Plastic scanner 2.0

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Advanced Embodiment Design Course 2022 - ID4175

Group 4 Plastic Scanner

Coach Wouter Kets

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1.1 Table of contents

1. Intro

1.1 Acnowledgements

We would like to express our deepest gratitude to Wouter Kets, who has been guiding and supporting us throughout this course. We also would like to thank our client Jerry Vos, who assigned us this project as a possibility within the course and provided us with a lot of insights and help to develop this project. But also, we would like to thank Jure Vidmar, who is collaboratively working with Jerry on the software and firmware of the plastic scanner and helped and informed us on these topics.

We were also very grateful for Kimm and Ivo Besselen, Everard Kramer, Huib van Gulik and many moreBesstrade employees as it was made possible to get insights, documentation and validation from their recycling facility. Thanks, should also go to Ben Mallet and John verhoeven as they made it possible to retrieve insights within the organization of Ocean plastics waste recycling within rivers and oceans.

Lastly we would also like to thank the course coördinator Bas Flipsen and all the expertise consultants for providing guidance and feedback.

1.2 Executive summary

During the Course Advanced Embodiment Design (AED) within the master IPD of the Faculty of Industrial Design, TU Delft, the focus laid on the embodiment design phase of a chosen project that needed to be further developed. The project assigned was the 'Plastic Scanner'.

The plastic scanner is a thesis project of Jerry Vos which currently is in development as an open-source project. Within the course the following design direction was given:

"Development of version 2 for commercial B2B use in "the first world" and production of larger quantities, used by companies active in the garbage collecting & recycling industry"

After context research, the proposed product is a handheld scanner with various features that apply to 2 different end-users within different companies. The end-users are:

- Sorting workers that need to retrieve information on waste samples and identify whether a sample may be recycled or not.
- Sorting workers that need to recycle different kinds of materials into specific waste categories.

With this solution, companies have a hand-held device that fulfils the needs of the end-users and the company. Additionally, the product can be manufactured within the price range that is interesting and has a great sustainable impact during use within these companies.

To put the product on the market, the following recommendations are made for improving the design:

- Making the rubber handle more sustainable and easier removable.
- Developing and testing the transparent light blocking element.
- Increasing durability by optimizing the waterproofness of the product.

1.3 Introduction

For the master course, Advanced Embodiment Design at the Faculty of Industrial Design, TU Delft, the Plastic Scanner was assigned to this group as a project proposal for this course. The plastic scanner is a prototype developed during the master thesis of Jerry Vos that enables users to scan and identify different types of plastics. Jerry won the Dyson sustainability award for his innovation as it solves one of the most pressing sustainability issues (India EducationDiary, 2021). The thesis focused on providing a solution for low-income countries, whereas our assignment is to develop a new commercial version.

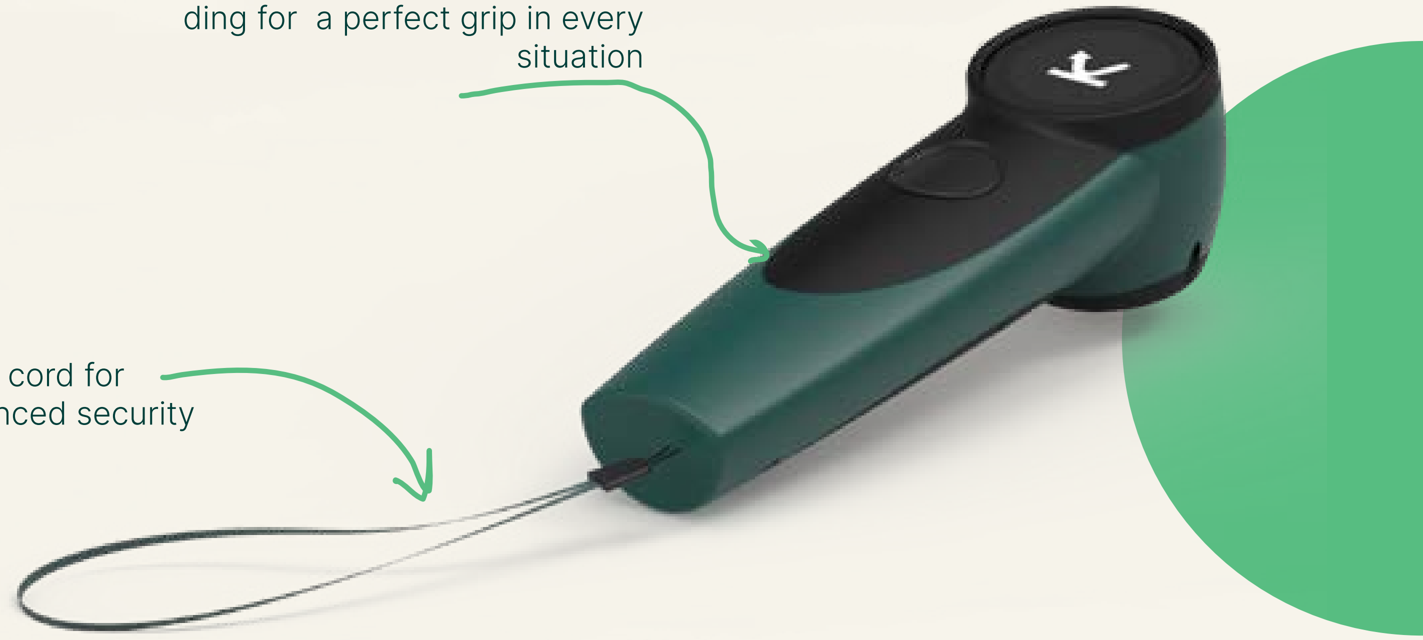
1.4 Final design

the output of this project, is a handheld plastic scanner, made specifically for making industrial manual identification of sorting of plastics easier and more efficient.

Reflection from lighting 8 Near infrared LED on a material, measured by the sensor and used to identify the plastic type

Ergonomic grip & rubber padding for a perfect grip in every situation

Hand cord for enhanced security



Press the button, and the scanner will wake up

When the scanner has woken up, press the button to scan

The scanner gives the user clear feedback: I successfully identified the plastic type

If the results were not conclusive, it will ask you to scan again


Result
PP


Result
PP


PVC


PP


Result
PP

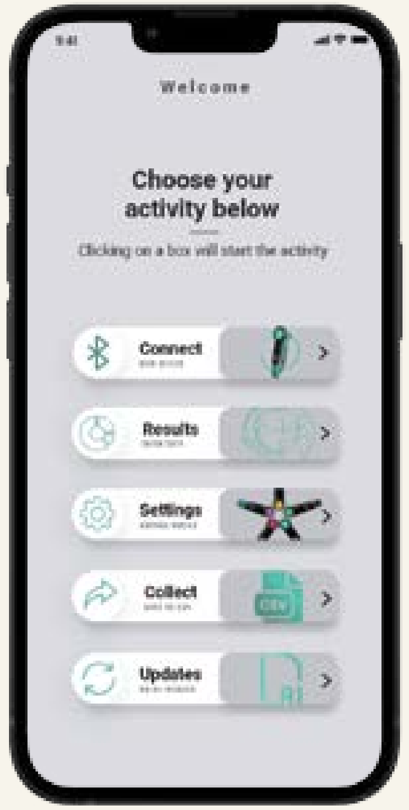

PP


PP

1.5 Companion app

To make the scanner as simple as possible, we made a companion app proposal

The phone pairs with the scanner via BLE



When paired, the user can collect data, update firmware and customise the color feedback

1.6 Customization

The user can customize the feedbackcolors to tailor the scanner perfectly for their specific context

If the company has 5 colored bins for the five types, the screens can match

If the company is only interested in specific plastic types, feedback can be tailored for that

2. Project Definition

2.1 The Plastic Problem

Plastic is an awesome material. It can be shaped in an unlimited number of shapes, melted, reshaped, and lasts for an eternity. But the longlasting abilities of polymers results in polymer-based garbage piling up in our natural environments, and microplastics end up in living beings (Plastic Free July, 2021). The sheer amount of plastic waste causes huge environmental problems and is impacting our health and threatens our oceans and wildlife.

The solution sounds simple: we need to recycle all plastic products, but the reality is complicated and current systems and solutions are not geared to keep up with the overwhelming amount of waste, resulting in only a small portion is being recycled and most plastics are being downcycled. With this project, we aim to take a step towards a circular plastic economy, by enabling users to identify and sort polymers to turn waste into valuable resources.

Figure 1: Plastic trash

2.2 Current product

The current plastic scanner is an open-source DIY project (Figure 2 and Figure 3), that was designed as part of a master thesis project by Jerry de Vos (de Vos, 2021). The handheld DIY scanner can be produced at low costs to help waste pickers in low-income countries to identify the most common types of plastic: PET, PE, PVC, PP, and PS.

Waste management in low-income countries is typically informal and insufficient causing plastic pollution (de Vos, 2021). Additionally, the sorting and recycling process is time consuming and labour-intensive. Identifying polymers is difficult for manual labour, and forces them to leave out plastics without a clear marking because they cannot categorise them. This problem is what the plastic scanner is trying to tackle, as it accelerates the recycling process by giving clear feedback to the user. With the plastic scanner they can ensure potential buyers or supervisors that their sorted batches are pure which increases the material value and thereby increases income for the sorter.

The plastic scanner scans an object by measuring the light reflected by the material at specific near infrared (NIR) wavelengths. Because different types of plastic have different energy absorbance at specific wavelengths, the scanner can compare the sensor data, and estimate the type of polymer. The technology is currently being developed further and the whole project is opensource, to make plastic identification accessible for everyone - and improve it with help from the online community.

Figure 3: Exploded view of Jerry's prototype

Figure 2: Plastic scanner scanning plastic product

2.3 Client Objectives

After our client Jerry (Figure 4) with the plastic scanner won the Dyson Award, an overwhelming number of businesses interest in the plastic scanner. This showed that there is a market demand for the product in a western industrial context. But the scanner was developed for low-income countries, and Plastic Scanner wants to develop a scanner model for industrial plastic recycling and identifying processes in western countries.

Specifically, the objective for this project is to develop a corporate version of the plastic scanner for small batch production (100-2000pcs). The project should identify and describe the new target group, and develop embodiment, usability, product interaction and looks that fit the new context and its users, while keeping the retail price below 2000 euros.

The commercial Plastic scanner version would help fund the open-source version to further improve the scanner and make it even more accessible to the informal recyclers.

Figure 4: Meeting with our client Jerry

2.4 Context analysis

More than 50 companies with a diverse portfolio of activities have expressed their interests to buy this Plastic scanner. An affordable plastic scanner could be used by many target groups, but to make our product analysis and design development more effective, focus needs to be narrowed down to a more specific user group and meet their requirements.

Interested companies were mapped and grouped together according to their industry and field of work, see Figure 5. A more detailed version can be found in Appendix A. From these clusters, main categories emerge, which are: recycling companies, ocean plastics collection and/or recycling, data analytics, plastic production, consumer goods, education, social and community focused NGO's, design studios.

Preliminary requirements were discussed and showed significant overlap between the different clusters. Therefore, the initial thought is that even while the Plastic Scanner will be designed for a specific target group, other groups will benefit from the use of the scanner as well. When looking at the map (Figure 5, detailed in Appendix A), the most interesting clusters seemed to be small to medium scale recycling companies and ocean plastic collectors and recyclers. Both clusters demonstrate significant overlap in initial requirements: durability to work in harsh environments, possibility to collect and retrieve scanning data, results should be gained easily and quickly. Both clusters seem to have the largest number of interested companies and both groups work directly with plastic recycling. After presenting the map to our client and discussing the initial requirements, an aligned target group choice was formed that covers both groups: recycling and ocean plastic companies.

Figure 5: Stakeholder map - for context analysis

2.5 User Insights

In the beginning the design process we conducted interviews with employees from the PVC recycling company BessTrade and the Ocean Clean-Up.

BessTrade

Figure 6: Company visit Besstrade - in the factory

The first company to interview was BessTrade, which is a medium-sized recycling company focusing on post-industrial PVC (BessTrade, n.d.). PVC waste is sourced from clients in large batches. At their facility the waste is identified, sorted, shredded, and remanufactured into pellets or powder for production of PVC parts depending on customer requirements. Context analysis was retrieved by interviewing the company's managers and collecting insights during the visit to recycling the facility.

Figure 7: Overview factory Besstrade

Figure 8: Company visit Besstrade - manager holding 'the Gun'.jpg

Main insights collected:

- Large factory area is divided into specific stages for each of the stages of the plastic recycling process. The plastic sorting process also has a specific area in the facility.
- The work environment is loud, mainly due to the shredding process and other operating machines. Workers wear protective headsets to block this loud noise.
- All workers wear rubber working gloves to protect their hands from sharp or contaminated waste parts.

Figure 9: Medical waste made form PVC

Main challenges(Figure 11):

- Main plastic type they work with is PVC. However, waste streams are often mixed with parts made from other plastics, especially medical equipment (Figure 9).
- Many incoming PVC waste parts have overlapping and mixed plastics. Layers (or thin films) are hard to differentiate and usually impossible to separate.
- Training new workers often take time until they can easily separate the plastics and determine whether they can be added into the recycling stream.
- When workers cannot differentiate between the types, it can increase the recycling time and can threaten the quality.

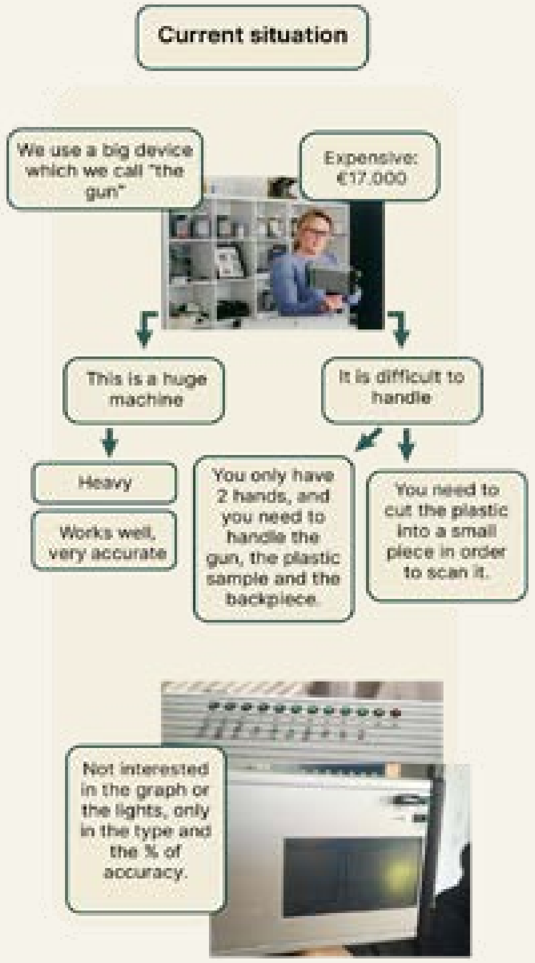


Figure 11: Insights Besstrade

Figure 10: Recycling worker Besstrade.jpg

Two use cases of our plastic scanner were discussed.

The managers: to enable them to scan the plastic types when analysing the waste batches or during meeting with clients for quick scanning.

The recycling workers: in the sorting area, so that they are able to scan plastic parts when uncertainty occurs around waste samples.

Collected insights are translated into the desired situation (Figure 12).

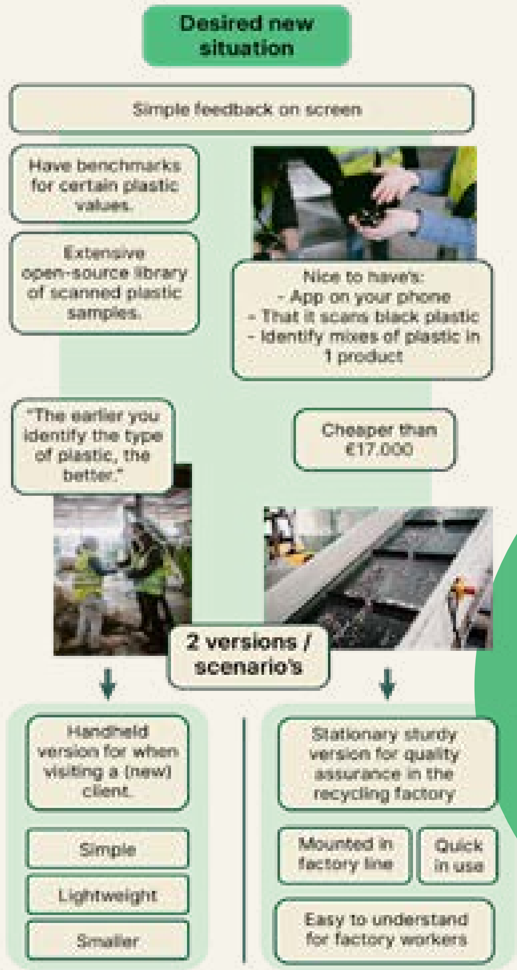


Figure 12: Desired situation for Besstrade

The Ocean Clean-up

(the interceptor group) Interceptor is a boat that is installed in rivers to catch flowing plastics and prevent them from entering the ocean (Figure 13) (The Ocean Cleanup, n.d.). Currently, 8 Interceptors operate in several countries (Dominican Republic, Jamaica, Vietnam, and Malaysia). The Ocean Clean-up organization sets up the equipment and have the know-how for each location and outsources waste handling and daily operations to local operators.


Figure 13: The interceptor - Ocean Clean-up.png

Main insights

- The current work process can be depicted: Extraction → offloading → sampling (one container once per month - manual sampling) → transport to end destinations (waste to energy, landfill).
- Manual sampling happens on the shore with usually 8 people working at sorting the waste. Electricity is often not accessible, but some facilities have near energy sources.
- The waste is wet and can be degraded
- The company wants to know the resin type, but due to lower-skill workers and worker rotations every 2 weeks, teaching them to differentiate plastics would not be a viable option.
- The Ocean Clean-up collects data about the waste types in each location to look for local recycling


Figure 14: The Interceptor's containers filled with collected river garbage (Ocean Cleanup, n.d.) .png

opportunities and get insights on the origin of the plastic waste.

Main challenges:

- Manual sampling of the container is labour intensive and slow due to waste being mixed with biomass, fishing nets and other materials (Figure 14)
- The waste streams are very differentiated among the rivers. Hard to distinguish which types of plastics are more common in which rivers. Harder to draw conclusions – harder to take actions for local recycling niches.

Insights about prospective Plastic Scanner use in The Ocean Clean-up:

- A supplementary tool for the workers sorting the container on the river shore. Help in differentiating the main plastic types as well as drastically speed up the sampling process.
- Collecting the more in-depth scanning data and using these datasets for each location to help allocate the opportunities for niche recyclers in the areas the Interceptors are operating.
- One worker would scan all the unknown plastics that are collected from the container, while others work on sampling the known plastic types.

This use case for the Plastic Scanner comes with requirements:

- Durability: the device needs to be dust-proof and waterproof to be able to function in this harsh environment close to the water.
- The device should be able to scan degraded and tainted plastic pieces because cleaning the plastic pieces before the scan would slow the process down and cause additional problems.
- Usability: the scanner needs to be an entry product due to employee rotation.

Data recording and collection for analysis would also be a requirement for the Plastic Scanner in this use case. Data recording and collection for analysis would also be a requirement for the Plastic Scanner in this use case.

Combining both target groups

Both contexts (Figure 15) can be classified as harsh environments for electronics devices to work in, therefore, our Plastic scanner should be designed to be protective and durable. To satisfy the needs of the Ocean Plastic company, the device should be waterproof as well.

Secondly, both contexts require easy and quick scanning results to ensure effective work, because the scanner will mainly be used by workers who are sorting the plastic pieces; only the essential information as which plastic type is needed. Both target groups need access to the plastic scan library to ensure quality scanning results. In addition, Ocean Clean-up also needs to collect the data to be used in their analysis.

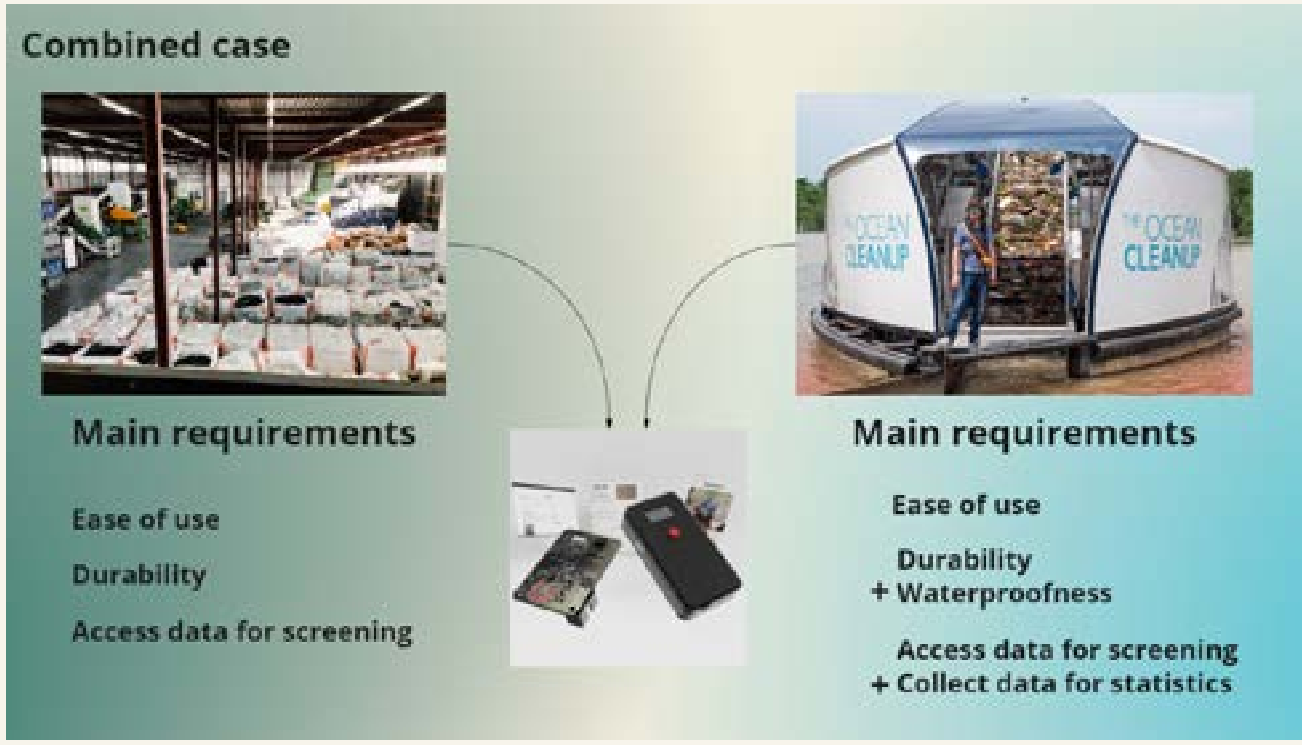


Figure 15: Combined requirements form both target groups

2.6 Current Market Solutions

The current market for handheld plastic scanners is three different devices as seen in Figure 16. Mainly, The miRoGun 4.0 and the microPHAZIR are highly sophisticated full spectrum infrared sensors with prices starting at €14.500 ex.vat., which is hard to afford for small to mid –sized businesses. Some handheld devices are designed to be used in harsher environments, with a rugged and waterproof casing, while others cannot be classified as a fitting device for factory or near-water working environments.

Most of the Near infrared plastic scanners can scan transparent plastic and all mainstream plastic types but cannot scan black plastics due to the limitations of the NIR reflection scanning method (Masoumi et al., 2012). The continuous full spectrum method is significantly more precise but requires an expensive MEMS sensor which results in a high price. The Plastic Scanner will fulfil a different market need: an affordable scanning via discrete measurements (<€2000) with the focus to help differentiate between the 5 most common and recyclable plastic types, but with lower accuracy.

Figure 16: Competitor comparison

2.7 Project Requirements

From the insights on context and potential users, the initial requirements are formulated as follows:

- Being able to store up to 2 MB of scanning data.
- Results retrieved within 2 seconds when pushing the scanning button.
- Information should be presented and retrieved: scanned plastic type, previous scans.
- Durability: product should survive multiple drops from 1m.
- Being able to adjust the results (load specific profiles).
- Controlling the measurement settings, such as the result colour on the screen.
- Have a rating of IP66.
- Having a possibility to upgrade and improve the scanning.
- Being able to scan dirty and degraded plastics .
- Have a comfortable and lightweight shape that is easy to carry.

For more detailed requirements see Appendix B.

PE

2.8 Project Goal

Goals

From context and user research the main challenges for our project are framed:

- How to design a precise, durable, and waterproof tool while maintaining it at low-cost?
- How to balance between product looking aesthetically pleasing and convey the message of robustness?
- How to design a handheld scanner for the environment with multiple users where it could also get lost?

Our design should be designed to satisfy these tensions (Figure 17).

Our vision

“To give enable Reliable and simple scanning of polymers, that gives the user precise, simple and actionable information in an effective, fast and easily understandable way to make a positive impact on the company and the world through collaboration.”

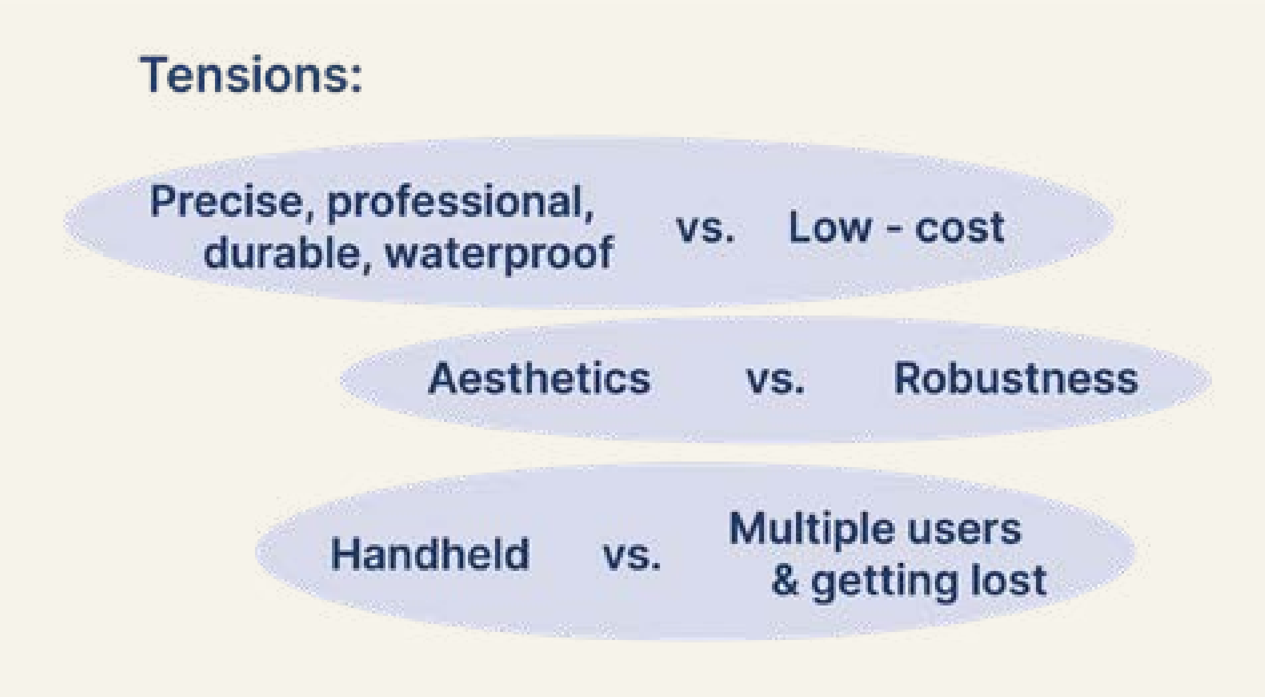


Figure 17: Project Tradeoffs

3. Midterm results

3.1 Concept proposal

The image below shows the presented design at the midterm. This design was mostly chosen and developed because of its high adaptability to the context and simplistic shape. The product can be attached to a wall attachment, and the product is handheld. The scanner can be used by recycling workers as well as factory managers or lab employees (see Figure 23).

