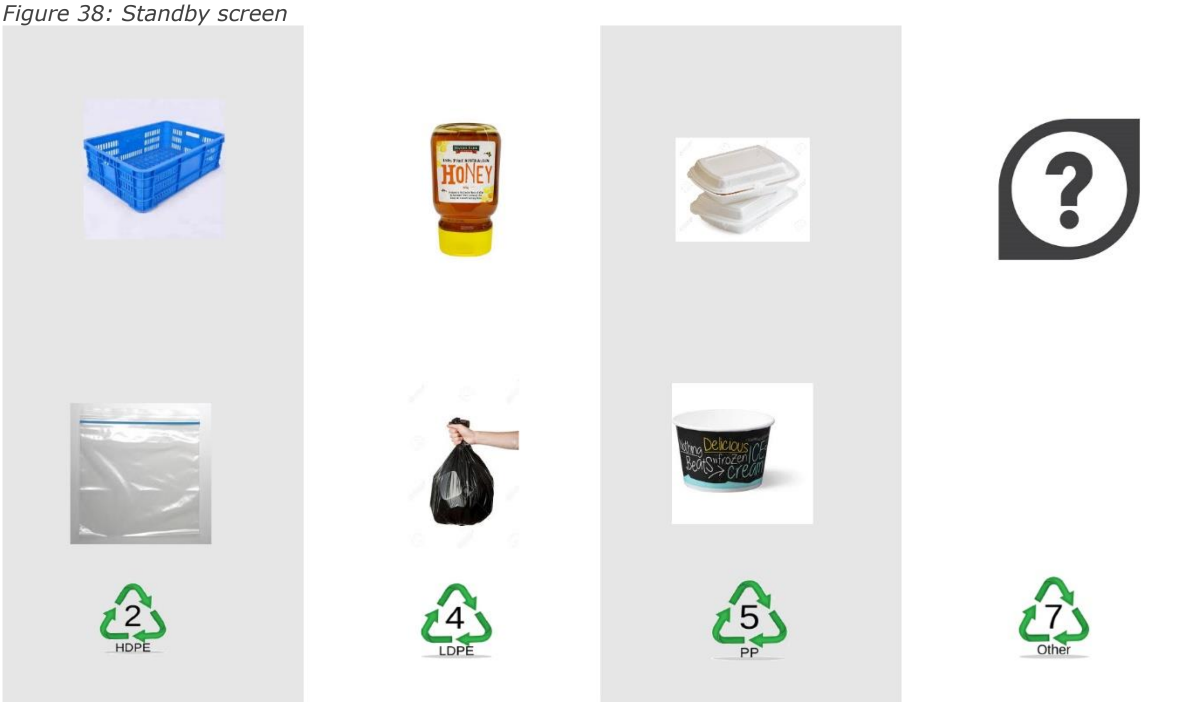


Figure 39: Image screen

Figure 40: list screen

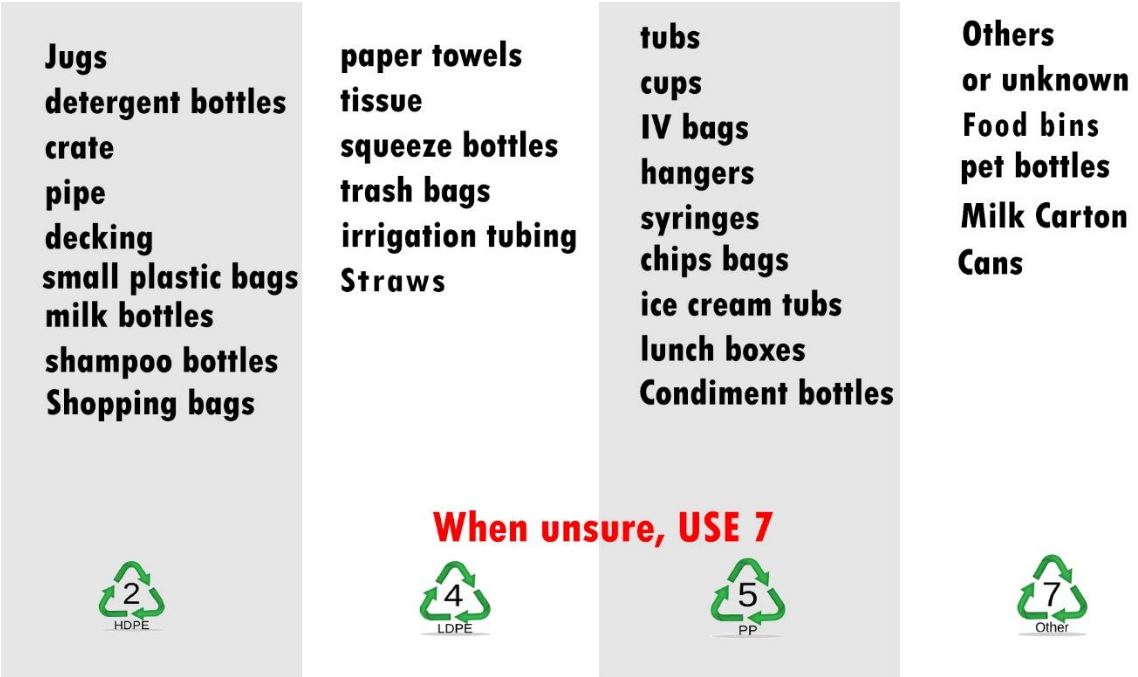


Figure 41: Extended list screen