The scanning element is placed on the bottom, and the screen is placed on the top. In order to scan transparent plastic, another rubber ring can be switched at the bottom. This rubber ring has a gap at the side, where a plastic sample can be clamped in between. When pressing on to the sample, this results in an (almost completely) closed-off environment for scanning (see Figure 23). Figure 22 shows all the components and how they fit into the concept.

Overall, the design received good feedback during the presentation moment. However, there were still some points of concern regarding the design, the target user group, the contexts of usage and our process. The main feedback points from the coach and experts as well as our own evaluation are elaborated in the next subchapter.

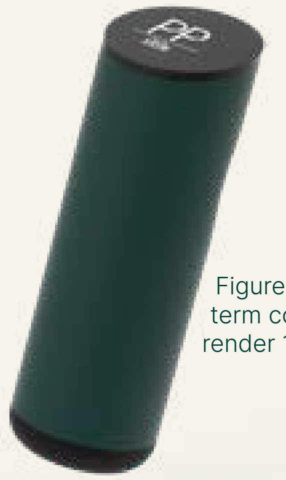


Figure 18: Midterm concept render 1

Figure 19: Midterm concept render 2

Figure 21: Midterm concept render 4

Figure 20: Midterm concept render 3

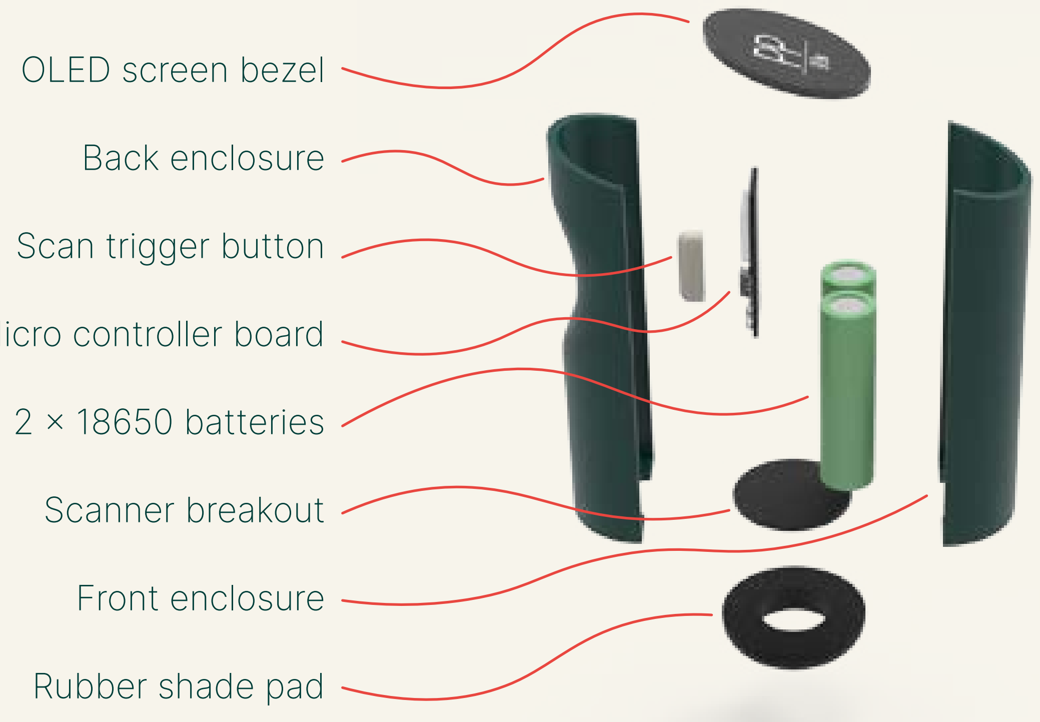


Figure 22: Exploded view of Q3 concept

Figure 23: Light Blocking concepts

3.2 Feedback & Evaluation

Feedback from experts & coach

Too many target groups and contexts of usage.

Design-4-all does not work, it would be better to choose one target group and define the usage context better.

Take-away: Redefine our target group, a persona and user journey has been made but not included in the midterm presentation. The persona and user journey should be revised and shown, to better visualize who the product is intended for and how it will be used.

Design Process and choices of the report are not clear

Guide the reader more through the process; show what the design opportunities were and which design decisions you made.

Take-away: Use a new structure to document our design process and the design decisions along the way, called 'Work Packages'. Show more visuals documenting the process.

Too high ambitions for a short project

We need to plan more realistic and prioritize our work.

Take-away: Re-iterate on our planning, keep evaluating and scope down later if needed.

Self evaluation

An overview of the product missed

We missed an overview of the product, that showed which parts are the product and which parts needed to be reconsidered and redesigned. So, this was one of the steps done at the start of Q4. With help of this overview, a planning was created for the work packages.

4. Challenges

4.1 Group challenges of Quarter 3

Covid & other sickness

During our project, several of us contracted covid, causing them to be sick for one or two weeks. Next to that, the course was very intensive which at times took its toll on a few of us, causing some to become ill several times during the project. This sickness resulted in additional pressure on the remaining students because the course has a tight schedule not allowing for many sicknesses. Additionally, we are with one person less and we also noticed the load off that when delivering the work.

MISSING FIGURE NUMBER

Making decisions & trusting each other

There were always a lot of discussions about every aspect where decisions had to be taken. Many times, these discussions were essential, because the concept direction was not clear, and we want everyone to be in line with the decision. However, in some cases, discussions took too long. Decisions are scary because not only do you choose what to bring to the next step of the design process, but also what to leave behind in that stage. Letting go of those possibilities affected us throughout this course. We wanted to keep all the possibilities open, being afraid of going in the wrong direction with our design, this made our design process slow due to indecision making. But, at the end of this quarter, when the deadlines were approaching, we were more actionable towards where to go and what to do. As a newly formed team, we still needed to learn to trust others' capabilities and let go of some parts of the process for more effective development of the design.

Figure 24: Prototyping in clay

Planning – balancing expertise areas with project work (PED)

In this past study quarter, a lot of focus from the course was directed on the expertise areas. There was almost every week a deadline for one of these expertise areas. At a certain moment, also due to the sickness of teammates, we stopped planning, and it felt like we were just running from deadline to deadline. A lot of the project work needed to be squeezed into the schedule somehow or was delayed because of all the deadlines. In the end, this led to us having a very stressful last couple of weeks when we still needed to complete a lot of PED work and integrate the expertise areas into one concept design. A big challenge for us is to balance the PED work more with the other expertise areas and keep up with the planning. Another factor which made this extra challenging was the unclarity of the course, and the unclarity of the expertise areas. A lot of time was spent figuring out what needed to be done and handed in (and when).

Communication & working together in covid times

In these covid times, hybrid working is getting more and more normal, however, when working with a team this also brings challenges. We partly worked on campus together (on Mondays and a few other days), next to that we worked a lot online or hybrid (when not all of us were able to come to campus). Especially working hybrid brought its challenges in working together efficiently and finding a good (low stimulus) environment that is adequate for this hybrid working posed a big challenge as well. Next to communicating in person, all our communication was done via WhatsApp (later signal), via these platform's communication was slow and unclear at times.

4.2 Concept challenges for Q4

In the last weeks, we have analysed the design brief, the market, and the new target group, and we have made an initial concept design for the Plastic Scanner 2.0 (see the subchapter before). This concept will be the starting point of our design process in Q4. However, many aspects still need to be further developed. The main aspects that need development (connected to each expertise area) are mentioned below.

Main challenges

Optimize the comfortable shape
- Optimal ergonomic comfort
- Fast and easy scanning in different scenario's (factory worker, ocean clean-up sorter, factory manager/ researcher etc.)
-

Optimizing the usability for fast and easy scanning on different scenario's

- The type of button/ exact button placement
- Implementing bimodal feedback (eg. light/vibration/sound)
- Size of screen
- Information on screen

Optimize the look & feel of product

- The product should look & feel professional, reliable and sturdy.

Develop the data storage and sharing
- Hardware
- Human Machine Interface
- Optimize machine learning model
- Mockup of software

Optimizing durability/ end-of-life
- Waterproof
- Dustproof
- Drop proof
- Design for sustainable end-of- life

Optimize scanning environments to improve accuracy of scanning
- Blocking out environmental light as much as possible
- Allow for accurate scanning of differently sized and shaped plastic objects

Design for optimal accurate scanning of transparent plastic
- Optimize the reflective back-piece for behind transparent plastic to reflect the IR light
- Block out environmental light as much as possible

Out of scope

We chose not to tackle the components on the breakout board and Scanning of black plastics (you need a different technology for this), because of the limited time and resources of the project.

4.3 Group Challenges of Q4

During quarter 4 we had a lot of similar challenges as in quarter 3, there still was a lot of pressure given by the course, some sickness, unclarity on deadlines, a high workload from the expertise areas and some miscommunication. We tried to control this better with more group agreements, friendly reminders, a better structure in our team meetings and clearer communication.

Struggles with 3D printing

During this quarter, we received a 3D printer to print our prototypes at home, due to the faculty printers being overbooked. This helped us a lot by being able to prototype relatively fast and without any limits. However, we still had some struggles in finding the right orientation to print the prototypes with, having the right tolerances and preventing the model from sticking to the bed. After some trial and error, many of these challenges were overcome. However, it did cause delays in our planning. This led to us including mistakes and re-iterations in the planning of prototyping.

Delayed Product parts

In the second quarter, we made many prototypes by 3D printing, as well as iterations of the electronic components. We ordered printing filament, 2 PCBs, 5 screens, multiple batteries in different sizes, different microcontrollers and many more parts. Many parts were delivered later than expected, delivered at another address or only partly delivered. The filament and the first PCB were delivered later than expected and that caused some delays in our planning, therefore for the second PCB we took the long delivery into account. And due to the fast pace of the course, there was not a lot of space for any delays.

Planning & expectation

As similar as quarter 3, in quarter 4 a lot of time was also spent on the expertise areas which took many hours away from the group (PED) work. For the expertise areas we needed to write many papers and the ambition of reaching TRL 8 was too hard. Next to that, there were many social activities after covid lockdown again which can be overwhelming and hard to combine with such a big course. However, PED was prioritised more, and the work was divided more efficiently than in the third quarter. Lastly, we had very different expectations and goals from the course than what we reached at the end. It would have been better to know what to expect from the course at the start.

ADD NEW LINKED FIGURES.

5. Design Process

5.1 Design Approach

Over the course of this project, we have worked with several design approaches, see Figure 20. More information on our design process before the midterm can be found in Appendix E. The process went in the following way:

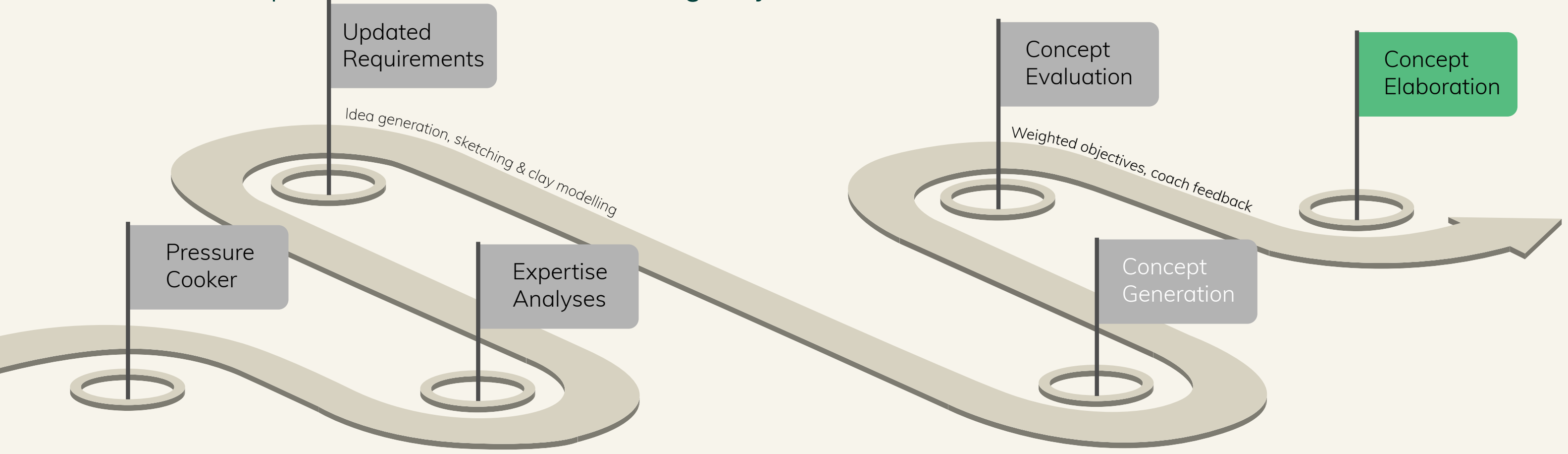


Figure 25: Roadmap of design approaches till midterm

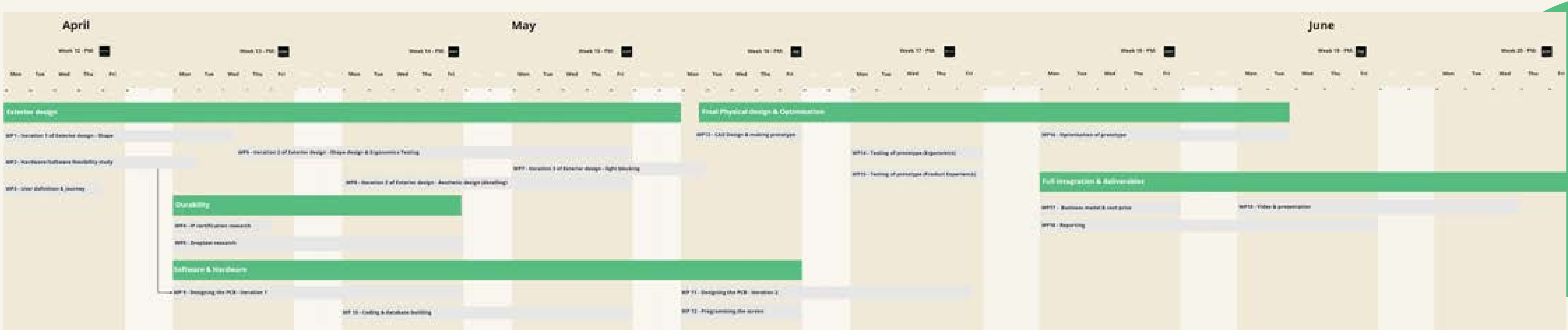
- First focus was mostly on exploring the fuzzy front end of the assignment. After the first conversation with our client, we defined our first product requirements.
- We kicked off with a pressure cooker (design iteration 1 in Figure 21) where a design sprint for the project was done in one day.
- We did context research for the project and the expertise areas, which led to updated requirements.
- We started brainstorming more and concept generation was done (design iteration 2 in Figure 21).
- The four concepts that were generated were evaluated.
- A concept evaluation and elaboration (design iteration 3 in Figure 21) were executed.

At the beginning of the second quarter, we reflected on our process and decided to continue the project by doing more design sprints. However, it was now time to delve into details and document our process better. From this, we decided to work with 'Work Packages', for each design iteration and topic. One or two members oversaw a work package depending on how big the tasks were in it. Each work package was chosen to cover a certain expertise area or design iteration. An overview of all the work packages and the planning can be seen in Figure 21. The work packages covered in fixed order the following:

- The challenges
- Solutions
- Results
- Next steps

During our stand-up meetings at the start of each working day we updated each other on the progress and the conclusions, for more details we could reach each other's work package. Next to that, we had an alternating project manager each week who would state the agenda and lead the group meetings to be as efficient as possible. This way of working helped us to create progress in a short matter of time.

Figure 26: Planning Workpackages



5.2 Design Process

PE

As input for our design process, we redefined our persona and the use case scenario, this persona and our vision led to the design of two mood boards which will be shown in this chapter.

Persona and use case scenario

The persona his key goals, needs, frustrations and skills are shown in Figure 22. We choose the context of a recycling worker at a recycling company because we assume the scanner is used most often in this context. And after a second interview with the Ocean Clean-up, we concluded that both our target users and target contexts were more similar than initially thought. After the context research, we have made a journey map, which shows the current and envisioned journey, shown in Appendix C .

Figure 27: Persona

PE

Sturdy:
Rugged & reliable
• Octagonal shape features
• Or non 90 degree
• Deep textures
• Multi-material
• Exposed fastening hardware
• Bulkier than needed
•Mostly black (with one accent colour)

Figure 29: Moodboard Sturdy

Mood boards

After defining our persona, several mood boards were made while considering the preference of the persona and additional insights. The mood boards cover essential characteristics that should be integrated: Professionality and Sturdyness (see Figure 24 and Figure 23). From these mood boards, we found that smooth lines, rubber parts and simple shapes are mostly used in professional and sturdy products. And in our design iterations, we sought to incorporate these elements.

Figure 28: Moodboard Proffesional.png

Proffesional:
Modern & attractive
- Simple geometric shapes
- Soft shape transitions
- Pastel colours, monotone white/black/silver/chrome
- Smooth or subtle textures

In Figure 25 the overview of our complete design process is presented. To reach to our result, we had a total of 9 design iteration rounds and 4 test moments. These iterations and test moments will be elaborated further on in the next subchapter of design opportunities.

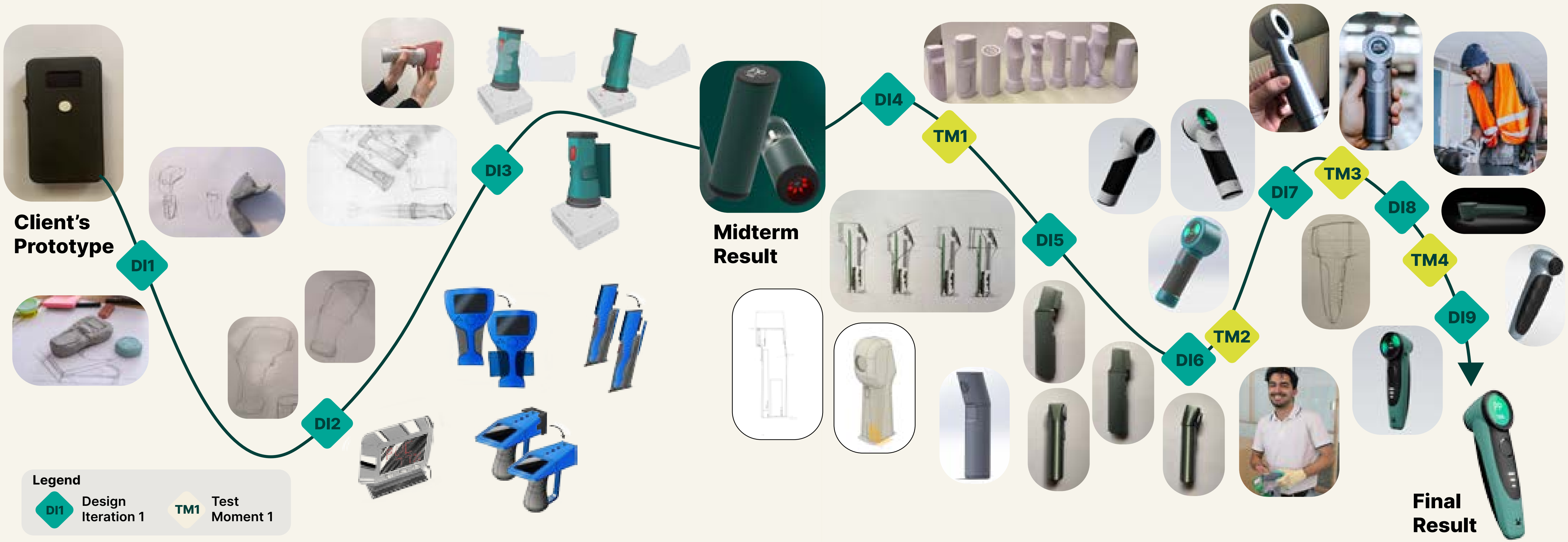


Figure 30: Design process overview Q3+Q4

5.3 Design Iterations

In this chapter a further elaboration is given on the different design iterations and test moments in Q4 and how they contributed to our final design. From each iteration, the challenges & opportunities are defined. Next, the different design alternatives and the chosen design are presented. Lastly, a conclusion and/or further steps are set forth.

Design Iteration 4 & Test moment 1

Why
In this iteration, the challenge was of making a more intriguing and ergonomically comfortable design.

Design options
A total of 9 foam models were made, see Figure 26.

Design Choice
After doing test on all the 9 models with our own group we discovered that the scanning orientation is not as comfortable as we thought around the midterm. That is why we decided to test with 2 simple models (models 1 and 3) which scanning orientation (forward or downwards) was more comfortable. From the test it was apparent that scanning forward (model 1) was more comfortable (4 out of 6 participants). For more information on all the test results see appendix G.

Next steps
After this we decided to start a new design iteration on a comfortable ergonomic and professional shape focusing on scanning forwards.

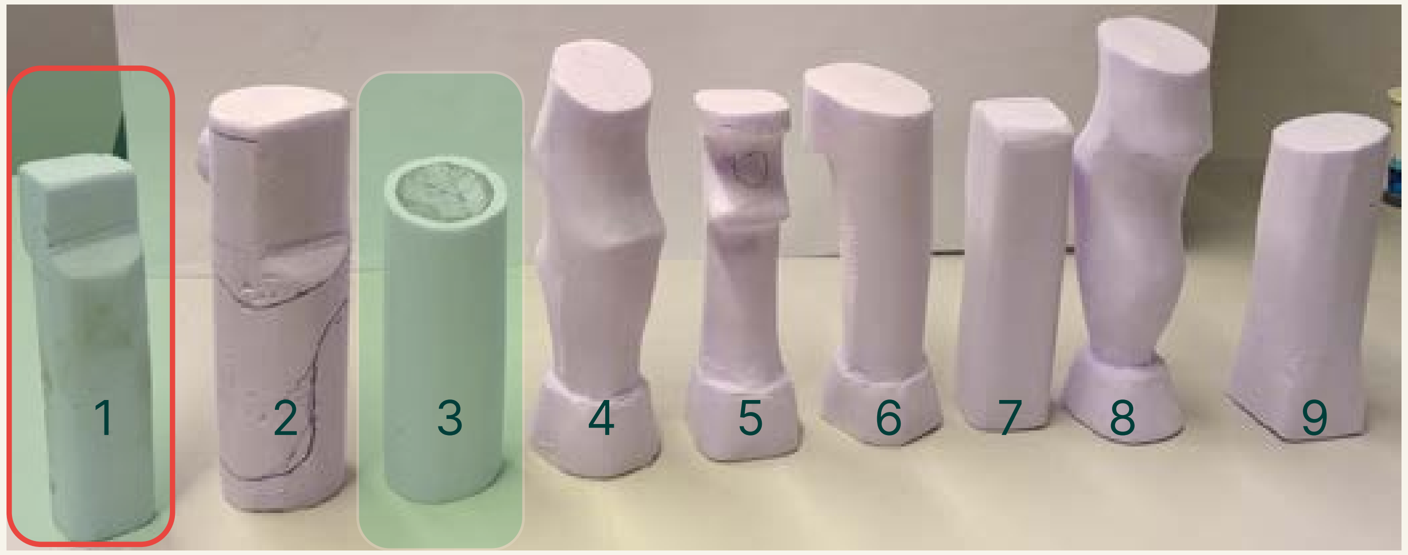


Figure 31: Foammodels

Design Iteration Round 5

Why
Because of the decision to go for a different scanning orientation (forward instead of downwards) we needed to design a new shape. For this iteration, we decided to pay more attention to the functional aspects of the design, see Figure 27. This meant stating where the parts will be placed while incorporating the necessary aspects of ergonomics, aesthetics and electronics. Therefore, we sketched on top of the functional design that was already generated and aimed to visually integrate professional and robust aesthetic elements.

Design options
The functional design was first based on the optimum shape for the PCB and after listing all the ergonomic requirements we found that we needed the PCB width to be smaller to create an optimum handle width (43 mm). After looking at possibilities we saw that there was more space in the height of the design and that the PCB could be made longer in height in order to fit the optimum handle.Additionally, there was some freedom to elongate the handle and top.


Figure 32: Functional Design & electronics overview

We made many sketches for this iteration and a few CAD models (Figure 28 more can be seen in Appendix H) . Some models have a square handle, some have a round handle, and some have an oval shape that is partly round and partly straight (in order to optimize scanning and holding).

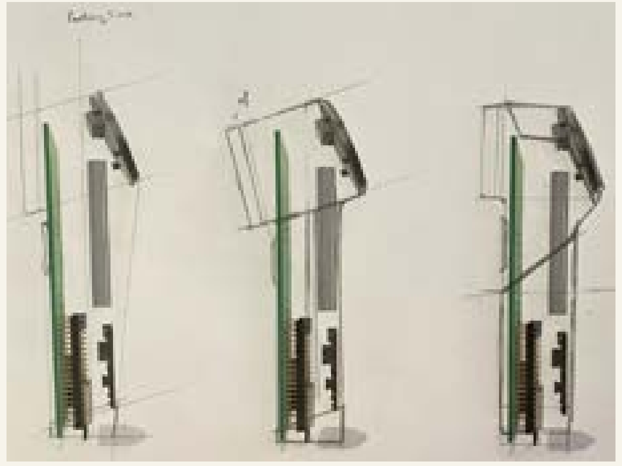


Figure 33: Sketches Design Iteration

Design decision
We discovered that aesthetically and ergonomically it potentially could be optimal to have an angle on the screen when scanning. Next to that, we were unsure which handle shape would be most ergonomically comfortable and stable. Therefore, we chose to make 4 simple models based on these sketches;

- model 1: with cylindrical handle with a 0-degree angle
- model 2: with cylindrical handle with a 10-degree angle,
- model 3: oval handle with a 0-degree angle,
- model 4: oval handle 10-degree angle (see Figures next to Figure 30).

Next steps
The next step is to test the 4 models with various users and find out which scanning/reading orientation and which handle shape is perceived as the most comfortable and stable.

Design Iteration Round 6 & Test Moment 2

Why
For this iteration, the goal is to find the optimal comfortable and stable handle shape for the plastic scanner. From previous scientific research as well as our own finding in test moment 1 (see appendix I), it is found that rounded shapes are more comfortable to hold than square shapes (Scarlett R. Herring et. al, 2007) (K. Hokari et. al, 2019). Additionally, it is found that having an angled screen with the top angled away from you can be more comfortable to read as well as minimize glare (Ankrum et al, 1995). Additionally, it is hypothesized that it looks visually pleasing and feels more stable if the scanning part of the product is angled the same as the screen.

Research question:
Which model is perceived the most comfortable and stable to hold and scan objects with?

Design Options
A total of 7 participants (6 male & 1 female, aged between 20-30, 1 left-handed, 1 ambidextrous, 5 right-handed) were asked to hold 5 different models (Figure 29-Figure 33) and act out the task of scanning an object; hold the scanning part up to a plastic sample, press against it so all light is blocked out, act as if you press the button once and look at the 'screen' (Figure 34). They were asked to rate the models on a scale from 0-10 on comfort and stability.


Figure 39: A participant acting out the task of scanning with one of the models

Design choice & conclusion
The result shows that model 2 has the The result shows that model 2 has the highest mean on the aspect of comfort with a 7,14 (SD of 1,21) and model 4 has the highest mean for stability with an 8.29 (SD of 0,76). However, when looking at the median, model 2 scores the highest on stability with a 9. The most preferred model is model 2 (3 participants) after that model 4 is preferred the most (2 participants) (more information can be seen in appendix I).


Figure 34: Model 1 - Jerry's Prototype


Figure 35: Model 2 - Cylindrical handle 0 degrees angle


Figure 36: Model 3 - Cylindrycal handle 10 degrees angle


Figure 37: Model 4 - Oval handle 0 degrees handle


Figure 38: Model 5 - Oval handle 10 degrees angle

Looking at the findings, we decided to design a handle shape which is a combination of a cylinder and an oval, as the results are very close together. Additionally, it was found that the button on the front (facing towards the user) is more comfortable and with that, a flatter surface on the front would work better. Next to that, the scanner will not have an angle in its design as this is the most comfortable to look at and scan with.

Design Iteration Round 7 & Test Moment 3

Why
In this iteration round, we further developed the aesthetic appearance of the model as well as integrated all the findings from the previous ergonomics test. For this iteration, we focused more on the screens and aimed to test the usability of the overall design for our intended target group.

Design options screens
First various screen styles, animation ideas and ways of communicating information were created while trying to present only the essential information, see Figure 35 .

This consisted of:

- Round and square screens
- Color contouring (to mimic a LED ring that lights up color for quick information processing)
- Animations
- Styles

Various principles stated by Adobe (Adobe & Babich, 2020) for designing the UI of smartwatches were followed when creating the screen designs for the plastic scanner. They covered:

- glanceability
- functionality
- responsiveness
- typography
- colors
- animation

The main purpose of these principles is to make the interaction comfortable and provide fast interactions of users care most about. Additionally, typography has been chosen to be Roboto Condensed as that is being used by Android smartwatches for its readability. The font size on the screen should be as big as possible with a minimum


Figure 40: first iteration; different screen designs for the plastic scanner

PE

of 4 mm and enough spacing in between lines as found during ergonomic research of the paper of Dobres et al. (2018).

Design Options Exterior Design

For the physical design of the exterior, two iterations were made (see Figure 36 and Figure 17). This shows the evolution that goes from a functional ergonomic design to a more aesthetic professional and sturdy-looking design.

Design Choice & Test results
The final prototype to test with, of whcih we made several iterations based on a simplistic version of the design, is shown in Figure 38. Next simplistic screens with a few animations were programmed, because this was determined to fit the context best (these animations are elaborated on in chapter 5.5). From the first screen drafts, it was chosen to continue with a round screen as that fits the aesthetic of the product most while it was found too sometimes be more unusual. This is because users are more used to square screens. However, people are getting more used to round screens because of screens on smartwatches and products like the Google Thermostat.

Conclusion
The results from this iteration and the test led us to make an even more optimised exterior and a more optimized screen interaction. More conclusions can be found in the next chapter on the prototype. The insights from these iterations together with input from design iteration 8 & test moment 4 led to a final design which is further developed in design iteration 9. For more information on the test that was done with the prototype, see the next subchapter 4.4 or see appendix I and F.


Figure 41: Design iteration exterior first draft


Figure 42: Design iteration exterior first draft

Design Iteration Round 8 & Test Moment 4

Why
For this iteration, we tested two different versions with a qualitative and quantitative test to derive which version fulfils the design vision the most. To test which design looks the most reliable, both in sense of being physically durable and in presenting reliable results to the user. More information about this design iteration and test moment can be found in the next Chapter 6, (Final Design, the part on the Shape and the Digital Design).

Design Options Exterior
We designed another version that is more detailed than the simple straightforward design and therefore has a different appearance while still integrating aspects as smooth lines and rubber details. Both design iterations are shown in Figure Figure 39.


Figure 43: Concept A & B

Figure 44: 2 chosen screen styles as possible directions for the product

Design Options Screens
Based on several iterations, the following 2 screen styles are created as they show two very different styles, see Figure 40.

Figure 45: Final prototype for testing

Design Iteration Round 9

In this final iteration round, final changes are made to the screens, exterior as well as interior. More information on the final design can be found in the next Chapter, Final Design.

Last design changes
The following changes have been implemented into the final screens (Figure 41):

- Bigger font for readability.
- Color coding for 2 situations that sorting workers face.
- Accuracy levels of scanned samples are removed.

For the exterior design final changes were implemented:

- The handle pattern was changed to a small pattern (based on the results of test moment 4)
- Multiple colors were added

For the interior design many elements were added as can be seen in (supportive ribs, screw holes and ladder edge) Figure 42:

Conclusion
After these last changes, the design was frozen for the report and the presentation. From this point on a reflection is done on what can be further improved regarding the product. These insights and recommendations are mentioned in Chapter 7, Client Material.

Figure 47: Last Design Iteration

Figure 46: Final screens

5.4 Prototyping

PE

ADE

Goal of test

To improve the usability of the plastic scanner, we made a prototype that was tested with several Besstrade employees (PVC recycling company). The main aim was to test the usability of the physical and cognitive ergonomics of the prototype (the shape and the interaction with the screen and button).

The main research question was:

- How do recycling employees perceive the handling of the plastic scanner in terms of usability and comfortability?

Sub research questions are;

- How is the comfortability and stability of the scanner perceived and how can it be improved?
- Do the users understand how to use the plastic scanner and the results that are presented and how can this usability be improved?

Secondly, some attention was put towards the aesthetics of the prototype and the two available screen versions. The aim was to see if users perceived the prototype as professional and robust, and how this could be improved.

Figure 48: Design of prototype

The prototype & production

For this test, a prototype was designed by means of 3D printing and with the use of an ESP32 board, that required programming beforehand. The prototype is based on a render that envisioned the aesthetic appearance of the product (Figure 43). An overview of the prototype can be seen in Figure 44. For this prototype, the rubber handle as seen in Figure 43, is 3D printed from the same materials as that was only available at that moment

Figure 49: Overview of prototype and the different screens

Method

With the use of a qualitative interview, we interviewed 4 employees of Besstrade for around 15 to 20 minutes per person (see Figure 45). After some instructions, they were first asked to hold the prototype and give their first impressions. Then they were asked questions about comfortability and stability. Secondly, they were asked to pretend that they are scanning an object, press the button and look at the screen (see Figure 46). Then they needed to answer questions and express their opinions about the scanning process. Lastly, they were asked some questions about the aesthetics of the products and the interview was wrapped up with questions about the participants themselves. More information on the test setup can be found in Appendix J. One interviewer asked questions and made some notes. The other interviewer was responsible for making sure the electronics worked, making pictures and videos and making observations.

Figure 50: Picture of interview

PE

Main insights

Overall, the participants liked the scanner a lot, it was perceived as comfortable, lightweight, stable and simple. One of the main comments mentioned was that the grip should be a bit smaller, and there could be some more space for the fingers. Next to that, it was not clear to many employees that they should only press the button once and it was not clear when the scanning was ready. Additionally, the text was too small, and the font was not readable enough for them. On a different note, many employees thought that the number underneath PVC presented how much of the product was made of PVC and not the accuracy of the scanning. Many employees were also not interested that much in the accuracy. Lastly, on the part of aesthetics, many thought it looked professional and robust because it was simple and big. However, it was perceived to be better if more rubber (around the screen) was added and/or if some metal was added. More information on the test results can be seen in Appendix X.

Figure 51: Instruction during interview

"It feels very lightweight and stable in the hand."

"I would like a cord in order to not loose it. "

"I can not read what is on the screen"

"I am waiting for it to be done scanning"

Quotes form Besstrade employees(2022)

Discussion

From this test, we have learned to make the grip smaller for increased comfort and to improve the readability and clarity of the results on the screens. We noticed that the level of understanding from the recycling workers is low and that some participants even have reading glasses which they do not use while working (see Figure 47). Therefore, we have decided to give the result screen a colored background, for quick identification. Hereby it is not necessary to read the text when they understand the meaning of the color. Next to that we increased the size of the text and changed the font. Additionally, we added the word 'result' on the screen design to clearly show the device finished scanning and took away the accuracy number. We propose to only include the accuracy in the app as this is more interesting for managers than for factory employees. Lastly, we did a design iteration in which more rubber was added to the design. All the changes are incorporated in the final design chapter, see this chapter for more details.

Overall, the results of the test are valid, and we received many helpful insights as input for the final design phase. However, in this prototype, the weight distribution is not completely the same as for the actual design and the feeling of the material of the enclosure (PP and rubber) is quite different. These aspects influence the perceived comfort and stability of the device. Also, the scanning process will be experienced differently if the device would scan the material and give an accurate result.

Recommendations

To improve the clarity that the scanner is done scanning it could be clearer to add one or two short vibrations at the end of scanning when the result is shown. However, this should be tested with participants in the factory environment wearing gloves. Lastly, a final test should be done with a more accurate weight distribution, similar materials as well as working electronics to scan the materials.

After this prototype test more iterations were done (Design Iteration 8 & 9) and a final prototype was created to present to the client at the final presentation, this version will have a different color as well as rubber elements.

Figure 52: Recycling worker without his reading glasses

6. Final design

6.1 Shape design

PE

Throughout the design process, the product shape has evolved to embody important aesthetical, ergonomic, and technological features incorporated along the way. In this section we focus on the final user tests and design choices made to make the final prototype. Firstly, the insights and choices from aesthetical and product meaning perspective will be presented, then ergonomics insights and choices will be discussed. The chapter is concluded with the main recommendations to improve the shape even further.

Most important findings in shape design

- Concept B is perceived as new er version of the design and more professional.
- Elements such as sharper lines and more rubber from Concept A can be added to concept B to improve the perception of sturdiness.
- Forward scanning direction was chosen.
- A round handle with different curves on the front and back as well as on the length was designed to optimise for comfortability (for different hand shapes).
- The rubber ring sticking out at the back and rubber elements on the handle increase the stability.

Aesthetics

Product shape communicates numerous important product features and impacts the way the scanner is perceived. For this use context, the plastic scanner should look reliable, both in sense of being physically durable and in presenting reliable results to the user. These aspects come down to the product looking aesthetically pleasing, reliable, professional, and sturdy.

Design Options

The two main options (Figure 48) were chosen as final design concepts to be evaluated.

To evaluate the different features, two types of user tests have been conducted. First to compare aesthetical appearance, by use of an online questionnaire with questions from the UVA model. Second to compare what features each design is associated with, by use of a guided interview with evaluation sheets and the most important keywords for the envisioned product experience mentioned. For a more detailed evaluation description, refer to PE research report in Appendix F.

From the questionnaire (20 participants from diverse backgrounds), it was noticed that the Concept B scored higher on most aspects: it was more aesthetically pleasing, had a better balance between unity and variety and was chosen as the preferred concept overall (Figure 49).

From the product meaning comparison interviews (9 people, diverse backgrounds), product associations have

Figure 53: The comparison between two design concepts A(Right) and B (left).

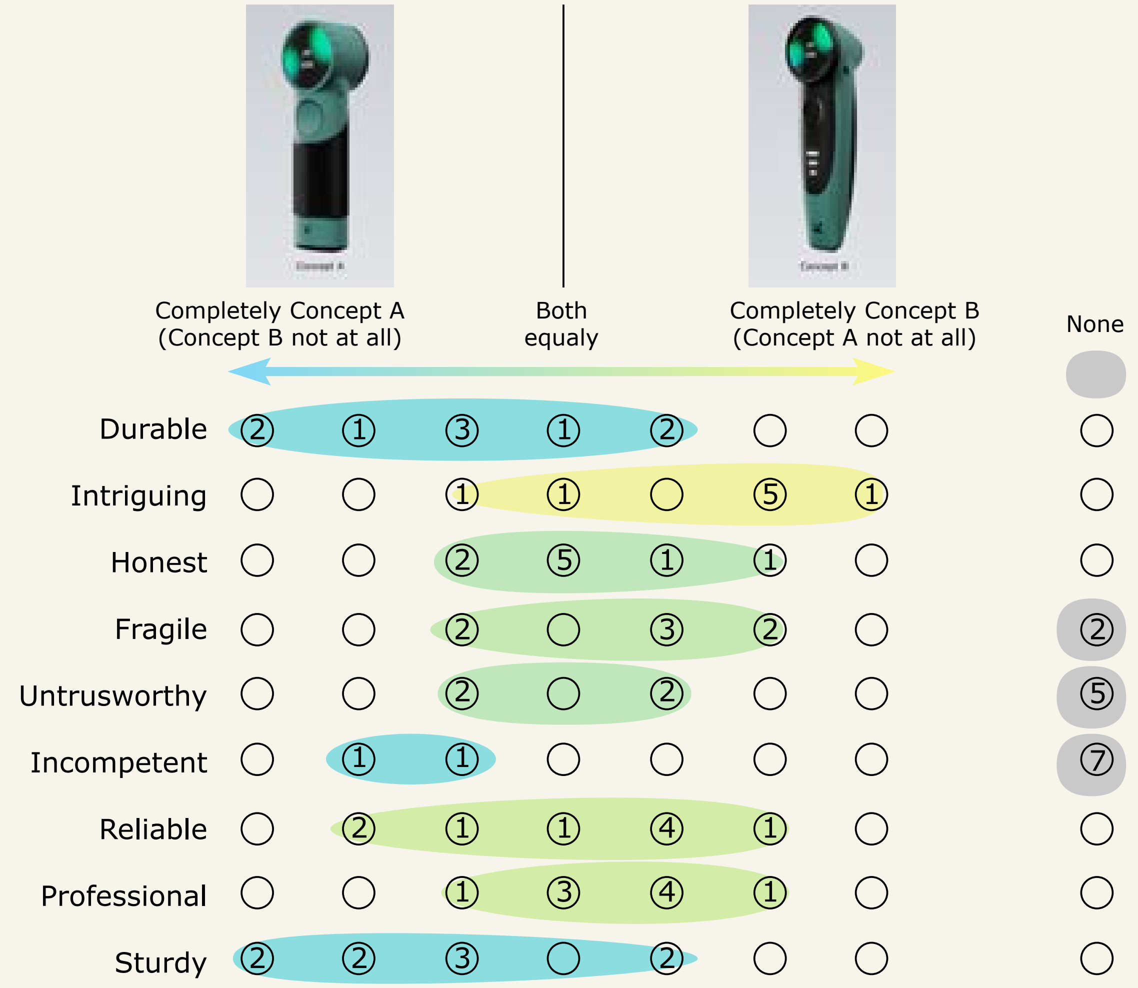


Figure 55: Concepts PE meaning evaluations

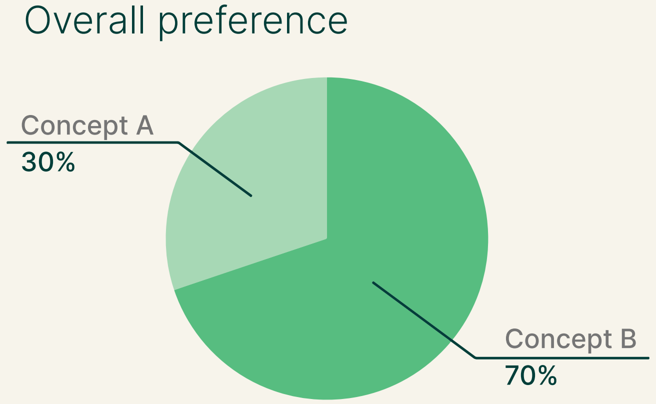


Figure 54: The overall shape preference

been evaluated, presented in Figure 49. It was noticed that both concepts appear similarly reliable, but the Concept A appeared as sturdier while Concept B appeared as more professional. Associations of 'sturdy' to Concept A mainly related to the simplistic, bulky, and 'massive' looking product shape, which was also related to the 'older design'. Associations of 'professional' to Concept B related to the shape appearing curvier and more modern. Concept B shape also resembled popular consumer electronics, such as a razor, which mostly positively influenced the evaluations. In addition, the majority has expressed they relate Concept B more to the product experience vision, mainly due to previously mentioned aspects.

Design Decision

Results from both user tests have shown that the Concept B is more aesthetically pleasing and appears as reliable and more professional. The shape looking similar to already popular consumer electronics makes it more recognizable which mainly has a positive effect because participants would tend to trust it more. Therefore, Concept B has been chosen for the final prototyping iteration.

Recommendations

For further development, the product shape could be improved: elements which convey sturdiness from the Concept A (such as making some elements more rigid with sharper lines or introducing the rubber around the complete handle) could be implemented to Concept B, therefore creating a shape which conveys all important product associations: reliability, professionalism, and sturdiness. In addition, the shape should be tested in the context of plastic recycling companies and with the user group of recycling workers to get better insights on how our target audience perceives the new plastic scanner.

6.2 Ergonomics

In this subchapter the main decisions are elaborated which led to a comfortable and stable shape of the plastic scanner, more details on parts of the design, in the field of physical and cognitive ergonomics, can be found in the functional design subchapter and the interaction design subchapter.

Why

For the scanner, we set out to optimise the physical ergonomics of the design by improving the following elements: comfortability, stability, and usability. This will consequently result in a better user experience as well as a high willingness to buy and recommend the product.

What options did we have?

We tested many prototypes on comfort, stability and usability. This process can be seen in the Design Process Chapter, mainly in Test moments 1 to 3.

What did we choose and why?

The main design decisions based on the research are: Functional design

Forward scanning orientation: Chosen, because from the user testing, it showed that the scanning orientation forward (faced away from the user, see Figure 51) is the most comfortable for the wrist (see 'Design Process' chapter and Appendix I).

Figure 56: Recycling employee scanning forward

PE

Ergonomic size of the handle

The context in which the Plastic Scanner will be operated, is mostly male dominated. The sizing of the final design is therefore predominantly determined by male anthropometry data. Therefore, an optimal shape for a cylindrical handle should have a maximum diameter of 50 mm, based on the grip circumference of P95 of male hands (Dutch population 20-30 years old) (DINED, 2004).

vavFurther ergonomic research shows that the handle should be at least 110mm in length (Herring et. al, 2007).

Combining the data mentioned above with our ergonomic research into handle shape design has led us to the final design. It has a width of 52 mm (and a maximum radius of 25 mm) on the widest part and the narrowest part at 38 mm (see Figure 52). Currently, the designed handle has a circumference of 142mm where it meets the scanning head and a smaller circumference at the bottom of the handle (Figure 52). The total length of the handle is roughly 135mm. The sizing, therefore, satisfied the previously mentioned requirements.

Curved handle shape

The rounded handle shape was found to be the most comfortable, see 'Design Process' chapter as well as in other scientific research (Scarlett R. Herring et. al, 2007; K. Hokari et. al, 2019). Optimizing the ergonomics with the electronics inside we chose to go for a more flattened curve (R35 on the sides) on the front and a more curved back side (R25), refer to Figure 53. This results in an optimal shape that fills up the space between user's fingers and palm and provides a flat part as the basis for your thumb to click the button (see Figure 53). By having a non-cylindrical handle with different curves, we achieved a shape that is comfortable for both smaller and bigger hands with the gloves on as proven with user tests.

Figure 57: Scanner in hand with dimensions

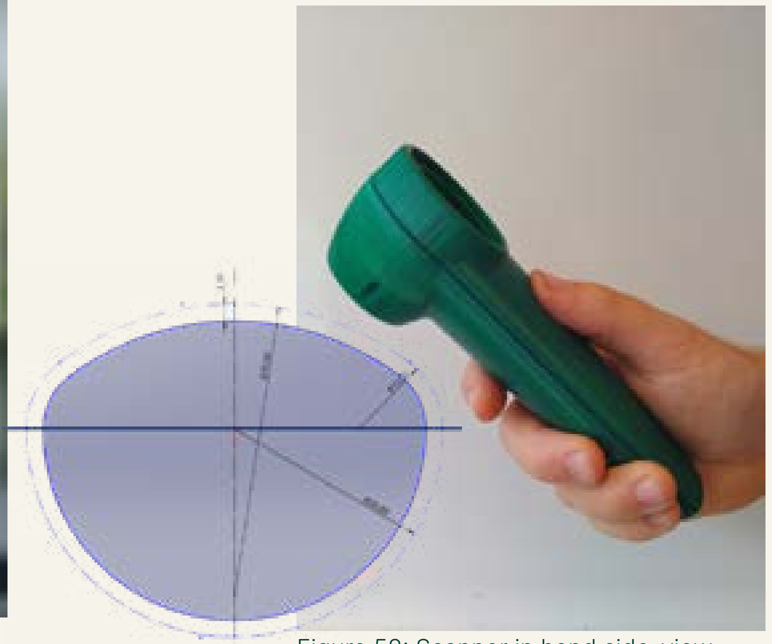


Figure 58: Scanner in hand side-view

Rounded edge bottom handle

The bottom of the handle edges were rounded off (Figure 53), because from the ergonomic test (Test moment 2 in 'Design Process' Chapter) it was found that there should be no sharp edges, which press into the hand palm during use (Appendix I).

Weight

Research of Zingale et al. (2005) states that hand-held equipment should not weigh more than 5.1 pounds (2.3 kg) and should be minimized as much as possible. However, the product should have some weight to provide grip and feeling of it being in the hand. The mass of the enclosure is 58.9 grams, adding weight from electronics the total mass will be about 152.5 grams. Testing with the prototype with electronics in it, prove already to be enough weight to do provide this feeling.

The button

The size of the button (Figure 54) is determined by the breadth of male thumbs, as the button will be operated with the thumb. DINED (2022) shows that P75 of thumb breadth is 24mm, the button face should therefore have a minimal width of 24mm. To account for the wearing of gloves in the context of use, the button has been sized at 25mm to ensure comfort. A raised edge around the button has been added for an easy orientation, comparable to the small bump on the F and J keys on Qwerty keyboards.

Figure 59: Button closeup

Part name	Units	Weight per part (g)	Total weight (g)	Notes
Enclosure	1	58,85g	58,85g	Estimation by SolidWorks
Custom PCB	1	42,08g	42,08g	Based on average weight of 0.475 lbs / 100 sq inch
ESP32	1	9,30g	9,30g	
2465 Adafruit PowerBoost 1000C Rev B v1	1	6,00g	6,00g	
Seamuing 3.7V 1000mAh battery	1	19,79g	19,79g	
MTD0130BCP02SF-1 screen	1	16,00g	16,00g	Weighed in Applied Labs
Capacitors	18	0,01g	0,11g	Average weight based on TCTP0J476M8R capacitor
Resistors	26	0,01g	0,14g	Average weight based on RK73H2ATTD2403F resistor
LEDs	8	0,03g	0,20g	Based on 5050 LED diode
ADS1256	1	0,07g	0,07g	
Total weight components (excl. enclosure)			93,70g	
Total weight			**152,55g**	

Figure 60: Weight distribution of various components

ADE

What would we recommend doing next?

To increase comfortability even further, we recommend optimizing the sizing and placement of the electronics so that the handle can be even smaller than the 52 mm on the widest part, we recommend achieving at least 50 mm, possibly even 48 mm in the width. After making improvements on the handle, we recommend testing the comfort and stability with a quantitative study. When changing the handle design, the PCB, ergonomic elements, and aesthetics all need to come together. This, while still taking the aspects of durability and manufacturing into account, can be a great design challenge. More details on how to improve the PCB design can be found in the next chapter 'Client Material', under hardware documentation of the PCB design.

The Rubber Coating
The rubber ring (around the scanning element) on the back is designed to stick out from the handle for extra stability in the hand (Figure 56). When the product slips, it will rest on your fingers on the back. Next to that, rubber parts are integrated into the housing to make the product more slip resistant.

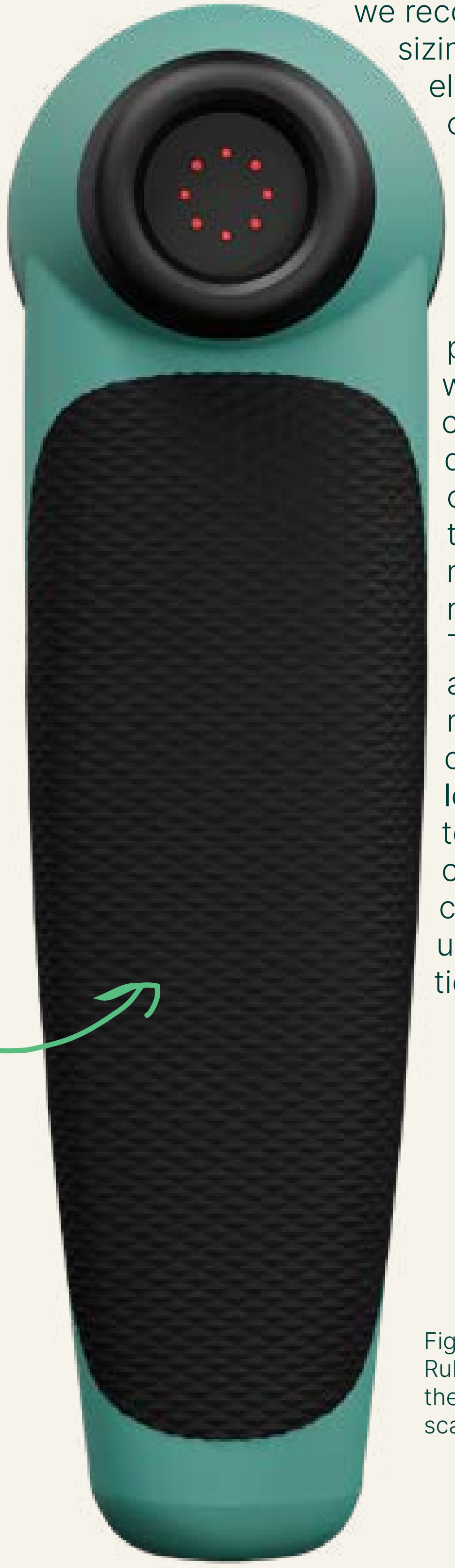


Figure 61: Rubberpadding on the back side of scanner

6.3 Functional design

In this chapter optimisations on digital and physical design are elaborated. First of all elaborating on the decisions made to implement a smart system. Secondly elaborating on sizing, weight, shock absorption, IP rating and optimal scanning. Therefore, explaining why our product fits the chosen context and other technical requirements.

Digital

In this subchapter we elaborate on the implementation of a smart system which will make the device fit the new context better. Decisions about the electronic components needed for the architecture of this system are given.

Why did we work on it?

The current plastic scanner had limited implemented features. To fulfil the user needs it is needed to implement the screens for visual feedback, scanning features, and a user-friendly system for retrieving results and to change settings on the device.

What options did we have?

The electronics based on ESP32 controller (design decision is explained in the chapter 'Client Material' – Hardware documentation) enables the scanner to have connectivity via Wi-Fi, Bluetooth BLE and an open/proprietary mesh protocol called ESP-MESH. This gives a vast number of opportunities for creating a smart system around the future plastic scanner and use cases with direct communication can be incorporated between a smart phone and the plastic scanner via BLE or Wi-Fi.

ESP MESH
For implementations where the scanning results are used for data gathering purposes, a mesh network of many scanners connected via ESP-MESH would be an optimal lightweight solution, that could cover a wide area with a single central broker collecting all information.