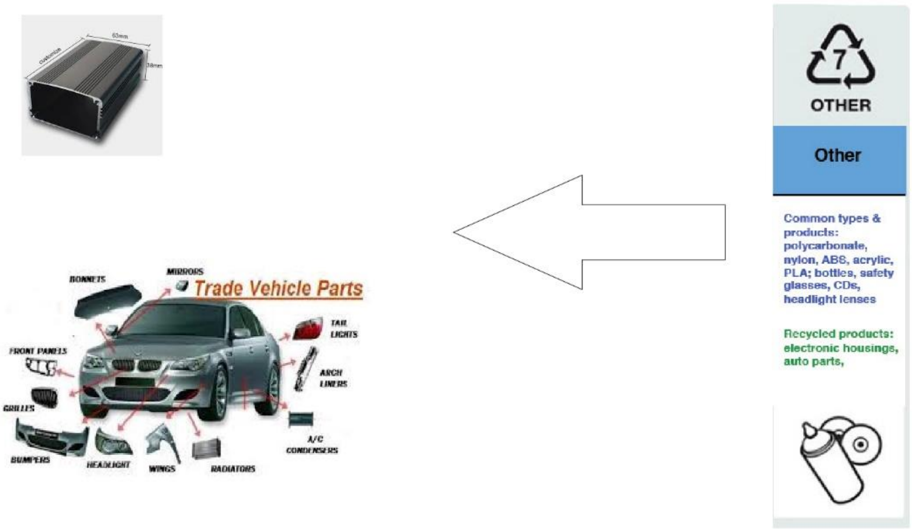


Figure 42: Purpose Screen A

Figure 43: Purpose Screen B

Figure 44: Purpose Screen C

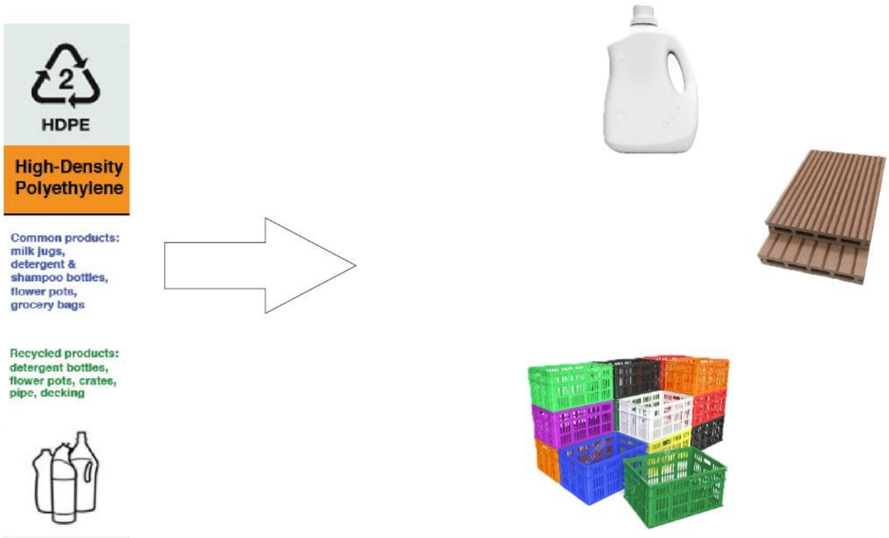


Figure 45: Purpose Screen D