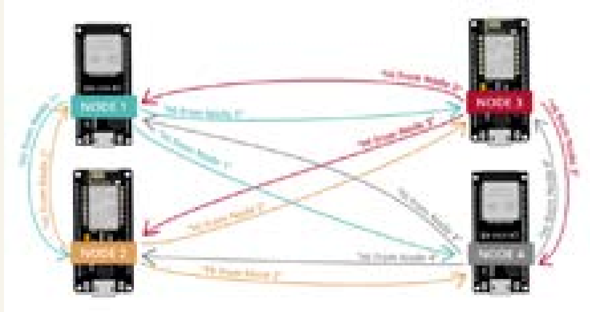


Figure 62: ESP MESH network visualization (Santos, 2020)

Wi-Fi
When using only one scanner, this network would not be optimal, and would still need an effortless way to change parameters and update the Machine Learning model (later ML model). Wi-Fi connection (either as the scanner acting as a hotspot or connected to an existing network) would cause problems if the device is used in different environments, with varying WIFI's, that need to be chosen on the device in an easy manner. A solution where the ESP32 is hosting a website, where a .csv file can be downloaded, and new firmware can be uploaded which is easy to implement but will lack usability and significantly raise the power consumption.

ADE

BLE – Bluetooth Low Energy
The last opportunity is to publish results via BLE characteristics, and pair the scanner to a smartphone for the result transfer, firmware updates and personalization to specific contexts. Using a smartphone to connect to the device and using the large touchscreen area to update settings via an app will enable to keep the interface on the scanner simple and elegant. This will also make it easier to update usability during the lifetime of the product.

What did we choose and why?

Wi-Fi was chosen to be used for this prototype, due to the time constraints for developing other communication interfaces (for example, an APP with a Bluetooth interface). This enabled an easy result transfer, but we have already experienced the downsides to using Wi-Fi: large power usage and trouble connecting to new networks, that have not been hardcoded into the firmware.

What would we recommend doing next?

For the next iteration we would recommend pairing the device with a smartphone via BLE, and control all settings via an app – an example of how the app could look like is presented in 'Digital Application' in the 'Interface and Interaction' subchapter. Here the user will be able to retrieve the results, change firmware and the ML model, and lastly give the user the opportunity to customize the visual feedback from results (for screen visuals and explanation refer to part on 'Digital Interface Product' in the 'Interface and Interaction' subchapter).

6.4 Physical

In this subchapter all design decisions that are made on a physical product level to increase functionality are elaborated. This entails sizing, weight, shock absorption, IP rating and optimal scanning.

Why did we work on it?

With the current plastic scanner, focus lies on the core functioning of the product, while the actual product is still at a prototype level. To take the new product to a level for implementation into B2B companies, the physical housing must be improved according to be sufficient for its operational environment.

What options did we have?

Initially, we had identified 4 different target groups for our design. These are scaled down to the following 2: Ocean Plastic sorting workers and recycling factory sorting workers, as these groups have enough overlap to design the same device. However, both groups will have different use-cases, as described in the subchapter in project definition. These different use-cases lead to the same and more specific requirements that need to be integrated into the final design.

What did we choose and why?

The physical design is based on the requirements that we have set for the product in the early stages of the project. These requirements are determined by literature reviews in fields of interest of handheld devices, context research at possible use environments and challenges for the prototype design by Jerry.

Figure 63: Rubber padding around the screen and the sensor.

ADE

Durability of enclosure
The Plastic Scanner is envisioned to be injection moulded. The enclosure is therefore modelled to make sure it fulfils the requirements of this manufacturing process, meaning draft angles of 2 degrees have been added to all the geometry that will be in the production enclosure. All geometry that does not have these features are only added for the functional prototype.

To make sure the product can operate in the harsh environment of a recycling facility, the first iteration enclosure parts have been analysed in a drop test, with a special focus on fastening features, to see if the structure would survive dropping out of hands. The analysis showed that the enclosure would not withstand the stresses of dropping the product from reaching height, more detailed results are accessible in Appendix L. The most important takeaways from this analysis have influenced the design of the enclosure parts. To distribute the stress caused by impact, the number of mounting locations is increased to 6, wherein the previous design this was 3 (technical datapackage, drawing 1). Next to this, ribs are included to dissipate the stress across the entire body, instead of only the region of impact. With these changes implemented, we expect the enclosure to withstand an impact from dropping the product from reaching height.

Durability of Rubber padding
The drop test analysis has also shown that the impact of the drop test is bigger than the critical thresholds, meaning the enclosure would show signs of plastic deformation, such as necking or even fracture. To further manage the regional stress on the product, rubber has been applied to critical edges of the model (Figure 58). The rubber, being a highly elastic material, absorbs some of the kinetic energy, causing smaller stresses to act on the main material of the enclosure. The centre of gravity of the product is located higher up in the enclosure, on the side of the scanning head, therefore most of the added rubber is on the edges of the scanning head.

Figure 64: Rubber padding on the back side

IP-rating
In our requirements we have stated that an IP rating of 6.7 should be achieved, because of the operational contexts of the Plastic Scanner, oceanic plastic sorting. This specific IP rating means that the enclosure should be dust tight and the enclosure should protect against the effects of immersion in water between 15cm and 1m for 30 minutes.

In the current design, not much attention has been paid to this requirement. The design features such as the lip and groove and glued components do however provide some level of protection of the internal components. We expect the current prototype to have an IP rating of 3.1, meaning it will protect against a solid object greater than 2.5mm and against vertically falling drops of water with limited ingress. Suggestions for improving the design in this area of expertise are mentioned in 'Recommendations' chapter.

Light blocking for better scan results
Throughout the process a concept idea was derived to block environmental light as much as possible to ensure accurate scanning as environmental light interferes. This has been implemented into the final product by adding a rubber cushion at the back, see Figure 59. This cushion is being pushed inwards, as it is hollow by pressing the waste sample against it. In this case even un-even waste samples be covered while blocking out the light. The possible technical implementations will be discussed in 'Recommendation' chapter.

Transparent plastic scanning
Throughout the process also the concept to scan translucent plastic was derived. Hereby, when wanting the scan translucent plastics, another head will be placed on the back. Due to time limitations, it was not possible to integrate this idea in the final product, but the conceptual design is further discussed in 'Recommendations' chapter.

What would we recommend doing next?

For continuation of the product, the following steps are recommended:

- Design a housing which can be injection moulded and withstand dropping.
- Evaluating the new design by doing a FEM analysis and drop test.
- Implement the translucent scanning into the product.
- An additional optimization could be to add the functionality of a camera to the device. Hereby more insights can be retrieved and tracked and possible more waste can be recognized.
-

PE

6.5 Interface & Interaction design

Why did we work on it?

It is important to convey the right message to the user that is easy to understand correctly and that all elements of the device are covered and can be communicated properly. This to have a pleasant user experience and proper functioning within the context the device will operate in. From research in ergonomics and from user research was found that the device will have to communicate glanceable information, thus the information should be easy to read and reflect the needed information. To design screens that will fulfil this, screen rules and designs for smartwatches were taken as reference as they also present glanceable information.

What options did we have?

Based on several iterations, the following 2 screen styles are created as they show two very different styles, see Figure 60. Hereby the information presented is simplistic, minimal and as large as possible. Screen style A is created while integrating colour elements with meaning and aesthetic pleasure, while screen style B is also simplistic on its look. Both screens have been tested with participants and within Besstrade, See Appendix F for the full testing procedure and results and Appendix J for testing results within Besstrade. From both tests has been found that the screens should be simplistic, with minimal information, as big as possible and that certain changes need to be implemented.

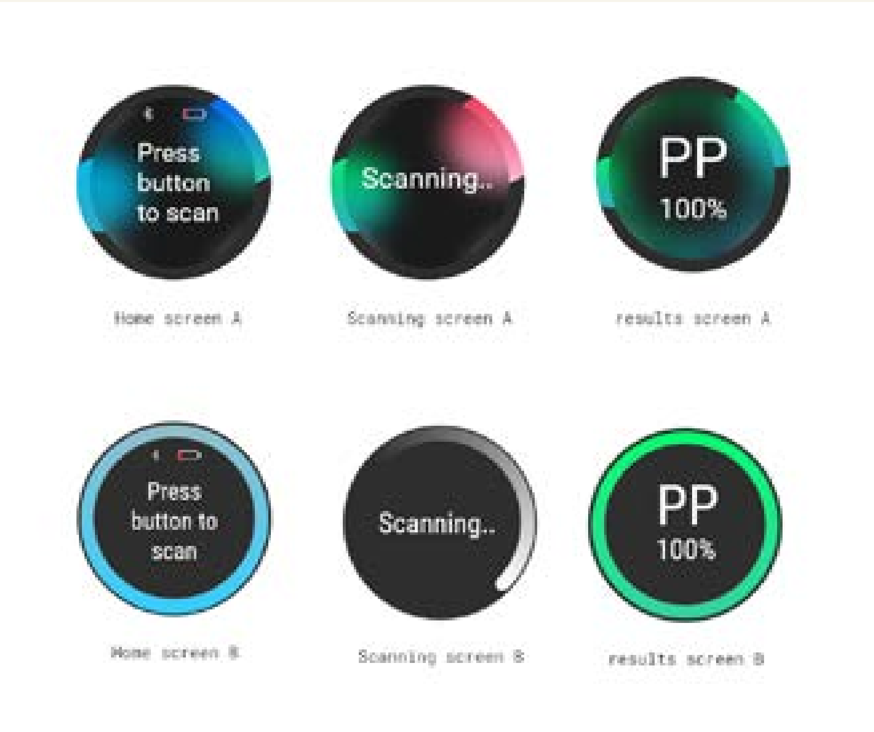


Figure 65: Chosen screen styles as possible directions for the product

What did we choose and why?

A last iteration on the screens is done according to the findings, See Figure X.

Figure x – final screens for the plastic scanner.

The following changes have been implemented into the final screens:

- Bigger font for readability.
- Colour coding for 2 situations that sorting workers face.
- Accuracy levels scanned samples are removed.

Standard identification mode
The standard identification mode is based on findings from the visit to Besstrade. The company only needs to identify whether the scanned part is made of PVC or not, therefore the scanner can feedback a success green light for PVC, and red for everything else in this mode. When the result is uncertain, the screen is highlighted in orange.

Sorting mode
The sorting mode is applicable to companies like Ocean Plastic, which want to sort plastic waste into different categories. For an optimal scanning process colours will be linked to specific plastics for sorters to quickly recognizer the plastic categories on longer term. This attached colour functions as an extra cue to optimize the sorting speed which is beneficial due to research on bi-modal feedback

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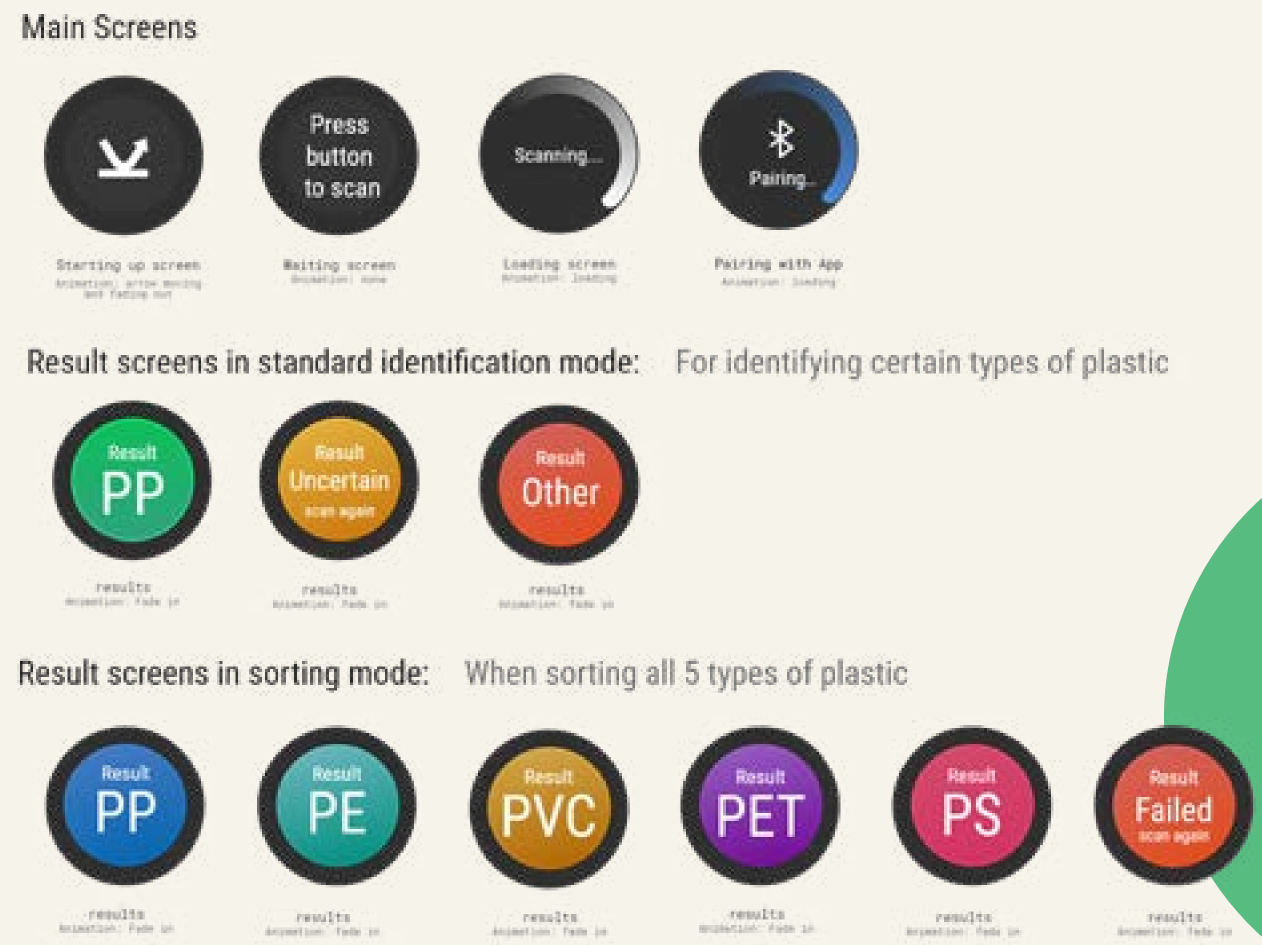

Figure 66: Final screens

What would we recommend doing next?

The screens have been validated and core functionalities are implemented in an efficient manner. However, the screens should be further tested and optimized. Hereby, uncertainties and better communication of the information to the users can be ensured. If any additional functionalities are being integrated this can result in the need for extra screens designs. Additionally, the following things can be next steps to implement:

- Create a touch-screen interface for managers within the company when that is desired.
- Integrate animations into the screens. Possibility is that the round colours of the results could be used to communicate the loading time instead of the current loading screen.
- Test whether the final screens are aesthetically pleasing while being simplistic.
- Test in context functioning of the final screens and make a last iteration.
- Find a manufacturer for the screens in the correct size.

Figure 67: Start up screen, home screen, Bluetooth pairing screen

6.6 Digital Application

PE

Why did we work on it?

There are certain functions that cannot be shown in an effective manner on the non touch-screen on the product. To still be able to incorporate additional necessary features an app has been created.

What options did we have?

Considered was to make an application for mobile devices and tablets or an online application which can be opened through browser.

What did we choose and why?

It was chosen to create an app that complements the product, as this was more suiting for the current project. Due to the time span of the project, elaborative research has not been done to derive all additional features that are necessary and suiting for multiple companies. Creating a complete functional dashboard and application is a project itself. Therefore, a "concept" application is created which gives a direction for a possible application and covers key functionalities that have been derived from insights along the project. Figure 62 presents this application.

Key functionalities have been implemented for the following reasons:

- Bluetooth pairing: To connect the plastic scanner with the app for data sharing, updates and to change modes.
- Results section: to get more insights into the scanned samples when needed. This is more important for managers and companies to get insights into waste trends.
- Settings: to change the modus of changing (identification vs sorting) which are presented in the final screens, Figure 62.
- Collect: to enable managers and companies to save the data as csv files and import them where needed.
- Updates: to update the algorithm when needed as changes and improvements will be made.

What would we recommend doing next?

- For further implementation of the application the following steps should be taken:
- Work out the complete application; design all the screens and features.
- Test designs and iterate.
- Develop and test the application.

PE

ADE

6.7 Physical

Why did we work on it?

To facilitate interactions between the users and the product that suits their objective and use-case, interaction design should be correctly implemented for the physical design. The interaction is perceived by the user in physical and emotional manners and is formed by perceiving elements of different fields of form, function and technology over time.

What options did we have?

During Test Moment 1 and 2 (see Design Process) we tested several options with a different scanning orientation (as well as screen orientation). During this test moment we also looked at the best location of the button.

The 2 Concepts A and Concept B, as mentioned before, were 2 possible directions for the project. When testing the prototypes within PE this led to different perceived interactions. Mainly because of the concept their looks and emotions, but also some different assumptions on their functionality. By testing the physical prototype at Besstrade additional insights were retrieved, mainly on the prototypes it's functioning.

What did we choose and why?

From testing it showed that the scanning orientation forward (faced away from you) is the most comfortable for the wrist.

To continue with overall Concept B is chosen as this scored highest on comfort, aesthetics and interaction. Implementing lights into the front was one of the features on Concept B. To implement this, 2 RGB LEDs are currently placed on the final PCB.

Next, the following main elements are integrated in the final concept, see Figure 63, in the following manner:

Figure 68: Plastic scanner details

Button
- Placement: On the front – From results of research in Appendix I, A button on the front gave a nicer feeling and interaction. Additionally, the button is aligned in the centre at a height where the thumb naturally would be placed.
- Feeling: Sticks out – The button sticks out on the product smoothly to be able to feel the placement of the button, especially with gloves on.
- Looks: Metal lining – To make the product look durable and professional metal details are added to the product.
- Feedback: Movement - the button can be clicked downwards because this movement reassures the user and gives validation, which was preferred during testing and also showed to be optimal from literature research.

Lights
- Feedback: Levels – Presenting the battery level on screen was too distracting and missed by participants (research PE and Besstrade). Lights communicate battery level to raise awareness as it drops down when lowering.
- Looks: Lights – Added because they were perceived as an attractive and exclusive feature. (research PE)
- Shape: Fluent - in-line with the rubber shape on the front to give a fluent feeling, inspiration is taken from razor designs.

Screen
- Feedback: Color – a big, colored circle has been integrated into the final product for sorting workers to quickly recognise the output.
- Looks: Rubber – Rubber lining around the screen has been added to communicate that the product can withstand daily use and dropping.
- Size: 2.1 inch – A fairly big screen is used to make sure it is easy to read off.

Rubber handle
- Looks: Rubber – Rubber detailing is added as this was prefered by users and sorting workers of Besstrade. Adding rubbers results in more grip for the user which is desired

for the use case. This makes the device is more stable in the hand, but also convinces durability and professionalism more.
- Shape: Fluent – Fluent shapes were preferred over a boxier design and communicated the dersired experience of the product. From ergonomic research was found that a combination of an oval handle on the front and cylindrical handle at the back shape was preferred when needing to hold the device.
- Pattern: Small – A diamond shape pattern is used in the handle to communicate and function for more grip. The pattern should be small to be more durable as scratches of wear and tear will be less visible.

Switch
- Feedback: Color + Movement – Green has been added to communicate that the product is turned on by switching it.
- Shape: Common - The switch button is designed in common product shape.
- Feeling: Sticking out - the button sticks out to easily feel and switch it.
- Looks: Metal - To make the product look durable and professional metal details are added to the product.

What would we recommend doing next?
When finalising the product an extra LED should be added to the PCB to communicate at least 3 levels of the battery. If additional use cases occur were sound could be beneficial to make a more efficient scanning process, this can be intergraded. At least, from research at Besstrade it was found that workers and manages would like to carry, store and charge the device somewhere. Therefore, additional accessories should be developed to facilitate for these interactions and functions.

6.8 Sustainability

Plastic scanner directly works towards increasing plastic recycling effectiveness and fighting plastic pollution.

Thr general sustainability opportunities and possible issues are presented in Figure 65. The Plastic Scanner is already focused a lot on fostering sustainable development, but it lacks strategic infrastructure for end-of-life or material extraction. The negative aspects of the current design offer insights into improvement options for the future design.

Further in this analysis we consider the product materials for the casing.

Why did we work on it?

The main sustainability improvement in this project is focus on optimizing product's casing. Current casing is made of Nylon using SLS 3D printing. The current manufacturing method and materials fit the current product, but if the commercial version with higher batch size is planned to be manufactured, certain things should be considered:

Negative consequences:
- The product currently is printed with a 3d printer, which uses 6.5 times more energy than when injection moulding a part (Mayer, n.d.).
- The current product is made out of virgin material, Nylon, which is a petroleum-based material.

In addition:
- Casing is the main product part the user directly interacts with, important values van be communicated through product exterior.
- Casing is the most viable change, considering project scale, product development level and production scale.

Figure 70: Sustainability opportunities and issues

Figure 69: Plastic scanner on granulates from recycled PP

What options did we have?

PLA for FDM 3D printing. In principle, mechanical recycling of sorted PLA from post-consumer waste is possible, but due to small fraction of PLA in the industry it is not financially viable (CE Delft, 2021). In addition, biodegradable plastics tend to be incinerated or composted, therefore EU is aiming the policy to incentivize the use of more sturdy recycled plastics (where it is feasible) over biodegradable ones. Bio-based and/or biodegradable plastics, like PLA, will require labelling to provide the users with their correct disposal (European Commission, 2020).

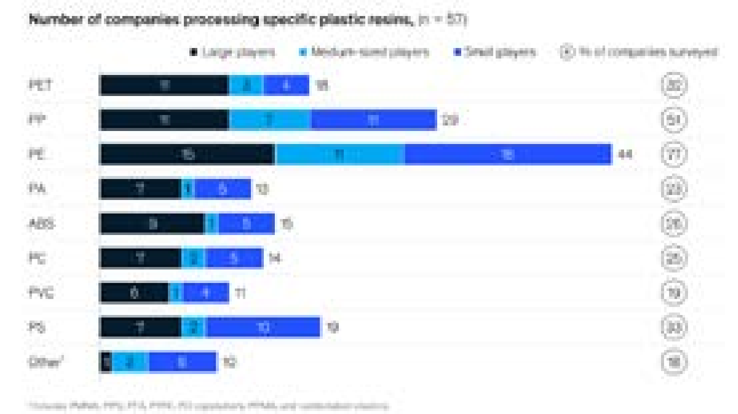

Figure 71: Results of analysis from McKinsey & Company (Kirilyuk et al., 2020)

PP (virgin) for Injection Moulding. The EU's plastics tax: driving virgin plastic price up. The Plastic tax on packaging and single use will apply to European Union block, but the Netherlands might put tax on all virgin plastic granules or powder (KPMG, 2021b). Plastic tax seeks to make virgin plastics more expensive to incentivize the use of recycled plastics. This can show a trend of where European policy is going. Currently, it is aimed at the sectors of highest plastic use and disposal, but virgin plastic tax can be introduced to further expand the incentive to use more recycled plastic in future products.

Recycled-PP P (70% recycled material) with Injection Moulding. European Green Deal, The Circular Economy Action Plan: required 15-30% recycled content to key products such as packaging, construction materials and vehicles (European Commission, 2020; KPMG, 2021). According to Kirilyuk et al. (2020) (Figure 66), PP is the second most recycled plastic type after PE. Recycled PP material produces the least amount of emissions and energy compared to other mentioned alternatives, from LCA analysis (Figure 67).

Stainless steel for CNC milling. "Over 90% of EoL stainless steel is currently collected and recycled into new products" (Eurofer, 2020). Materials and manufacturing produce the most emissions and energy from LCA analysis (Figure 67). CNC milling will lead to a large loss of material. Stainless steel has higher tensile strength – therefore drastically more durable casing.

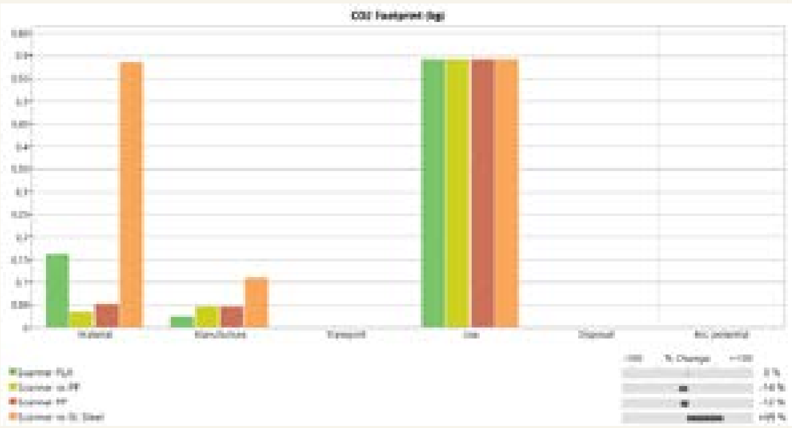

Figure 72: Granta EduPack LCA analysis of all four alternatives discussed.

What did we choose and why?

From LCA analysis it is also seen that the use of recycled PP has the least impact, mainly because it avoids using finite materials, and mechanical recycling has less impact compared to virgin material polymerisation. From the legislation point of view, EU Commission is continuing to create strategies to incentivise the use of recycled plastics. We chose recycled PP from ocean plastics because it directly connects back to the general vision of the product and the client: to enhance circular economy and fight plastic pollution. Oceanworks (Oceanworks, n.d.) is one of the suitable suppliers, which provides various types of nearshore or ocean-bound plastic, from which we chose Nearshore PP. Figure 68 illustrates this choice as well as other alternatives for the future sustainability improvements.

What would we recommend doing next?

As illustrated in Figure 68 further design optimizations should focus on minimizing the impacts of electronics, as this usually is the part containing most critical materials and toxic manufacturing methods. Two approaches are possible: increasing the recyclability and recycled content in the PCB and explore additive manufacturing of the PCB.

Another important focus point is to design for repair and disassembly. Refer to 'Recommendations' section for more elaborate description about what to consider and how it could be achieved.

Further sustainability considerations

As mentioned in the project definition chapter, the plastic scanner should function in more rough environments, such as recycling factories or warehouses where ocean plastics are mixed with dirt and water. The product should be durable and waterproof to guarantee prolonged and effective functioning of the device. In many cases this negatively impacts recyclability, because more materials are introduced to ensure tight, and study fit. Therefore, certain trade-offs should be discussed, and priorities considered. To do this we refer to Product Value Hill based on Circular Economy framework where the priority is to prolong product's life by maintaining and repairing the product, while resorting to recycling should be positioned as the last step.

Figure 73: Sustainability optimization. In color - the chosen implementation, in grey - possibilities for further improvement

Recommendations

Maintain. Focus on durability and waterproofness for the device to prolong product's life in these harsh environments. Refer to 'Recommendations' chapter for more specific information on enhancing durability and waterproofness.

Repair. The device should be made easy to repair by making the casing possible to open using standard screwdrivers. If there are issues with electronics, a possibility to offer repair as a service by the client could be explored, in case of few components' replacement, our client could store electronic components and sell them.

Recycle. Current design enables easy separation of electronics. As a general practice, batteries are always removed before product shredding. In this case the battery and the PCB are both liberated once the housing is opened, enabling easy separation. For other recommendations on recyclability, refer to 'Recommendations' chapter.

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6.9 Manufacturing

This chapter aims to describe how we intend the final prototype to be manufactured, and the thoughts and principles used to ensure that the product can be manufactured with relatively standard manufacturing techniques.

The final prototype is still a prototype, and more development needs to go into product to make it fully ready for production.

Why did we work on it?

There are multiple considerations when designing a functional, final prototype. First of all, it is important to keep in mind the manufacturing method of the prototype and of the to be manufactured product. This is very important, as it determines much of the geometry limitations, material finish and final product similarities.

The second consideration is determining how the parts of the final prototype will be connected. Fastening entails how the enclosure parts come together and how parts will be secured within this enclosure.

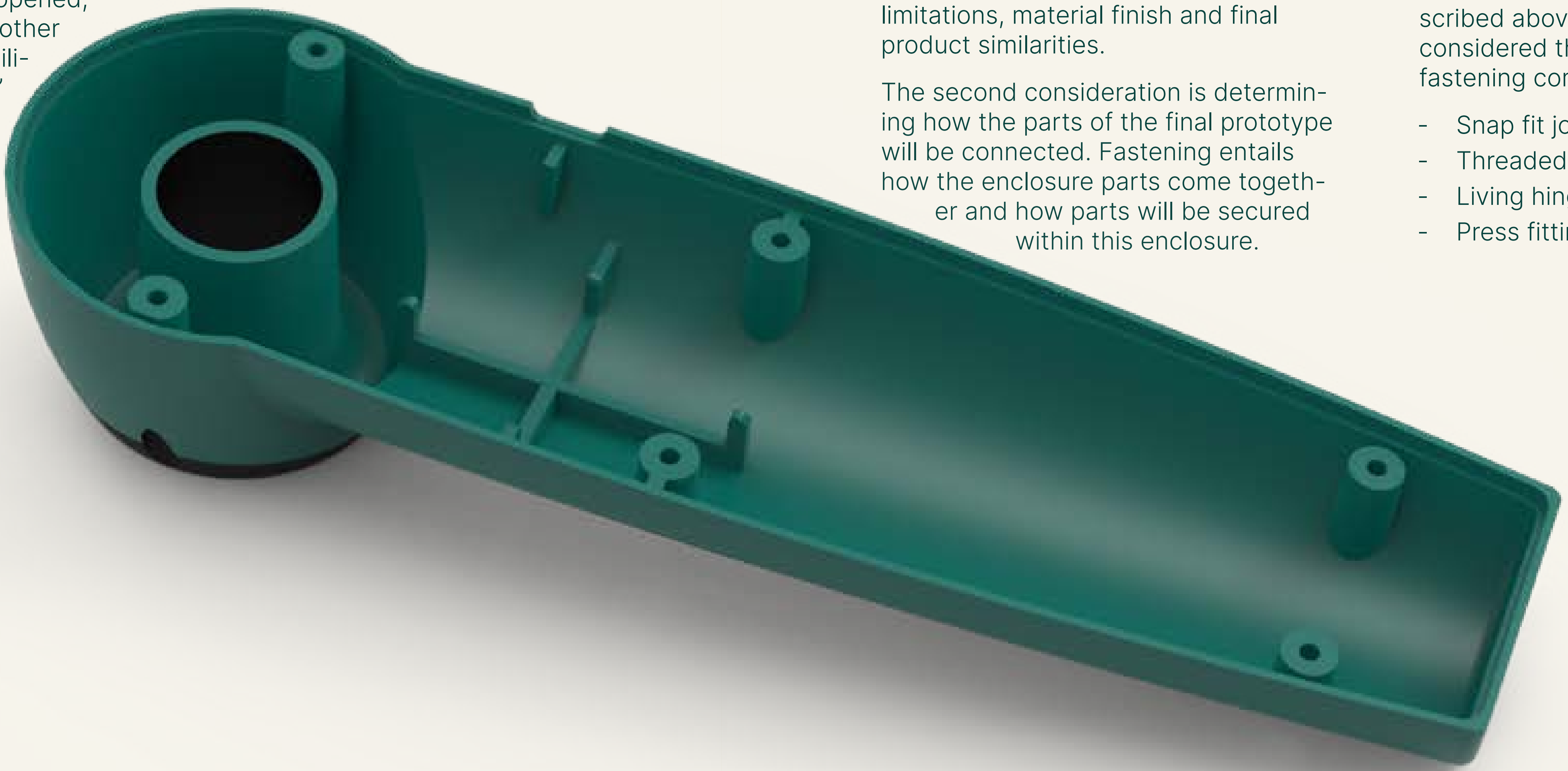
What options did we have?

We envision the Plastic Scanner 2.0 enclosure to be injection moulded in polypropylene. To make the final prototype that matches the production model as closely as possible, we had the following manufacturing options:

- FDM 3D printing
- Material jetting
- SLA 3D printing mould inserts followed by small batch injection moulding

Within the process of injection moulding for the production model, there are several fastening options (Hubs, n.d.). These fastening options are possible with all manufacturing methods described above. Therefore we have considered the following options for fastening components:

- Snap fit joints
- Threaded fasteners
- Living hinges
- Press fitting



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What did we choose and why?

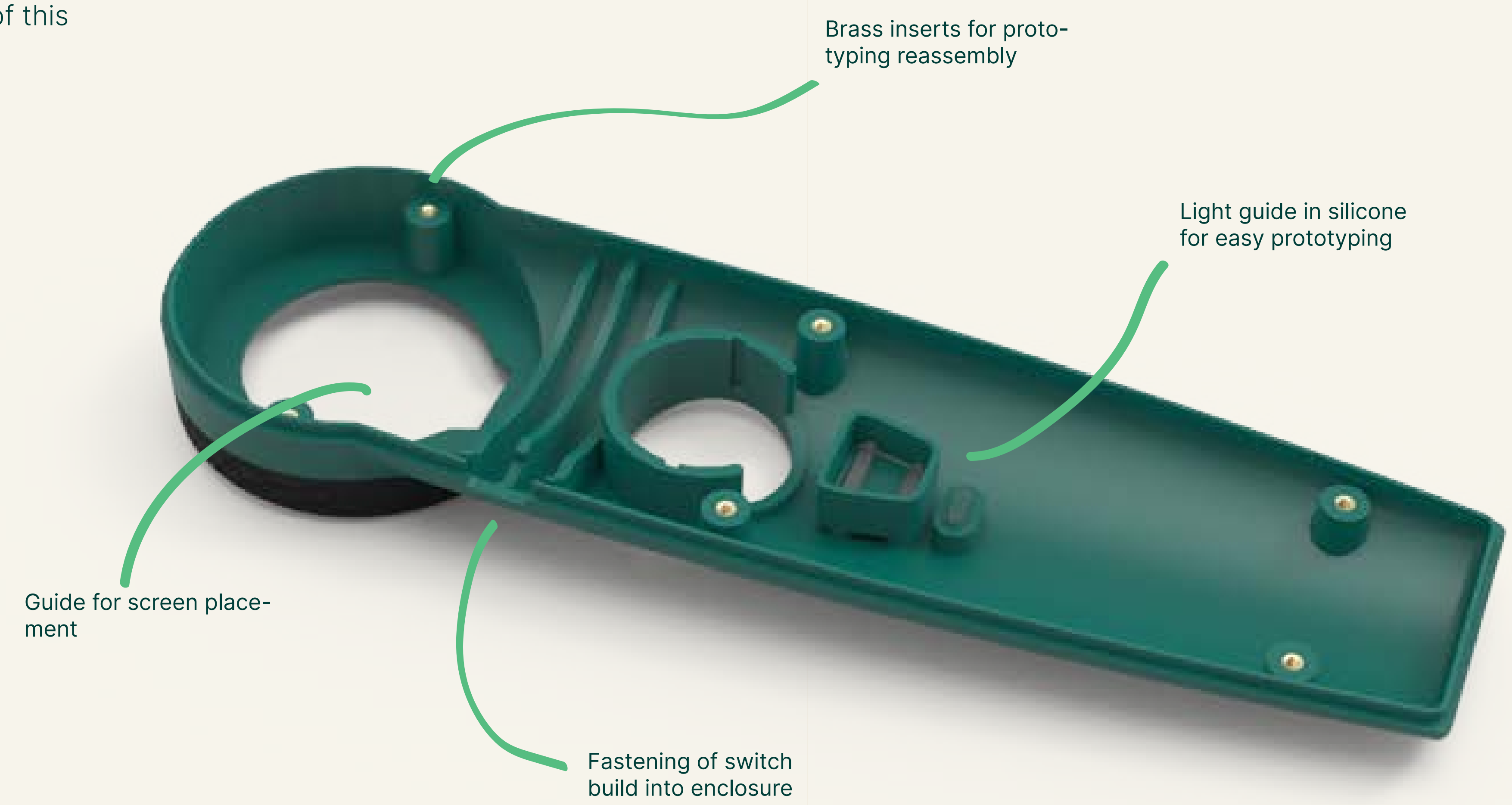
Choosing a manufacturing method for the final prototype is a balance between cost, lead time, availability, accuracy and surface finish. Our final prototype is to be a functional prototype. It should therefore demonstrate all assembly features, component alignment and most importantly let the user experience the full functionality of the product. We have chosen to manufacture the final prototype with FDM 3D printing for the following reasons:

- We had an FDM 3D printer with generous amounts of filament available to us during the prototyping phase of this project. Using only a single manufacturing method allowed us to make quick model iterations before having to present the final prototype, granting multiple moments to find problems with the production model. All of this was possible at a very low cost, because we did not have outsourced anything.
- Having access to the FDM 3D printer 24/7 helped us to reduce delays in the project, because the lead time was as low as possible. We could design iterations during the day, print the prototype at night and tested it the next morning.
- With the publishing of Ultimaker Cura 5.0 during prototyping, a new feature called "Tree Supports" was added. This allowed us to print overhangs much quicker, with less material and with cleaner surface finishes (Gharge, 2022). At first we printed without support material, but this proved to be very detrimental to part accuracy. This feature also diminished the post-processing time of the prints massively.

Using the FDM 3D printing does have a downside, namely the surface finish. The surface finish of FDM 3D printing is not even close to the smooth (and more accurate) surfaces produced by the other two manufacturing possibilities. The texture added by the FDM 3D printing process is not of negative influence on the possibility to demonstrate assembly features and component alignment. Next to this we think the surface finish only has negligible influence on the user experience, because users will interact with the prototype using gloves. Therefore it is only a small visual difference.

One thing that was important to us, was that (except for the tolerances) the entire design could be carried over for injection moulding. This was achieved by applying draft angles of 2 degrees everywhere and making sure that the two mould halves are loosened. We also paid attention to making sure the parts have a uniform wall thickness to reduce the chance of sink marks appearing in the production model.

The final prototype uses many different ways of securing the different components. The two enclosure halves are mounted together using a lip and groove feature to align the two parts, while 6 inserts and bolts are used to tighten the components. We have chosen 6 bolts to make sure we apply enough pressure to reduce gaps between the components. In a future design a gasket should be used between these components to provide waterproofing, having enough points of contact is even more important then.



In some locations of the design, it is impossible to use screws to fasten components due to the geometry limitations of injection moulding. We have therefore also used other fastening methods. An example of this is the use of press fitting the on/off button between the two enclosure halves (Figure 69). Using a structure to press fit the part, in this case by adding ribs that enclose the button on all sides.

We have not made use of snap fit joints or living hinges in our prototype. Snap fits joints were not used because we value easy and repeatable assembly and disassembly. Implementing these could have us run the risk of the snap fit joints becoming loose, causing the product to lose its ability to repel water. The living hinges are not necessary for our design and would only increase the mould size in production, adding to the costs. To keep the costs and complexity of the model down, we chose to not implement living hinges.

Recommendations

Before producing the Plastic Scanner in bulk, we recommend doing small batch injection moulding using SLA 3D printing mould inserts. This allows for a relatively small cost, but it is very close to final production prototype. This prototype can be used to do a last check on tolerances, mould design features and overall part finish. It is important to do this step as the tolerances from FDM 3D printing and SLA 3D printing are rather different. The model therefore needs adjustment and further testing.

Our prototype model is fitted with metal inserts, because self-tapping screws and FDM 3D printing are not a good match. For the final part, it is possible (and even suggested) to use metal inserts in injection moulded parts to allow for many cycles of assembly and disassembly. From a sustainability standpoint we would however suggest to use self-tapping screws, because this is easier for EOL. We do not expect the parts to need many cycles of assembly and disassembly, therefore self-tapping screws are a good alternative.

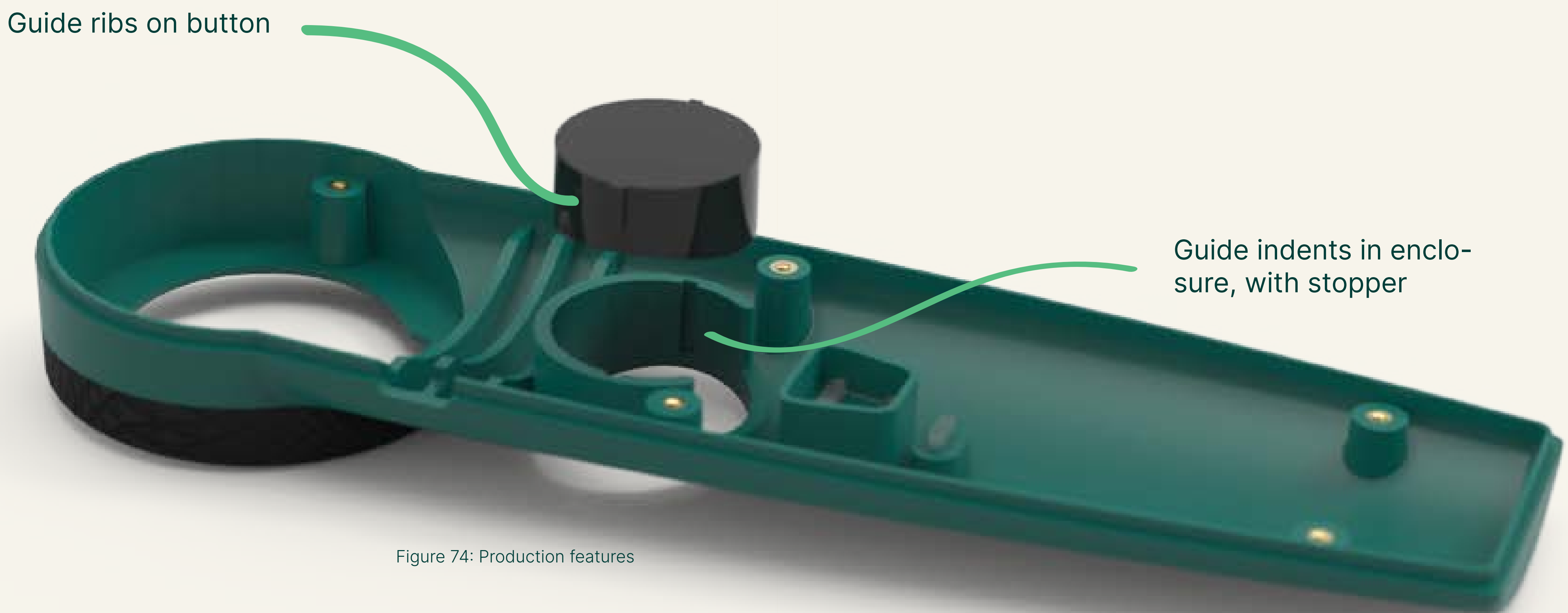


Figure 74: Production features

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6.10 Envisioned production

The final prototypes 3D printed manufacturing method is not a financially viable option for larger batch sizes and does not output consumer grade product finish. Therefore, we have researched methods for mass production, and designed the parts to be capable of this manufacturing process.

Options

For production of larger quantities of products, injection moudling is the cheapest and best option. But the startup cost at low to medium volumes are high, due to expensive moulds. We see three viable options, as described in Figure 71.

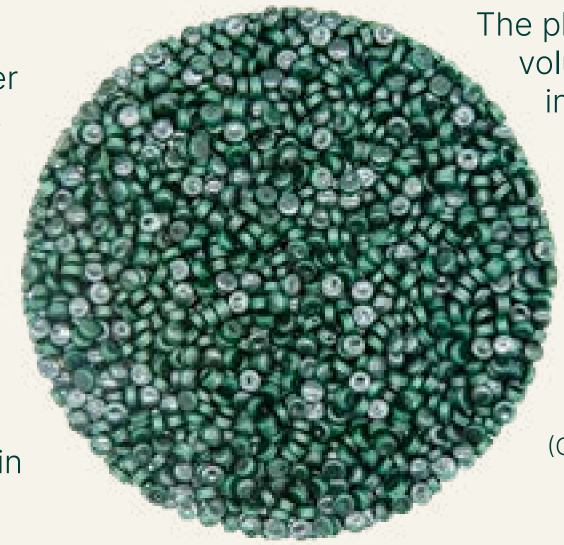


Figure 75: Oceanworks Item PP 190252 pellets (Oceanworks, n.d.)

Choice

We recommend going for the mid volume option, of 1000-5000pcs, manufactured in a Polypropylene material made by 98% recycled fishing nets, manufactured by PLASTIX (Oceanworks Item PP 190252 / PLASTIX OCEANIX rPPC 210-001) Figure 70.

The plastic parts has a total volume of 65cm^2, resulting in a weight of 60,5g plastic use pr model. With a bulk price of 11.9€/kg this will mean a material cost of around €0,5 pr model.

	Low volume	Mid volume	High volume
Production volume	100	1.000	100.000
Method	In house mold production and in house molding	Outsourced mold production and molding	Outsourced mold production and molding
Mold	3D printed polymer	Machined aluminum	Machined steel
Lead time to final parts	1-3 days	3-4 weeks	4-8 weeks
Equipment required	3D printer, desktop injection molding machine*	-	-
Mold cost	€900,00	€3.500,00	€20.000,00
Material cost pr part	€0,50	€0,50	€0,50
Overmould Cost	€600,00	€3.500,00	€20.000,00
Overmould material Cost	€0,50	€0,50	€0,50
Labor costs pr. part	€5,00	€1,50	€1,00
Total Labor cost	€500,00	€1.500,00	€100.000,00
Total tooling cost	€1.500,00	€7.000,00	€40.000,00
Total Material cost	€50,50	€500,50	€50.000,50
Total production cost	€2.050,50	€9.000,50	€190.000,50
Cost per part	**€20,51**	**€9,00**	**€1,90**

Figure 76: Production options

Implications

The choice of injection moulding as production method, made is necessary to design the prototypes in a way that would be both realistic and good to 3D print, and possible to injection mould.

During the final design, we have designed our prototype keeping the following principles in mind

7. Client material

ADE

7.1 Price estimation

In this section, we estimate the cost per product in two different scenarios:

- 1. Micro-batch of 100 units with enclosure components made via 3D printed injection moulding, based on figures published by Formlabs.
- 2. proposed production batch size of 1000 units, produced with light-weight aluminium, injection moulds, that can expand the production volume up to 3-5000 units.

The main findings from this price evaluation are:

- The total cost price of the product will be €261 at 100pcs and decrease to €148 at 1000pcs (Figure 66.
- The PCB and soldered components take up most of the cost price, 60% (€159) at 100pcs and increasing to 63% (€93) at 1000pcs (Figure 65).
- The cost price is decreased by 40% from €159 to €93 when increasing the batch size from 100 to 1000.

The retail price of the product can be set at €1000 (Figure 67), with a profit margin of 225% thereby fulfilling the client's requirement to not exceed a retail price of €2000. The client has expressed interest in a "Buy one, and donate one for charity" model, where the customer is funding the handout of scanners in low-income countries by ordering a scanner for themselves. Thereby giving persons in low-income co untries a chance to earn money on sorting trash into valuable resources. The low-income version could be a simplified version using a smaller screen, and less connectivity to further reduce the price.

1000 pcs

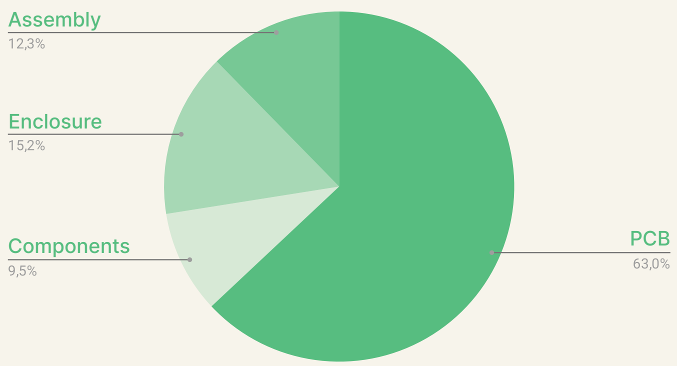


Figure 77: Cost distribution

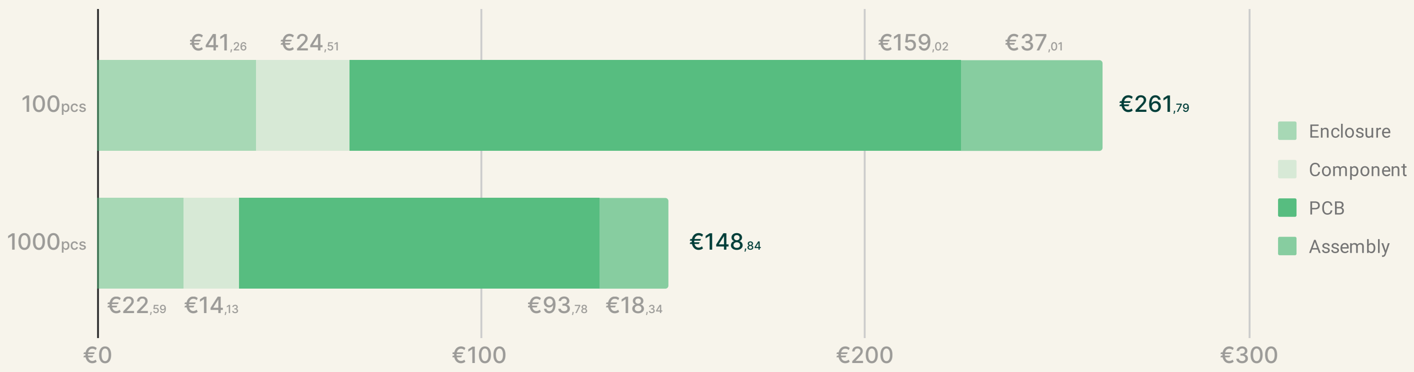


Figure 78: comparison of cost distribution

Production cost

The price estimate of cause builds upon assumptions regarding assembly time, and hourly costs of assembly of 10min at 15€/hr., which is an estimate that can vary greatly.

Furthermore, we have assumed that there is needed further development that can be done with a combination of in-house and outsourced. For this, we have allocated €100.000. this should include a simple app, with the feature described within this report, and further development of the mechanical parts and hardware. The price estimation does not include the costs of maintenance of the app.

The total cost of 1000units is roughly €250.000, which exceeds the capital currently in the possession of the client does not have at the current moment. We see two options, being one: receive funding from interested companies like Besstrade, Van Werfen and The Ocean Cleanup. The other option is going through a crowdfunding campaign via IndieGoGo or Kickstarter. Based on the overwhelming feedback from the public and open-source Community, a crowdfunding campaign could make sense, but it also risks shipping thousands of scanners out to customers who don't really need them. We would therefore recommend finding a source of funding that understand and align with the overall sustainability direction of the concept.

Total cost	1000 pcs
Development	€100.000,00
Material	€108.410,61
Labour	€19.843,33
Tooling	€7.000,00
Marketing	€10.000,00
Distribution	€10.000,00
Total	**€255.253,94**

Cost per unit	1000 pcs
Development	€100,00
Material	€108,41
Labour	€19,84
Tooling	€7,00
Marketing	€10,00
Distribution	€10,00
Total	**€255,25**

Retail price	
Cost price	€255,25
Profit	€571,19
Profit (%)	224%
Net price	€826,45
Vat (21%)	€210,00
Retail price	**€1.000,00**

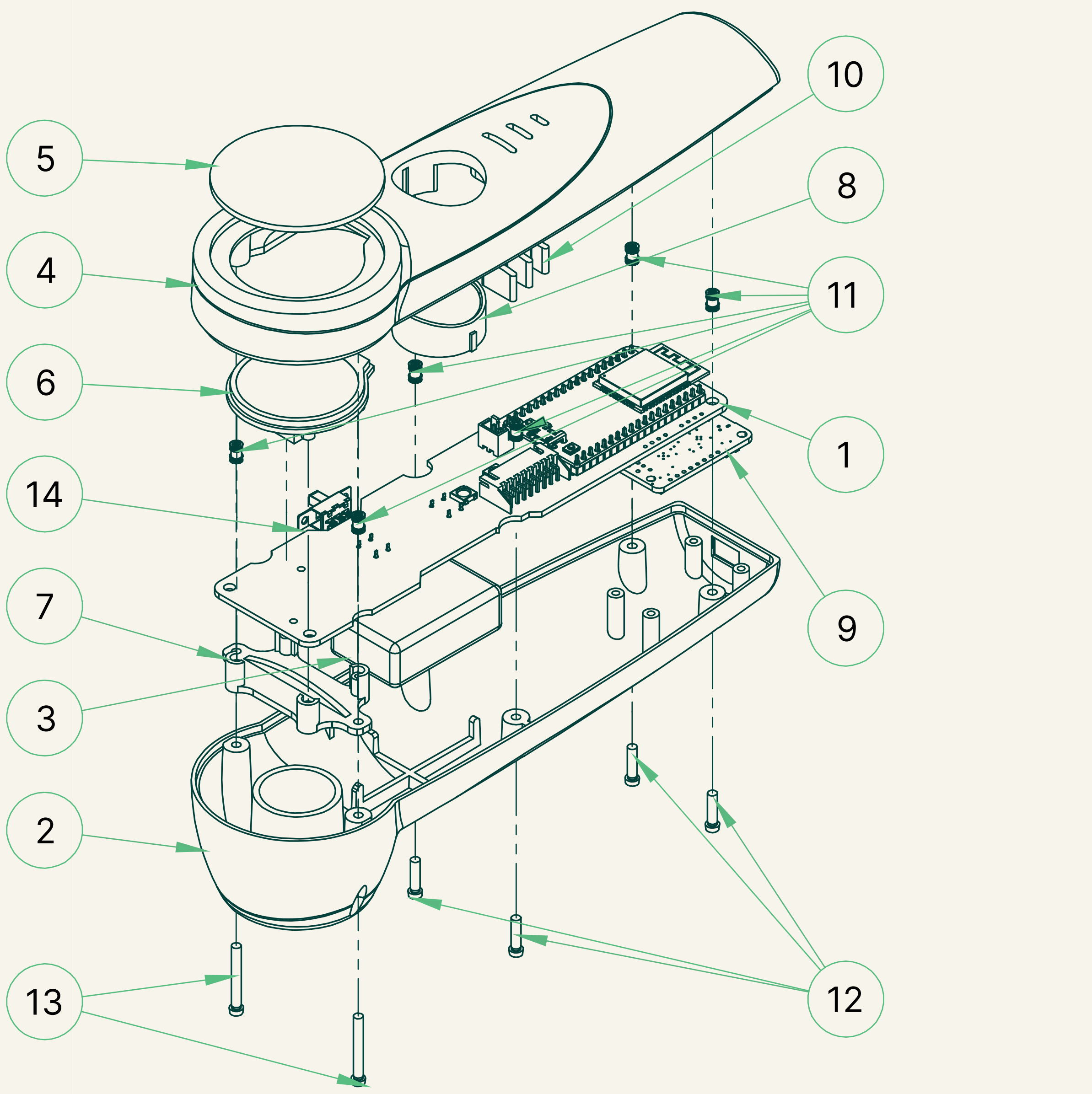
Figure 79: Retail price breakdown

ADE

7.4 Technical design package

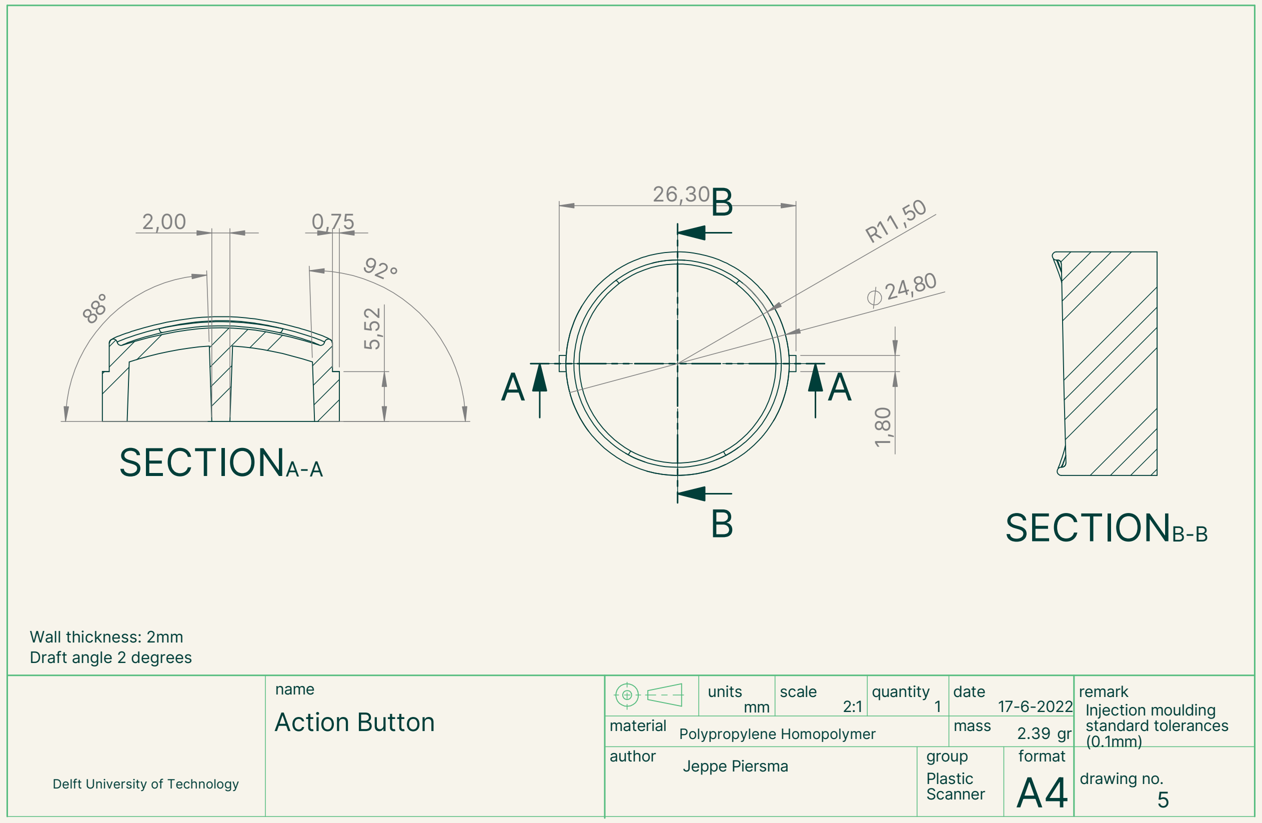
For the development of the plastic scanner a lot of effort was put into detailing the enclosure and the PCB. The details to these parts can be seen in the product drawings, more details can be seen in Appendix M and N.

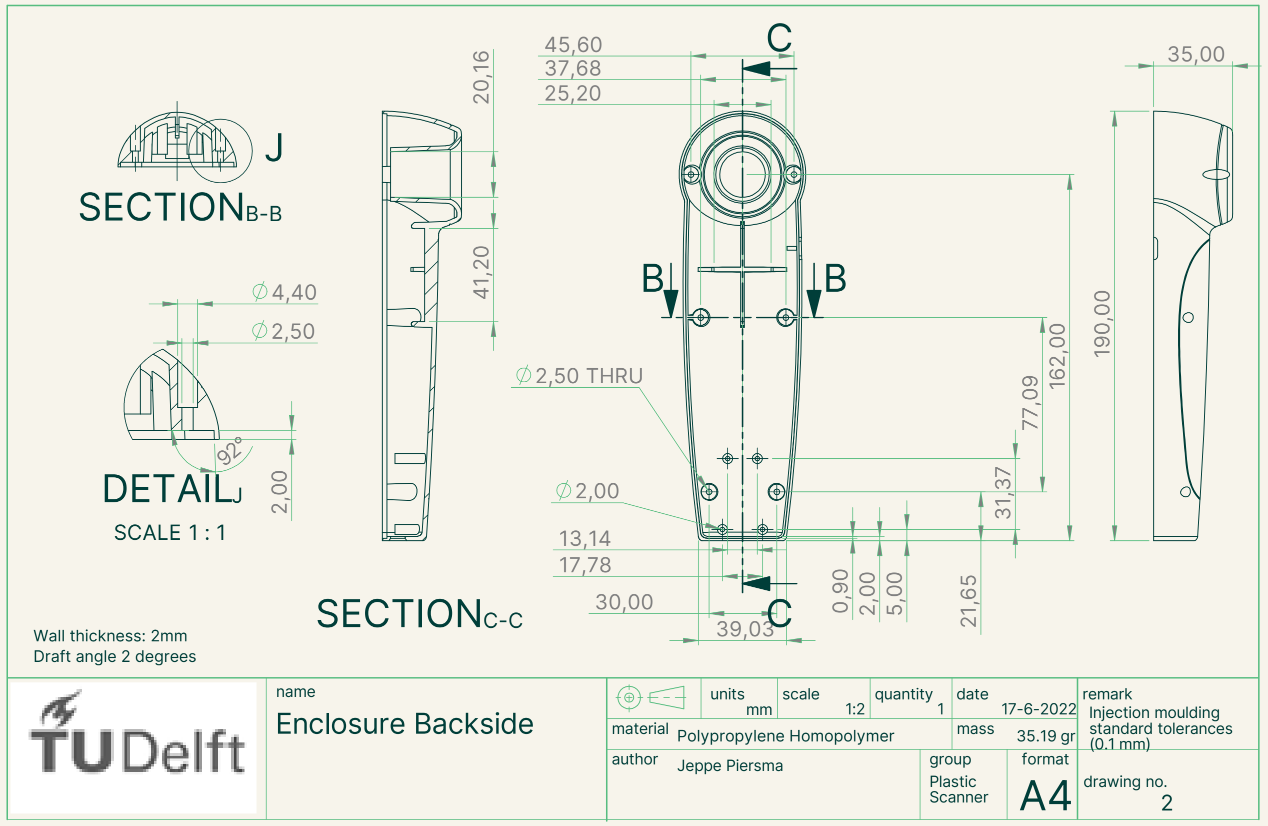
The front and backside of the enclosure are produced with injection moulding and optimised for manufacturing. The PCB has been produced already for prototyping purposes (5 pieces).



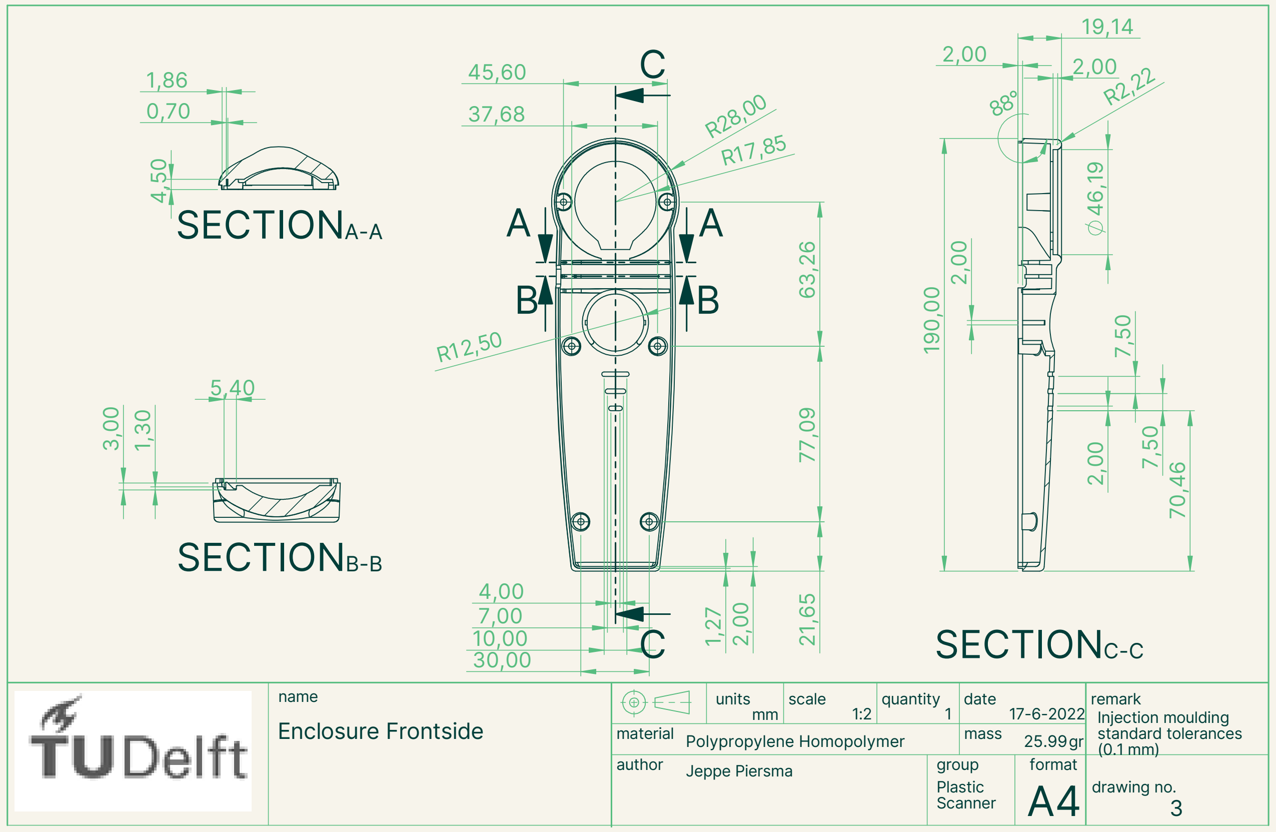
ITEM NO.	PART NUMBER	QTY.
1	Plastic Scanner 2.0 PCB	1
2	Enclosure Backside	1
3	Seamuing 1000 mAh LiPo	1
4	Enclosure Frontside	1
5	Glass	1
6	Screen module	1
7	Screen fixation	1
8	Action button	1
9	Power module - PowerBoost 1000C Rev B v1	1
10	Battery indication light carrier	1
11	Threaded Insert M2x5x3.5	6
12	ISO 14580 - #2 x 10 x 9.2 - 4.8-	4
13	ISO 14580 - #2 x 20 x 19.2 - 4.8-	2
14	SS12F15	1

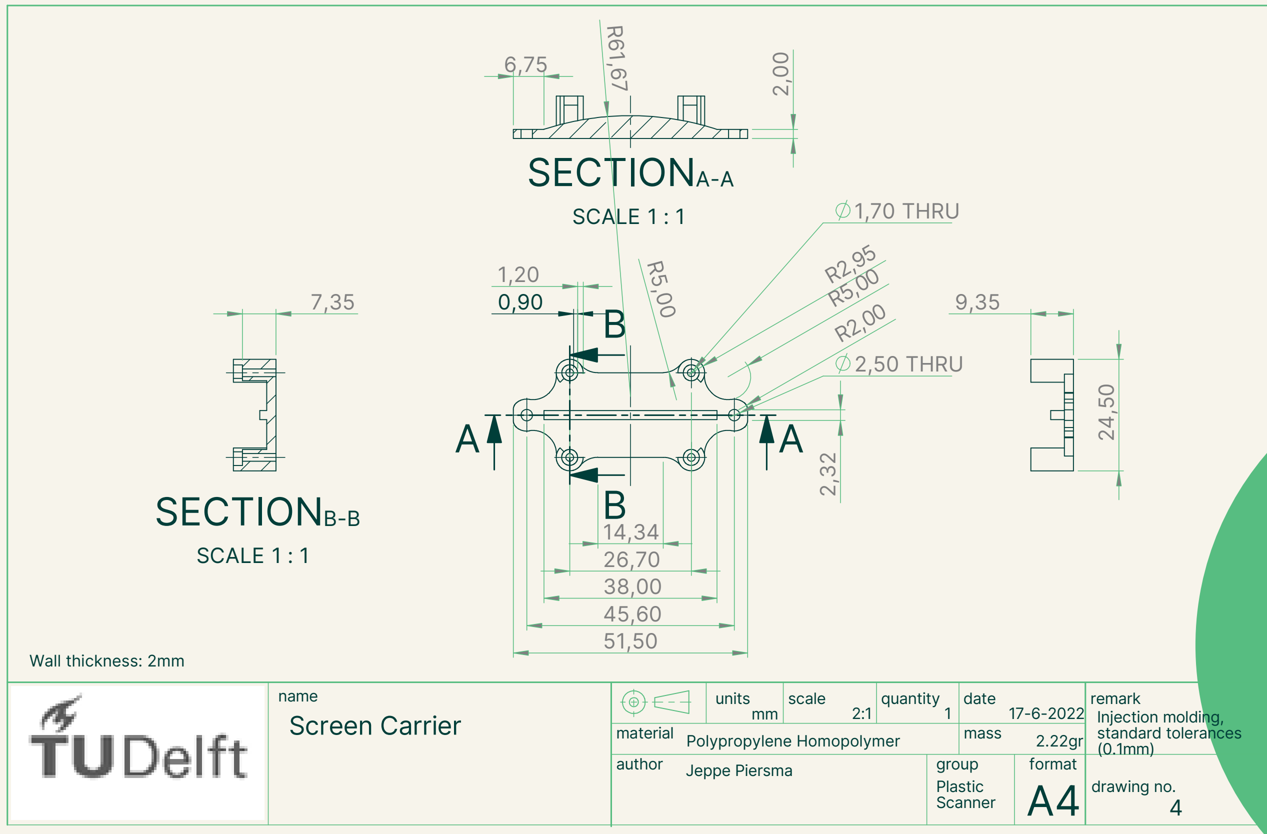
name: Plastic Scanner 2.0 Assembly	units: mm	scale: 1:2	quantity: 1	date: 17-6-2022	remark: -
	material			mass: 152.55gr	
	author: Jeppe Piersma		group: Plastic Scanner	format: A4	drawing no.: 1





The cost estimation of all parts can be found in the next subchapter.





Bill of materials

Name	Description	Category	Supplier	ID	Units	Unit Price 100	Unit Price 1000	Total 100	Total 1000
WS2812B LED	RGB LED	PCB	Digikey	COM-16347	2	€0,68	€0,56	€1,36	€1,13
Tactile button 6mm	Trigger button	PCB	Digikey	1825910-6	1	€0,11	€0,07	€0,11	€0,07
TLC59208FIPWR	I2C chip	PCB	Digikey	TLC59208FIPWR	1	€1,84	€1,03	€1,84	€1,03
JST XH 8	Screen Connector	PCB	Digikey	S8B-XH-A(LF)(SN)	1	€0,46	€0,22	€0,46	€0,22
Tactile button 6mm	Reset button	PCB	Digikey	1825910-6	1	€0,11	€0,07	€0,11	€0,07
JST XH 2	Power connector	PCB	Digikey	B2B-XH-A-M(LF)(SN)	1	€0,16	€0,07	€0,16	€0,07
POWER LED		PCB	Digikey	SML-LX1206GW-TR	1	€0,41	€0,11	€0,41	€0,11
OPA2376xxD	Power leveler	PCB	Digikey	LMV772MMX/NOPB	1	€1,81	€1,01	€1,81	€1,01
LM285D-2.5	Power leveler	PCB	Digikey	LM285D-2.5R2G	1	€0,81	€0,36	€0,81	€0,36
940nm IR	940nm IR LED	PCB	RS Components	OIS-330-IT940-X-TU	1	€0,43	€0,38	€0,43	€0,38
1050nm IR	1050nm IR LED	PCB	Digikey	MTSM5010-843-IR	1	€16,64	€9,33	€16,64	€9,33
1200nm IR	1200nm IR LED	PCB	Digikey	MTSM0012-844-IR	1	€11,66	€5,46	€11,66	€5,46
1300nm IR	1300nm IR LED	PCB	Digikey	MTSM0013-844-IR	1	€11,66	€5,46	€11,66	€5,46
1460nm IR	1460nm IR LED	PCB	Digikey	MTSM6014-844-IR	1	€11,66	€5,46	€11,66	€5,46
1550nm IR	1550nm IR LED	PCB	Digikey	MTSM5015-844-IR	1	€11,66	€5,46	€11,66	€5,46
1650nm IR	1650nm IR LED	PCB	Digikey	SWIR EMITTER 1650NM 1206 SMD	1	€18,81	€10,94	€18,81	€10,94
1720nm IR	1720nm IR LED	PCB			1	€37,62	€21,89	€37,62	€21,89
FerriteBead	Ferrite bead	PCB	Digikey	MH2029-400Y	1	€0,09	€0,03	€0,09	€0,03
ESP32-DevKitC	Microcontroller	PCB	Mouser	356-ESP32-DEVKITC32D	1	€9,50	€9,50	€9,50	€9,50
JST SH 4	Button connector	PCB	Digikey	BM04B-SRSS-TB(LF)(SN)	1	€0,55	€0,34	€0,55	€0,34
AMS1117-3.3	Power leveler	PCB	Tinytronics	AMS1117 3.3V - SOT-223	1	€0,50	€0,50	€0,50	€0,50
ADS1256IDBT	ADC SPI module	PCB	Digikey	ADS1256IDBT	1	€18,83	€14,81	€18,83	€14,81
8MHz	Crystal	PCB	Digikey	830108313809	1	€0,54	€0,39	€0,54	€0,39
82 Ohm	82 Ohm resistor	PCB	Digikey	RMCF0805FT82R0	1	€0,09	€0,00	€0,09	€0,00
75 Ohm	75 Ohm resistor	PCB	Digikey	AC0805FR-0775RL	4	€0,09	€0,01	€0,36	€0,03
70 Ohm	70 Ohm resistor	PCB	Digikey	RMCF0805FT69R8	1	€0,09	€0,00	€0,09	€0,00
62 Ohm	62 Ohm resistor	PCB	Digikey	RMCF0805FT62R0	1	€0,09	€0,00	€0,09	€0,00
56 Ohm	56 Ohm resistor	PCB	Digikey	CRCW080556R0FKEA	1	€0,09	€0,01	€0,09	€0,01
51pF	51pF capacitor	PCB	Digikey	CC0805JRNPO9BN510	2	€0,13	€0,03	€0,26	€0,05
49.9 Ohm	49.9 Ohm resistor	PCB	Digikey	RNCP0805FTD49R9	2	€0,09	€0,01	€0,18	€0,02
47nF	47nF capacitor	PCB	Digikey		1	€0,09	€0,01	€0,09	€0,01
301 Ohm	301 Ohm resistor	PCB	Digikey	RNCP0805FTD301R	2	€0,09	€0,01	€0,18	€0,02
240k Ohm	240k Ohm resistor	PCB	Digikey	RMCF0805FT240K	2	€0,09	€0,00	€0,18	€0,01
22uF	22uF capacitor	PCB	Digikey	CL21A226MQQNNNG	3	€0,13	€0,03	€0,39	€0,08
1k Ohm	1k Ohm resistor	PCB	Digikey	RNCP0805FTD1K00	2	€0,09	€0,01	€0,18	€0,02
18pF	18pF capacitor	PCB	Digikey	C0805C180M3HAC7800	2	€0,09	€0,02	€0,18	€0,03
170 Ohm	170 Ohm resistor	PCB	Digikey	RMCF0805FT169R	1	€0,09	€0,00	€0,09	€0,00
150 Ohm	150 Ohm resistor	PCB	Digikey	CR0805-FX-1500ELF	1	€0,09	€0,00	€0,09	€0,00
10uF	10uF capacitor	PCB	Digikey	CL21A106KOQNNNG	1	€0,10	€0,02	€0,10	€0,02
10k Ohm	10k Ohm resistor	PCB	Digikey	RNCP0805FTD10K0	4	€0,09	€0,01	€0,36	€0,05
104 Ohm	104 Ohm resistor	PCB	Digikey	CL21C101JCANNNC	2	€0,09	€0,01	€0,18	€0,02
100pF	100pF capacitor	PCB	Digikey	CL21C101JCANNNC	2	€0,09	€0,01	€0,18	€0,02
100nF	100nF capacitor	PCB			6	€0,09	€0,01	€0,54	€0,07
100 Ohm	100 Ohm resistor	PCB	Digikey	CRG0805F100R	5	€0,09	€0,01	€0,45	€0,05
10F	10F capacitor	PCB	Digikey	CML0805C0G100JT50V	1	€0,09	€0,01	€0,09	€0,01
Green diffused	Green diffused LED	PCB	Digikey	SML-LX1206GW-TR	1	€0,41	€0,11	€0,41	€0,11
0 Ohm	0 Ohm resistor	PCB	Digikey		5	€0,09	€0,01	€0,45	€0,05
Screen	Screen	Component	Amazon	Link	1	€24,01	€14,01	€24,01	€14,01
3.7V 1000mAh	Battery	Component	Amazon	Link	1	€4,25	€4,25	€4,25	€4,25
Powerboost 1000	Battery management	Component	Amazon	Link	1	€23,89	€6,00	€23,89	€6,00
46mm x 2mm	Glass screen screen	Enclosure	Timeparts.nl	Link	1	€7,75	€2,58	€7,75	€2,58
18mm x 1.5mm	Glass screen sensor	Enclosure	Timeparts.nl	Link	1	€5,25	€1,75	€5,25	€1,75
BN 20138	Pan head PT® screws	Assembly	Bossard	3218789	10	€0,07	€0,04	€0,65	€0,40
Upper Enclosure	Upper Enclosure	Enclosure	Injection Moulding		1	€17,50	€7,25	€17,50	€7,25
Lower Enclosure	Lower Enclosure	Enclosure	Injection Moulding		1	€17,50	€7,25	€17,50	€7,25
Assembly Minutes	Assembly Minutes	Assembly	Assembly		10	€0,25	€0,20	€2,50	€2,00
Gasket	Gasket	Assembly			1	€0,50	€0,20	€0,50	€0,20
Total								**€266,31**	**€140,40**

Figure 80: Bill of Materials with costs

7.2 Hardware documentation

ADE

In this section we will present the hardware related choices we have made; on what basis we have made the decisions on and describe the impact for the design.

Choice of screen

From the first meeting with Besstrade, and online research, we quickly found out that the user interface of the existing products, was a major user pain point, that we needed to tackle. Therefore, we set out to find screen solutions that could be integrated in the product in an aesthetically pleasing way, and give simple, precise, and easily understandable information to the user.

What options did we have?

There are an almost unlimited number of screens on the market with a variety of possibilities. The team looked at options ranging from dot matrix and classical 7-element digit displays as seen on old digital clocks. Here the information level was too simple, due to the very limited number of colours (monochrome) and low resolution (7-element pr. Digit) or 8×8 dot matrix. Therefore, we looked at screens with higher resolution. We found a variety of LCD/TFT, OLED and e-ink displays that could fit the purpose. We ended up going for a LCD screen because it would enable us to use different colours for signalling success, progress and errors to the user in a simple and effective way.

Finally, it was a requirement for the screen to have available information on how to interface with Arduino devices, to make it easier to develop prototypes and make visually pleasing screen content.

What did we choose and why?

Due to the design direction moving towards a rounded scan head for the aesthetic design, we went searching for a round LCD screen. We found a 1.28-inch round LCD development board with a 240×240px resolution and SPI interface, that fitted all requirements . The screen runs on a GC9A01 screen driver, that can be controlled via the relatively well documented and active "TFT_eSPI" library for Arduino.

For future development we have found larger screens that can fill the whole bezel area intended for the screen and give better readability through larger text. This screen has a driver that is supported by the TFT_eSPI library but requires specific power handling and an interface for the flexible FPC cable. This was not possible to implement during our project but would contribute with significant improvements if implemented.

ADE

Choice of microcontroller

The original hardware is based on an Arduino Uno microcontroller, that can be mounted on the main PCB. The current PCB design is a rectangle of 10×15cm with all soldering done on the top side, which means that the scanning area is facing upwards. Furthermore, we do not currently have the possibility to connect breakout boards for prototyping various peripherals like the screen, SD cards or wireless connectivity.

We want to implement a new microcontroller to get a smaller PCB footprint to make it possible to be handheld, have more pins for sensors and screen and the possibility to add wireless connectivity, to prepare the proposed PCB design for future further development of e.g., mobile apps, but at the same time minimizing the porting effort from the current to proposed hardware/software.

Options
To simplify development, we focus on "System-On-a-Chip" (SOC's or devboards), instead of specific chips or modules. The current solution is an Arduino UNO which is a simple and very popular prototyping board, with only simple microcontroller abilities. In recent years, the ESP32 microcontroller has become popular due to its low price, and active open-source developer community. The chip has Wi-Fi, Bluetooth and its own mesh protocol build in, and is very energy efficient. Furthermore, it can use (but not train) machine learning models via tensor flow lite. There exists a lot of modules like ESP32. They typically have very similar performance, features and formfactor, but a significantly smaller and less active community. The last option is the mini version of the "Computer-on-a-chip" Raspberry pi Zero, which is a smaller version of the raspberry pi. This chip has the wireless connectivity via Bluetooth and Wi-fi, and processing power enough to train simple machine learning models via tensor flow, due to its higher computational power, which also results in significantly higher energy consumption.

The ESP32 can be programmed in Arduino IDE and works with most Arduino libraries, which makes it easy to transition from an Arduino Uno to ESP32. The Raspberry Pi Zero would need a full rewrite of all code.

Choice: ESP32
Based on the need for high portability, connectivity, and low energy consumption, it seems like the ESP32 would be the best module to implement. In our design we have implemented a pre-designed development board onto the PCB, but in the future the form factor can be further reduced by implementing an esp32 module instead. It should be noted that the current ESP32 is being replaced by newer generations: ESP32-S2 and S3. These should have a very similar formfactor and performance and are both supported by the Arduino framework as well.

	Arduino Uno	ESP32	Raspberry pi Zero
Cost	€22	€13	€13
Type	Micro controller	Micro controller	Micro computer
Bluetooth	No	Yes	Yes
Wi-fi	No	Yes	Yes
Energy Consumption	Medium	Low	High
Processing Power	Very low	Low	High
SD card	Breakout board	Breakout board	Build in
Programming language	Arduino (C++)	Arduino (C++)	UNX
Library support from current firmware	Yes	Mostly yes	No
Effort to change	Low	High	Very high

ADE

PCB Design

We see three main strategies to reach our goal. Firstly, we can black box the components and ask the client to design something that fits our requirements. That would probably mean that it's not possible to have a fully working prototype within our project time frame. This also means that we will only be able to work on an Arduino UNO during the project, which makes it hard to prototype with connectivity via Wi-Fi/Bluetooth/SD card.

The second strategy is to fully develop a PCB design for an ESP32, based on the current KiCad files, that fits our needs and enables storage to the SD card. This will take a lot of effort to firstly learn the routing program which the current project is made within: KiCad and afterwards understanding how the routing works, and what we need.

The third strategy is a mix of the two. This strategy is to develop an MVP demonstration of the full system, using the current "PCB #2" in our possession as a breakout board, connected to on an ESP32 and other relevant peripherals like SD card slot.

This will enable us to use other control units, and thereby more easily prototype wireless connectivity and SD card storage.

Goal
Create a working prototype with a dedicated PCB with a form factor that enables us to test the prototype in context

Options
The design of the PCB(Figure 69) has been an iterative process going back and forth between wishes for aesthetic design requirements and the possibilities in the technical design. The two main problems have been to get the PCB front as close as possible to the scanning surface of the object, and to have a slim enough form factor to allow a slim handle that fits the hand of the user optimally.

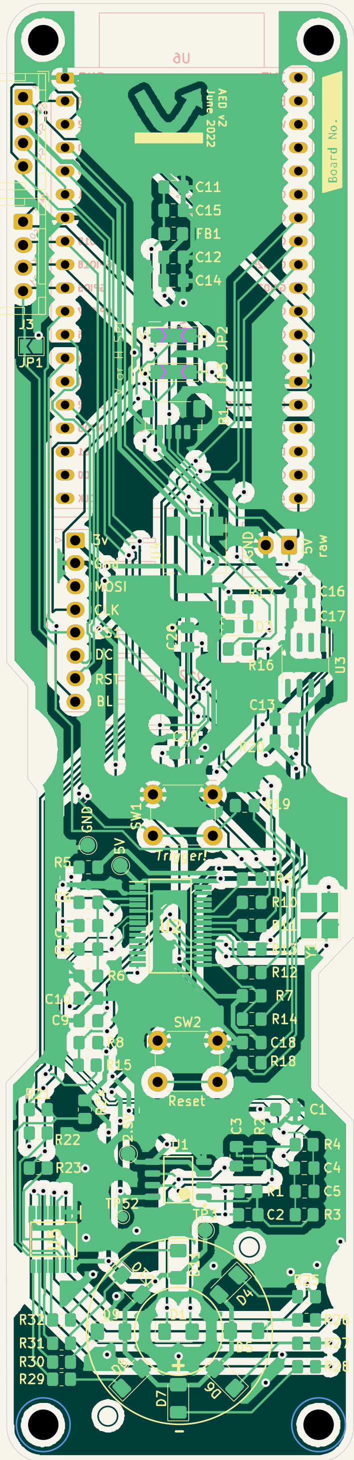


Figure 81: PCB

Changes from original
We have implemented an ESP32 microcontroller, to enhance connectivity and reduce formfactor. This has given us the possibility to use more SPI interfaces, due to the chip having both HSPI and VSPI, compared to the UNO's single SPI interface. We have added solder jumpers on the PCB, so it's possible to alter which SPI connection the screen is using [Insert picture of solder jumpers here].

We saw a need for giving simple light cues to the user and concluded that the existing single colour LED would be constraining for future UX development. Therefore, have added two RGB LEDs on the side of the PCB facing towards the user, to enable light ques for e.g., battery indication, light feedback, or status indication. We chose LEDs are of the type "WS2812B" over a conventional three pin RGB LED because it uses only one signal pin and can be addressed via its placement in a series of LEDs, and we have placed a series of two LED's.

We have changed the button placement to be aligned with the physical button in the product. The button is a through-hole component but can be left out and replaced by a button connected by the optional JST connector placed on the lower side of the PCB.

To handle power, we have chosen not to not design our own power handling solution, because it is simply not within our professional field of work. Therefore, we are using an off the shelf component: Adafruit PowerBoost 1000 module, to charge a 2000mAh LiPo battery, and ensure sufficient and stable 5v power supply to our PCB.

PCB has gained connectors of the type JSP XH, to interface the 8-pin connection to the screen and the 2-pin connection from the power Adafruit PowerBoost 1000 module handling charging and draw from the 2000mAh LiPo battery. We have picked the XH series of connectors because they have the same footprint as regular 2.54mm through-hole connections and could therefore be moved to any side of the PCB, or just used for debugging without a pin.

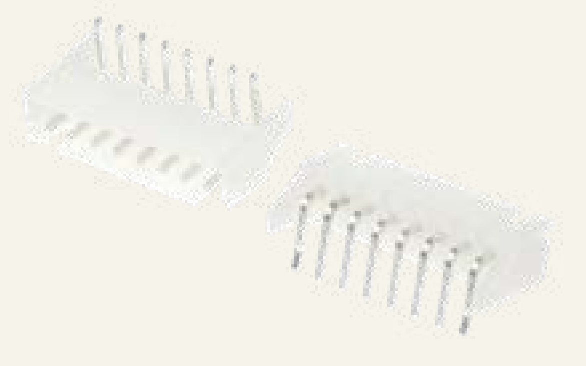
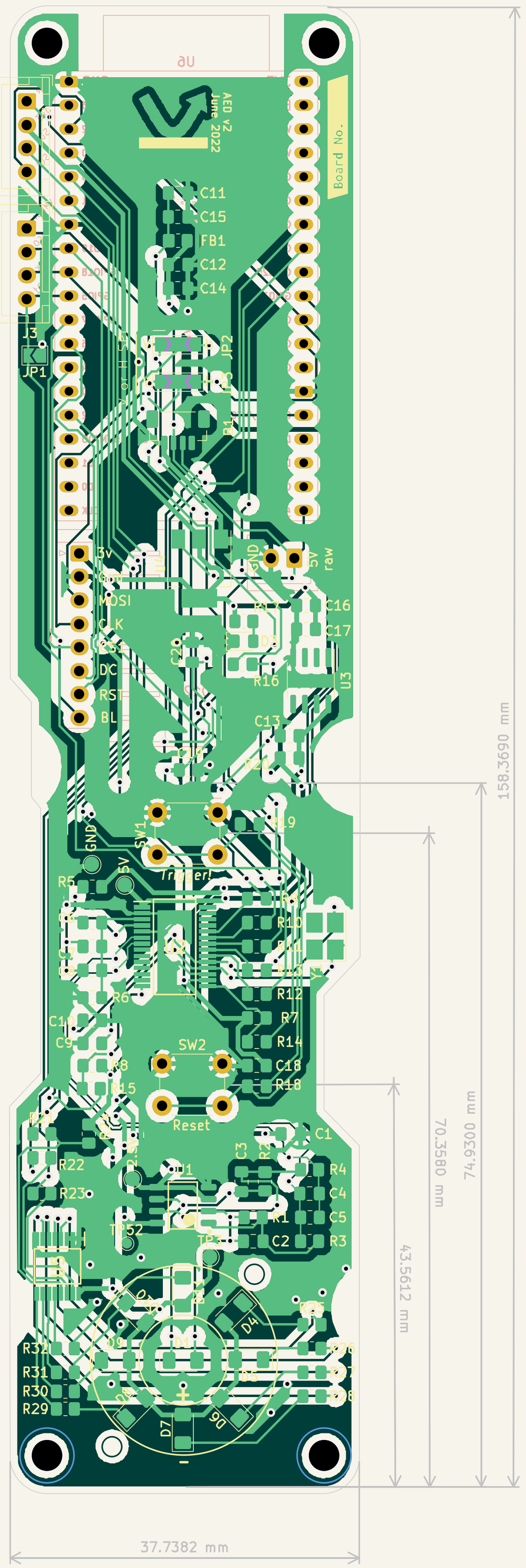
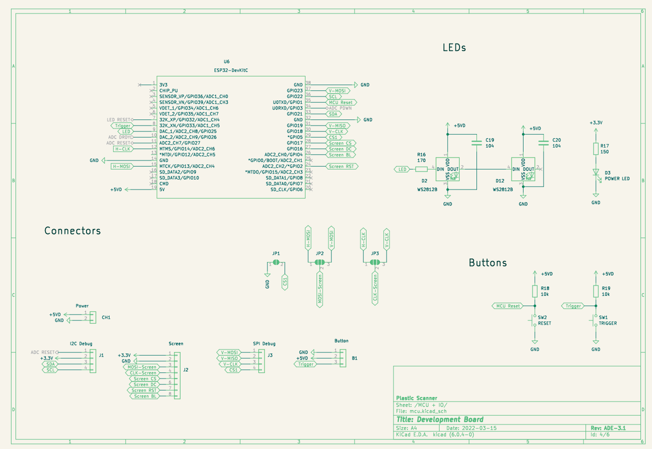
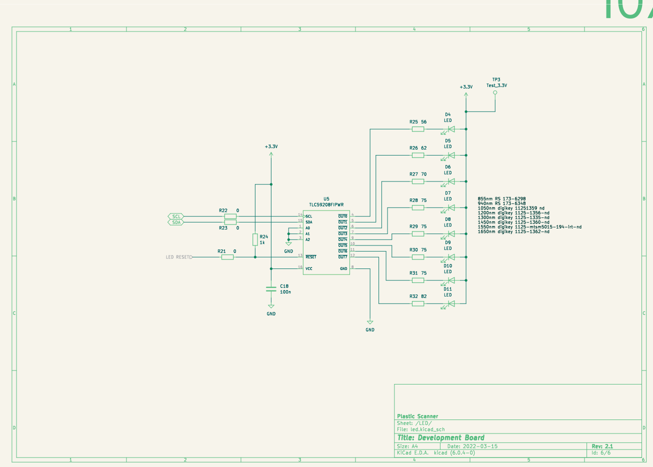


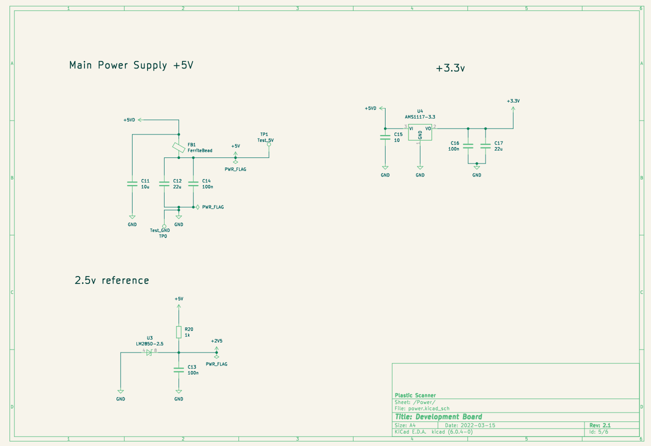
Figure 82: Pins

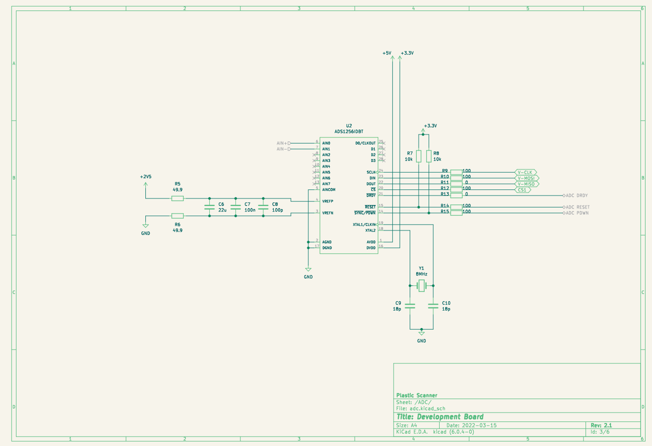
ADE

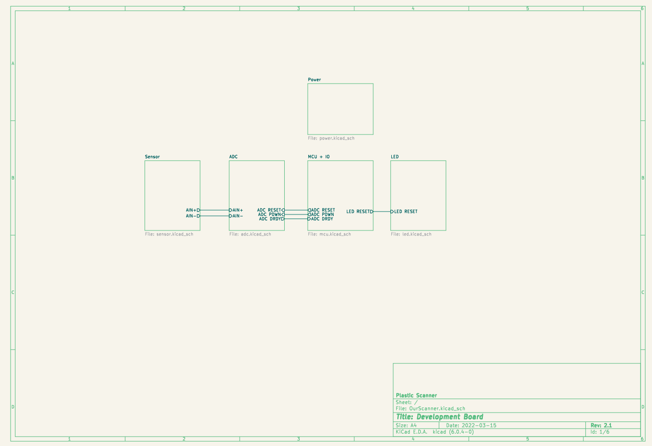

AED v2
June 2022
Board No.
C11
C15
FB1
C12
C14
J3
JP1
MOSI
CLK
DC
RST
BL
C16
C17
R16
U3
C13
Trimmer
SW2
Reset
C1
R4
C4
C5
R1
C2
R3
R22
R23
R29
R30
R31
D4
D7
158.3690 mm
74.9300 mm
70.3580 mm
43.5612 mm
37.7382 mm

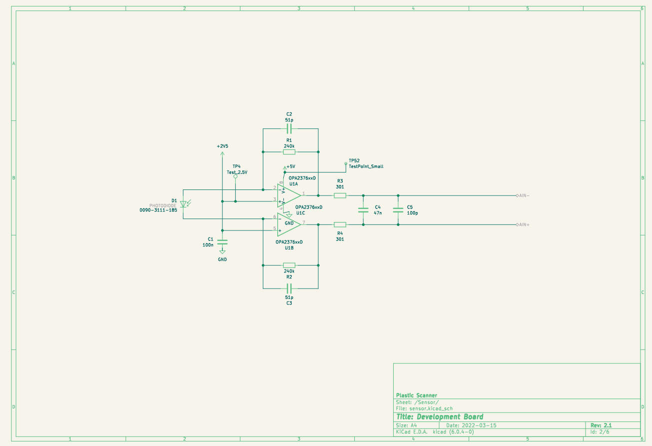

LEDs
Connectors
Buttons




Main Power Supply +5V
+3.3v
2.5v reference







Recommendations PCB Design
The proposed PCB design is trying to give space for screws and mounting features of the two shells and give space for the other components.

The PCB has Four M3 holes for screwing the PCB onto the lower shell and has cut-outs to enable cables to go from connectors on the lower side to their placement on the upper side. Furthermore, we have made cut-outs to give room for screw bosses for connecting the upper and lower enclosure parts.

For future improvements of the PCB, we have a couple of recommendations

First of all, it would be ideal to further minimise the PCB footprint by switching from a ESP32 development board to a smaller ESP32 SOC module that is SMD soldered directly onto the PCB. This will cut down the footprint size and reduce the thickness of the PCB assembly. To further minimise this, we would recommend switching to smaller and more compact horizontally oriented JST connectors like she SH instead of the bulky through hole XH connectors used now. This will make the cables smaller and save a lot of space in general.

We would also recommend integrating the power handling module, which is right now an off-the-shelf product from Adafruit. Adafruit is publishing the schematics as Open source which makes the integration easier. This will of cause increase footprint size but can also replace some existing components used for power handling.

The current design is missing a USB interface for charging that is accessible when the product is assembled. We would recommend implementing a IP-67 USB-C connector to the PCB facing the end of the product, to enable charging and maybe data transfer.

Lastly we would recommend to implement an on/off switch on the PCB, to further reduce energy usage during standby, and better align the buttons and LEDs in relation to the enclosure.

7.3 Firmware Documentation

Firmware structure
All firmware is uploaded and documented on the ReadMe.md on GitHub

Why did we work on it?
The original firmware was running a program that listened for serial commands from a computer, for triggering the scanning and sending the results to the computer via serial. This was the only functions the scanner had. To have a functional prototype, we needed to rewrite the software to trigger a scanning via a build in button, use a Machine learning model to determine the type of polymer, give visual feedback via a screen, and implement ways to distribute the results.

Prerequisites
The project uses several external libraries, that it pulls in from a public online repository. All code is published on Github. To get started with the PlatformIO project, make sure to open the project via PlatformIO vis VS code, and have the IDE install the ADS1256, SPI, Wire, TFT_eSPI and multiWifi libraries defined in the platform.ini file.

Diagram
The functional diagram is shown in Figure 71.

When powered on, the ESP32 is booting up and running the setup section initiating serial for debugging, SPI, I2C and Wi-Fi, before running the loop function.

In the loop function the program is first checking if the button state is low, which means that the button has been pressed. If pressed, it runs the scan() function. The scan functions updates the screen, makes a scanning, show the results and send the data, and save the current time in a variable calls LastUsedMills before exiting back to the main loop().

If the button state not low, the program will compare the current time, with the lastUsedMills. If the difference is larger than the predefined sleep timer value, then the code will run a DeepSleep() function, making the ESP32 turn off all peripherals, the radio module, BLE, Wi-Fi and core memory, and only use the dedicated ultra-low power coprocessor that listens for a button press, and initiates a boot when triggered. The Deep sleep mode reduces the typical power consumption from ~200μA (excluding the screen and) to just 10μA.

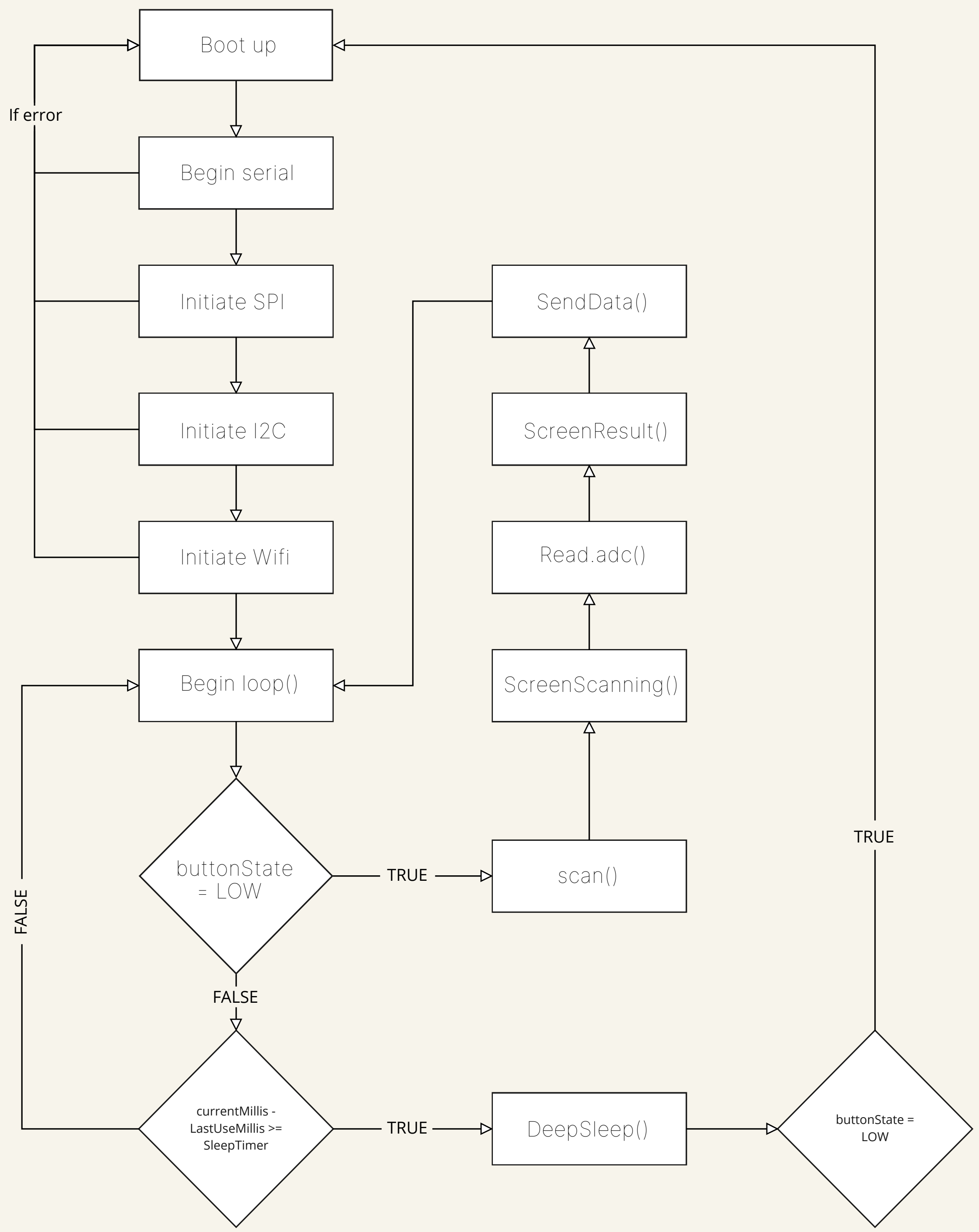


Figure 83: Flow diagram

What would we recommend doing next?

The current code has issues with the communication with the ADC module, delivering results from the sensor. The ADC used in the original Plastic Scanner project is not adequately defined, and occupies the chip select persistently, making it impossible to use communicate with other devices via SPI. In our current hardware design, we have utilized that the ESP32 has two separated SPI interfaces to communicate with the screen and sensor on different interfaces. In the future this needs to be resolved, either by rewriting the library for interaction with the sensor or initiate and end the SPI communication via a function when needed to only occupy the SPI line when scanning.

Furthermore, we recommend making a mobile app for handling all settings, machine learning models and results on a good touch screen. To do this we would recommend using BLE for the mobile to device communication. The ESP can be programmed to broadcast results as a characteristic, which an app can be programmed to listen for. A solution to make Over the Air (OTA) updates of firmware has been published by the major maker community Sparkfun, which means that updating the machine learning model should be possible as well. Else the phone could make a mobile hotspot for the ESP32 to connect to and transfer the new updated ML model via.

Screen interface

From the PE research two directions of screen designs were tested in a digital way. This meant that users were shown pictures of screen designs (Figure X). The digital images need to be converted to C++ written file in order to work with the ESP32 that will be powering the Plastic Scanner 2.0. From the Adobe XD file, the conclusion can be made that nearly every screen has an animation. To make this animations, we cannot simply make convert the images from the file into an array of coloured pixels. Animations can only be shown on the screen if we install a library, that we use to program the screen.

What options did we have?
We have chosen for a circular screen in the design therefore we needed a circular screen to prototype on. The most readily available screen was the Waveshare 1.28inch round LCD display module. A round display with very minimal bezels and great resolution and colour range. The display is powered using an SPI bus, with the GC9A01 driver. This means we have to find a library that supports the GC9A01 driver.

- Adafruit GFX
- GFX Library for Arduino
- TFT_eSPI
- Lovyan GFX

Having picked the library to use, a way of building the screens must be determined. Within the library there are multiple options of building and displaying parts of the screen:

- Storing and displaying images from storage.
- Creating and showing shapes and/or text directly on the screen.
-
- Creating sprites (composites of previously mentioned stored in RAM, ready for use)

What did we choose and why?
We chose the TFT_eSPI library by Bodmer to code our display for multiple reasons:

- This library has a very broad implementation and has many more drivers that are supported. This is convenient in the case that we or the client want to change to a different screen in the future.
- With the library having predefined many things for us, this means there is less coding to do and time to be saved by using this library in comparison to the Adafruit GFX library.
- The library has performance optimizations build in for the ESP32, this means it will run faster than most other comparable libraries.
- The library has great and elaborate documentation and examples. Next to this the library is used by many people implementing TFT displays, therefore having a lot of helpful tutorials and other documentation online. This makes troubleshooting much faster compared to other libraries.
- While libraries such as LovyanGFX include more features, these features are not relevant to this product. This means implementing such libraries would have a negative impact on system performance, not to mention taking up precious storage on the ESP32.

Our design uses different ways of compiling the screens in our final prototype:

- On system boot, the Plastic Scanner logo is displayed. This is an image stored on the ESP32. We could create the logo using multiple shape layers and store them as a sprite, saving quite some storage on the ESP32. This however would take much more time than simply converting the shape into a UFTF image file and displaying that on boot. If we do not implement too many (and especially not big resolution) image files, we can get away with it.
- The other screens are build using sprites, because they are a combination of many shapes and text items. It is faster to create the sprites at boot and then call them later than it is to let the ESP compute all the images on the spot.
- Screens that are very simple and require just a single shape and some text are coded in line, while the processing time is then very low.
- Screens that require animations are also composed with sprites, because those offer more pre-programmed functions to move items around within the sprite. A good example is the scanning bar on the scanning screen. The scanning bar is a sprite, which moved within the background sprite using a scrolling function.

What would we recommend doing next?
The screen we have used for prototyping is very fitting in the context and allows us to test all requirements for our design. There is however a problem that exists with the size of the display. The display for prototyping is smaller than the proposed final design, the display should therefore be swapped out by a bigger, 2 inch LCD display. Finding a larger screen that is supported by the library proved more difficult than expected. The most prevalent display driver for larger displays is the ST7701S, a 3-wire SPI and RGB LCM interface. This is not supported by the TFT_eSPI library, because this uses 9-bit instead of 8-bit.

In the end we have found a display that is supported by the TFT_eSPI library that fits our design rather well. For the future design we would recommend implementing the Xintech round 2.1 inch IPS LCD display (Figure 72). The display driver is ST7789, which is already supported by the TFT_eSPI library. The display has a minimum order quantity of 1000 pieces, so going for this option requires a large investment. The display can be hardwired to the PCB, freeing up space that is now occupied by the adapter board.

Figure 84: Display Recommendation

Machine learning model

Working on machine learning (ML) model to see if the accuracy or collecting and processing learning dataset can be improved. Initially, Jerry has been already working with the algorithm and the database in the first project. Current solution uses Tensorflow Lite, which is an open source machine learning platform for microcontrollers. The client has documented the workflow, covering the topics of how to take the measurements, ML model training and integrating ML model into the main code. Measurement taking requires the use of spectralon - while ceramic plate which reflects almost all IR waves – which is used to help scan transparent plastic and retrieve the maximum reflectance values for the rest of the dataset.

Why did we work on it?
We want to ideate and improve ML workflow by testing out several different algorithms to see if the accuracy and training dataset collection can be improved. In addition, the current workflow requires spectralon which is considered used for optical scientific measurements and comes, is relatively expensive and hard to get.

What options did we have?
To test different ML models, a small dataset was collected using client's samples ("Figure 73: Sorted plastic types to the Dataset" on page 114) mainly consisting of PP and HDPE. The dataset was organized into the table depicting measurements from different wavelength reflectance, sample ID, plastic type, colour and texture ("Figure 73: Sorted plastic types to the Dataset" on page 114).

The data was prepared as a training dataset for different types of ML models: SVC, Random Forest, XBoost (Optimized Gradient Boosting). Algorithms have a different way of learning to classify data ("Figure 74: ML learning models and how they learn from the given dataset" on page 111) therefore it was decided to compare the test accuracy and see which of the ML models performs the best. Differently from the client's TensorFlow use, Scikit-learn ML environment was used. The code for ML model training was written in Python, previously mentioned dataset was used (less processing was done compared to the client's approach). The results have shown that transparent plastic scans without reflective material behind confuse ML models too much, therefore the transparent scanning readings have been taken out. The results have showed that XBoost (Gradient Boosting) model presents the most accurate results ("Figure 75: Machine Learning Model results" on page 115).

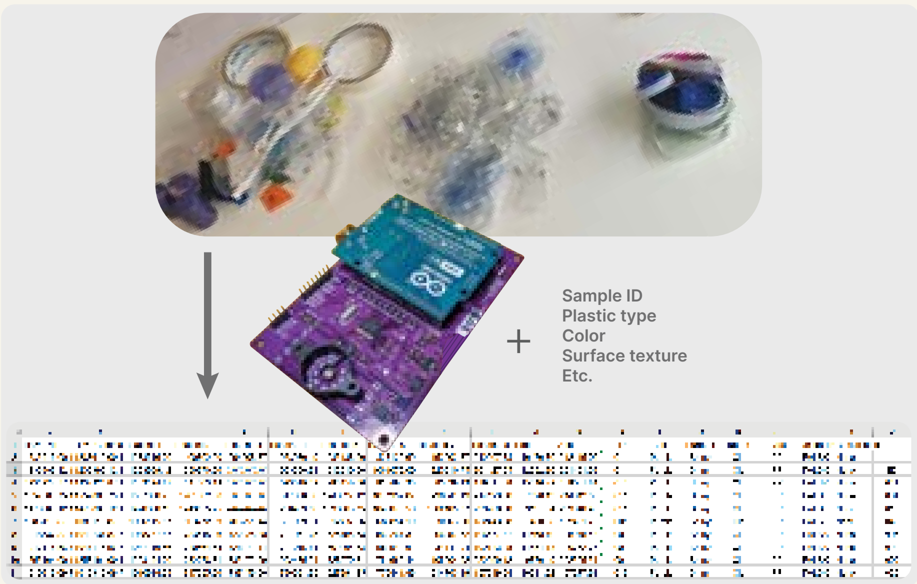


Figure 85: Sorted plastic types to the Dataset

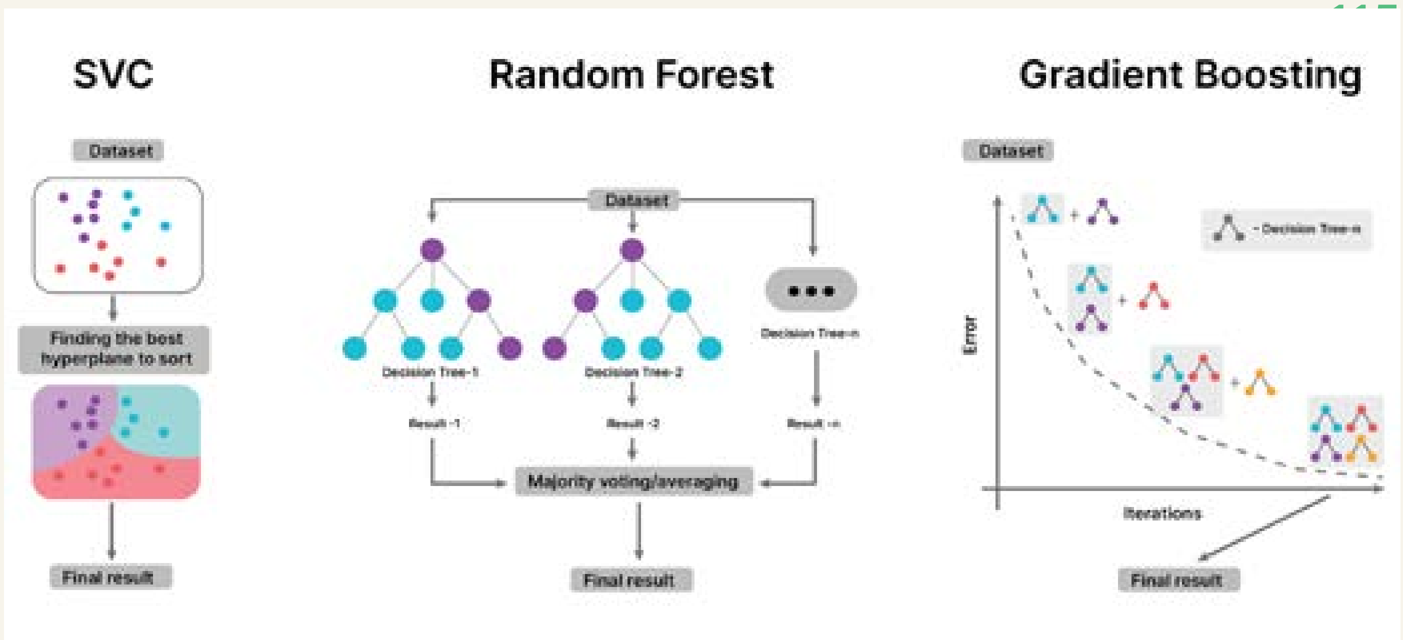


Figure 86: ML learning models and how they learn from the given dataset (Data Science Team, 2020; TIBCO, n.d.; Fraj, 2018).

What did we choose and why?

XBoost ML algorithm demonstrated the best accuracy results with relatively limited dataset and a minimum amount of processing. In Addition, it was decided to look for more other reflector solutions which could be used instead of spectralon as the reflector was proved to be a necessary part while scanning for transparent plastics.

What would we recommend doing next?
ML model. Current model demonstrates relatively high accuracy in distinguishing the measurements between PP and HDPE. Therefore, further iterations adding more plastic types could be tested with a better quality dataset: better measurements, more data pre-processing, increasing the number of samples.

Using the model in ESP32. Currently Scikit-learn ML models can be used in microcontrollers by using an open-source MicroML generator 'micromlgen' (Elonquent Arduino, 2021; Github, n.d.). It would be recommended to test the implementation of this workflow on the current ESP32 microcontroller used for Plastic scanner.

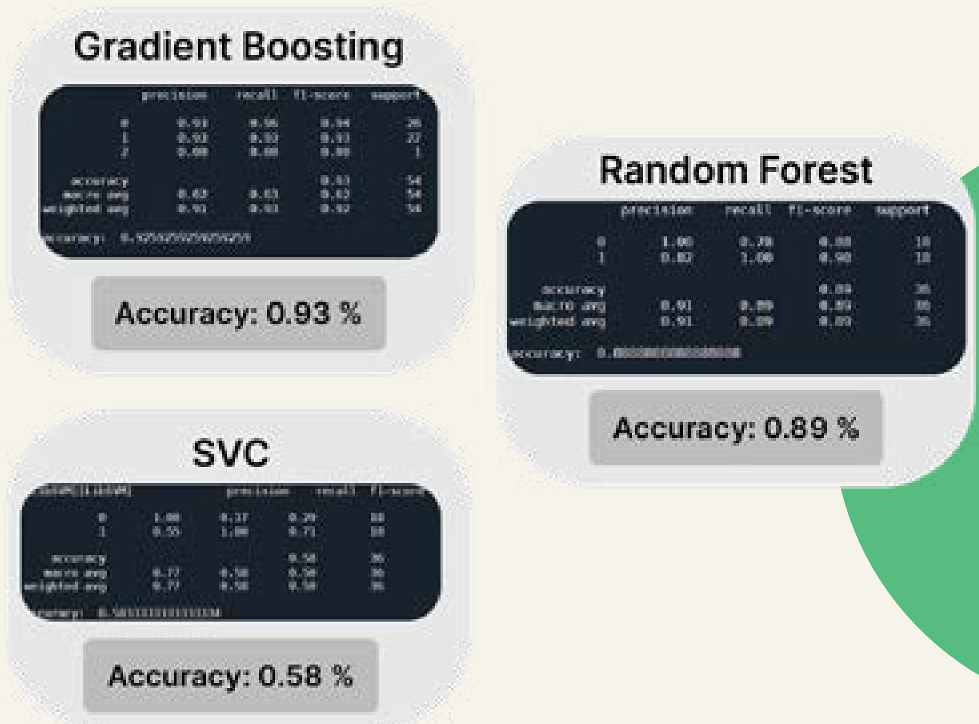


Figure 87: Machine Learning Model results

7.5 TRL Level evaluation

ADE

According the project definition and the first version of the scanner we can state that the initial TRL is 4. The expected goal for this project has been TRL 7 but due to a complete change of the use context and major changes done to hardware (housing, structural and interactive elements, user interface, electronics). The overall TRL level of the final design is 5, because a rough working prototype was tested in intended environment with recycling facility workers (Figure 76), with functioning screen but not the actual scanning. Separate design elements have reached varied levels of TRL (Figure 77):

Figure 88: Prototype testing in use context

Casing parts
3D printed and can be assembled with the electronics, but not injection moulded, manufacturing details still need to be developed.

Waterproof assembly
Applications for IP66 rating have been explored, but not implemented.

Screens
the UI designs have been designed and tested with the users using qualitative and quantitative test.

PCB
has been manufactured in small scale (10 pcs) and tested.

Scanning
The code for the scanning is tested and the readings are presented in the Excel sheet. Parts of comparing the reading to the database and presenting the result to the user are still needed to be developed.

User Interface
the screens have been tested in the intended context with the users. The core principles are working. Further on, the screen designs have to be coded to reflect that intended UI design.

Machine learning model
Different ML models have been trained to evaluate the accuracy from two different plastic types. Database has to be expanded with 5 plastic types and their readings. Then the ML model needs to be trained again and implemented into the code of ESP32.

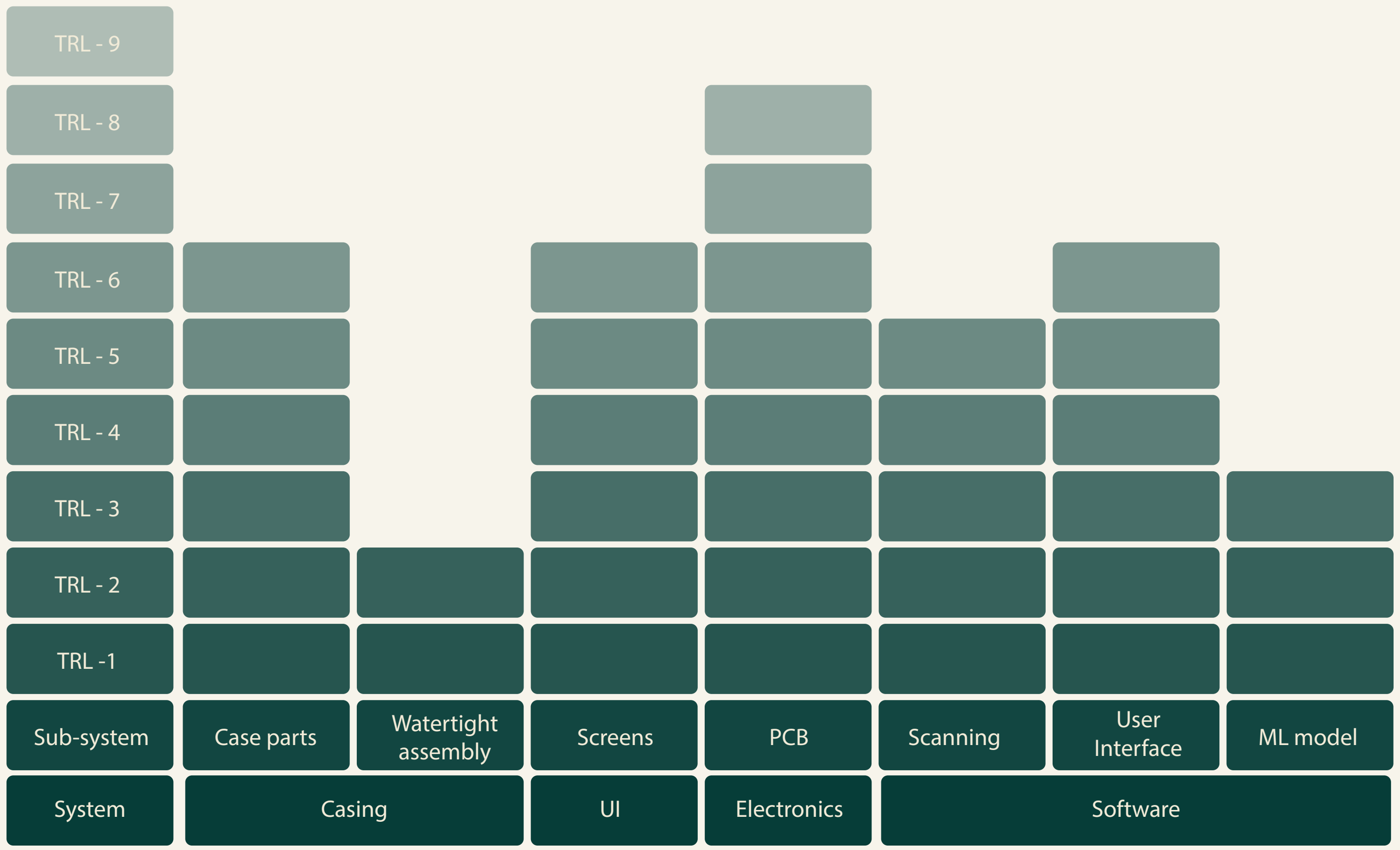


Figure 89: Technology Readiness Level (TRL) evaluation

7.6 Branding

PE

To have communicate in-line with the design of the product branding rules have been created for a coherent and professional look.

What options did we have?

Options were: choosing a specific font and specific colors.

What did we choose and why?

When designing the screens was found that Roboto (mainly the condensed version) resulted in high readability and is used for smaller screens. To keep the overall style coherent Roboto Condensed has been chosen as branding font for the plastic scanner. The main color of the product is green (#528073), as this is the color of plastic resin that is mainly retrieved from recovering PP fishing nets sold by Oceanworks. Additional colors that are being used are shades of green and grey (Figure 78).

What would we recommend doing next?

The product can have more color options then only green, as Oceanworks sells more color options. Thus, the product can be produced in multiple colors. This can be handy to distinguish scanners for specific workers in the future (such as sorters versus managers). Or a certain company could prefer to have a different color. In Figure 79 multiple color variations are presented that are in style with the first green model. Hereby, the detailing colors are coherent throughout the different variations and for branding, the same additional color grey can be used.

Insights and recommendations

Conclude with your main findings, critical analysis of testing the primary functions and recommendations for the client. Besides project related parts, a critical assessment on the projects' results is expected in this report including the aspects achieved and failed.

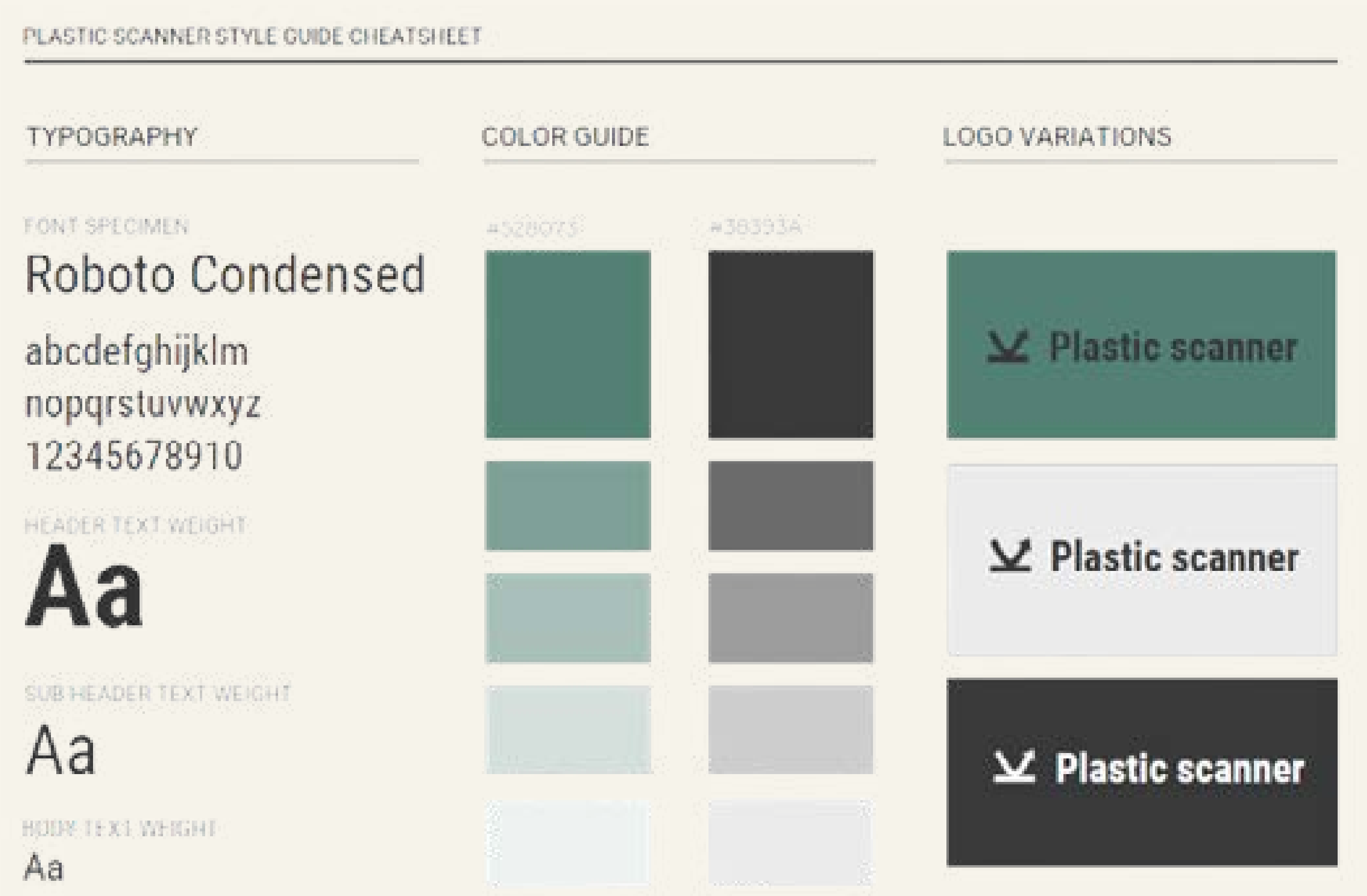


Figure 90: Brand cheatsheet

Figure 91: Color options of the plastic scanner

8. Insights & recommendations

7.7 Findings

Context of use:
There is need for two different types of interactions when scanning: 1. the company is working with one type of plastic (for example PVC) and 2. when the company sorts various types of plastics. In the first scenario, the worker wants to know whether the scanned sample is PVC or not. With the second scenario, color coding is assigned to distinguish 5 different types of plastics quickly to sort the samples more efficient.

Shape
Both shapes were found to be perceived as reliable: the curvy shape looks more professional, but the bulky shape looks more sturdy but less professional. Overall, the curvy and more modern shape was preferred. This shape preference was also affected by the resemblance of a razor because people tend to prefer the shape, they can relate to most.

Screen style
The simplistic screens are overall preferred mainly due to the utilitarian value assigned to the Plastic scanner. The screens which enable users to reach the result faster and are less distracting are preferred, therefore simplistic, colored screens are designed. Text on the screen should be presented largely.

Handle width
The semi-cylindrical handle width of varied width sizes enables a comfortable grip for a larger variety of hand sizes.

Rubber
Integrating rubber elements into the design greatly increases the perception of durability and sturdiness.

Interaction
Users prefer the scanning element to be placed facing away from them while scanning and the button to be placed on the front, prefer the added lights on the front and do not like the battery level visible on the screen.

Machine learning models
Several Machine learning models have demonstrated the potential to be used in classification with fewer steps needed in dataset preparation. Testing the different ML models further with more categories could lead to a more effective ML and sorting.

Systems & Technologies
Smart systems can be employed to create effective communication between the Plastic Scanner, and the company's database. A better and more extensive database can be used for improving the ML model and to make the scanner more accurate. The database can be improved with the help of other companies, using a collaborative approach which is contrary to the current practices of other scanners hiding useful information.

Business plan
The financing for manufacturing the first batch can be done in two ways: through crowdfunding on online platforms, or through collaborative funding from various recycling companies which expressed high interest in having this plastic scanner.

Sustainability
The enclosure can be made from ocean plastic, to align with the client's vision to enhance the circular economy by using plastic waste material and fight plastic pollution by avoiding virgin materials as much as possible.

7.8 Limitations

PE

ADE

Shape vs electronics
The handle dimensions did not completely match with the findings from ergonomics (the handle is slightly too large in width) due to PCB and the number of electronic components needed to be fitted there.

Scanning of black plastics
All the interviewed companies expressed the need to scan black plastics, however due to technological constrains of IR spectroscopy, it is not currently viable to do so.

Comfortable scanning of transparent plastics

Transparent plastics do not reflect enough IR light for an effective scanning without supplementary material which would enhance the reflectance back to the sensor. Therefore, many times an add-on is used behind the scanned sample, which compromises the comfort and speed of the scanning because a separate piece needs to be taken and aligned.

Plastic scan database and effective ML model
Due to not enough plastics in the database, it was not possible to make an extensive database and test with ML models to further improve the accuracy of the scanning.

Sustainability trade-offs.
Recyclability vs durability and easier manufacturing: The enclosure is designed with rubber parts to drastically improve the durability of the product: it protects the enclosure and electronics by absorbing the tensile stress caused by the impact when the scanner falls. 2K injection moulding, (over-moulding of the rubber parts) is the easiest and preferred manufacturing method, but it makes the enclosure part not recyclable anymore. Possible solutions are discussed in 'Recommendations', but these trade-offs cannot be completely solved.

7.9 Recommendations

PE

ADE

Rubber handle

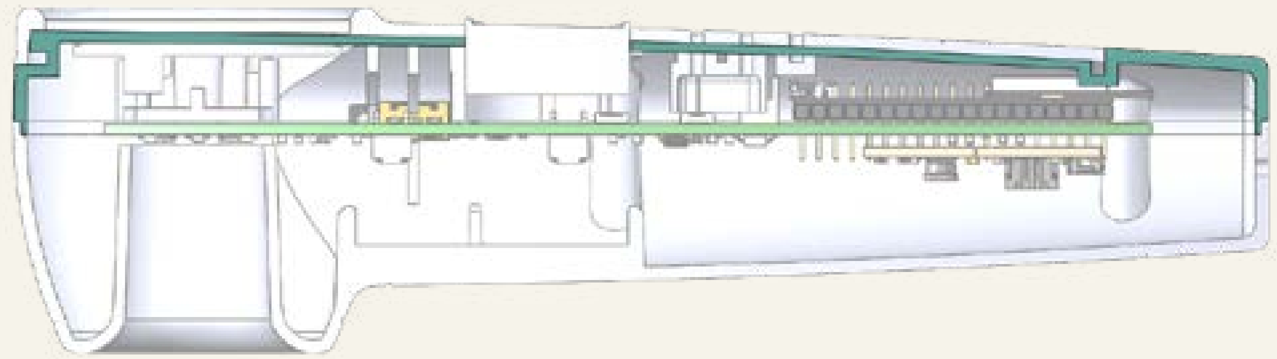
The implementation of the rubber handle parts as shown in the current design (Figure 80, left) is not in line with the sustainability goals set for the product. The most important goal is that the materials used in the product are easily separated, to improve recyclability. The current design can only be achieved by 2K injection moulding, meaning the two handle materials will be fused together. Next to this, the current design does not cover all the areas in which the hand of the user will interact with the handle Figure 80, left). During the product experience testing, we have found that people really like the wrap around rubber component from Design Iteration 7 (DI7) (Figure 80, right) compared to the current design.

With these remarks in mind, we would suggest changing the rubber geometry for the production model to return to a sleeve design like DI7, while keeping in mind product experience of the final prototype. We have identified an opportunity to do so in Figure 81. The recommended design ensures that all parts of the hand are touching rubber parts when in use as can be seen on the right side of the image.

With this suggested design change, the enclosure geometry should also be adapted slightly. This allows for mounting the rubber sleeve in a secure way, without having to fuse them together in 2K injection moulding (Figure 81).

Figure 93: New-Handle-Lines.png:

Figure 92: Rubber-CurrentDesign-Iteration4.png:



Light blocking element.

As is it shown in the Figure 84, current light blocking element should be designed as a cushion made from rubber or other flexible material. The cushion would be fitted into the housing and should be offset no more than 3 mm from the sensor and the IR LEDs, because the distance influencing the spectral characteristics due to light dispersion (Figure 83) (Zhu et al., 2019).

In addition, the piece can be changed to another cushion designed for transparent plastic scanning, which includes highly reflective material at the back side (Figure 82). It has a slot where a plastic sample can be pushed into. The hollow slot thin but made of rubber therefore more adaptable for varied thickness of the plastic samples.

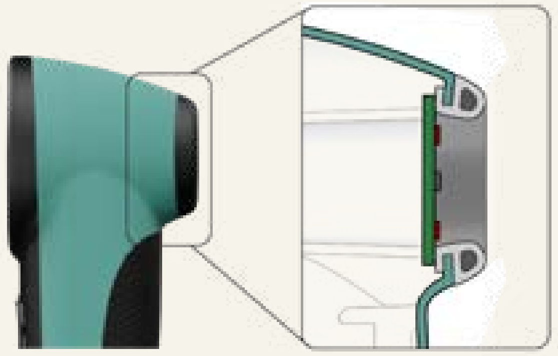


Figure 96: Light blocking flexible cushion for opaque

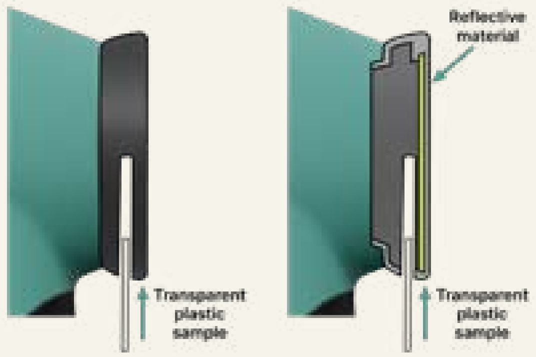
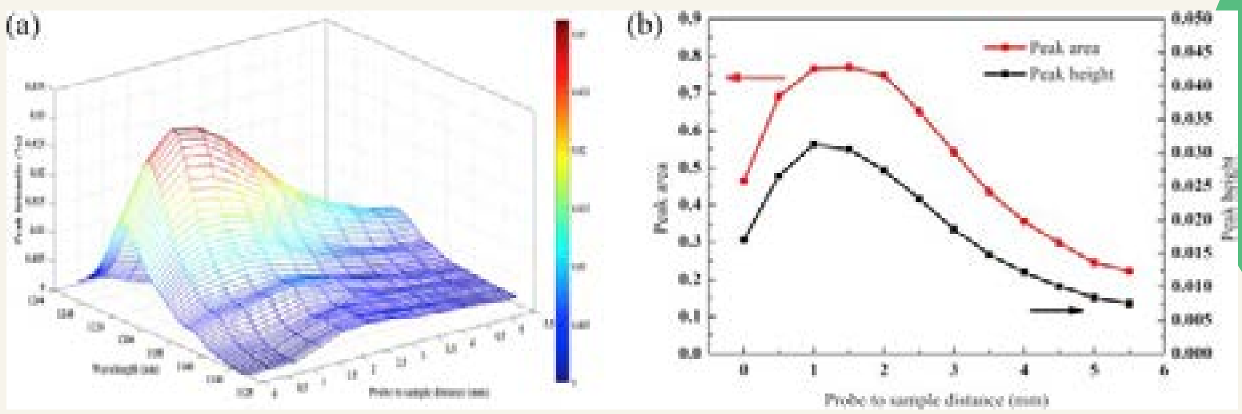


Figure 94: Light blocking element for transparent plastics.

Figure 95: The distance between samples and probe and its influence on scanned spectral characteristics (Zhu et al., 2019)



ADE

Reflective material

In order to deal with high spectralon costs, it is recommended to try out the alternatives: currently, polished aluminium is used by the client, but interestingly, polished Copper demonstrates better reflectance results for the NIR wavelengths between 850 to 1650nm compared to Aluminum see Figure 85 (Layertec, n.d.). If the reflection of polished copper surface is deemed to be acceptable, the plastic scanner devices can be equipped with an additional part to enhance the transparent plastic scanning quality in more economically viable way.

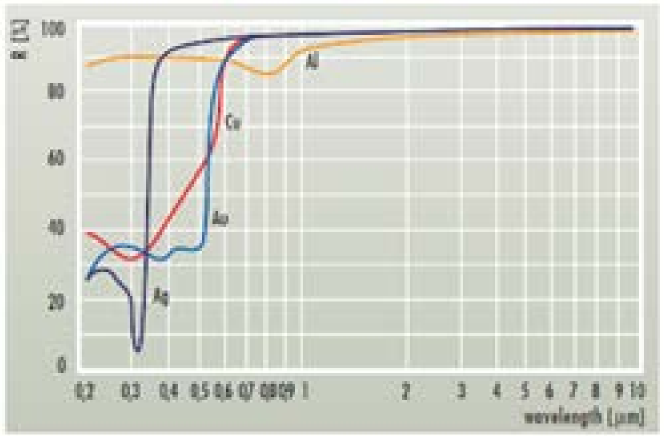


Figure 97: Different material reflectance graph (Layertec, nd)

Increased durability

As mentioned earlier in the report, we expect the current prototype to have reached an IP rating of IP31, this is far of the required IP67 we were aiming for. To reach the intended IP67 rating requires multiple changes to the current design, including enclosure geometry changes for gaskets, changing components and adding extra in house designed components. We would recommend applying the changes described below.

The most critical area of the design is the big opening at the NIR LEDs in the final prototype. To make this area IP67 certified, we would suggest adding a carrier for a piece of quartz glass and sealing that with a gasket.Figure 86 shows the implementation and placement of such a carrier and gasket.

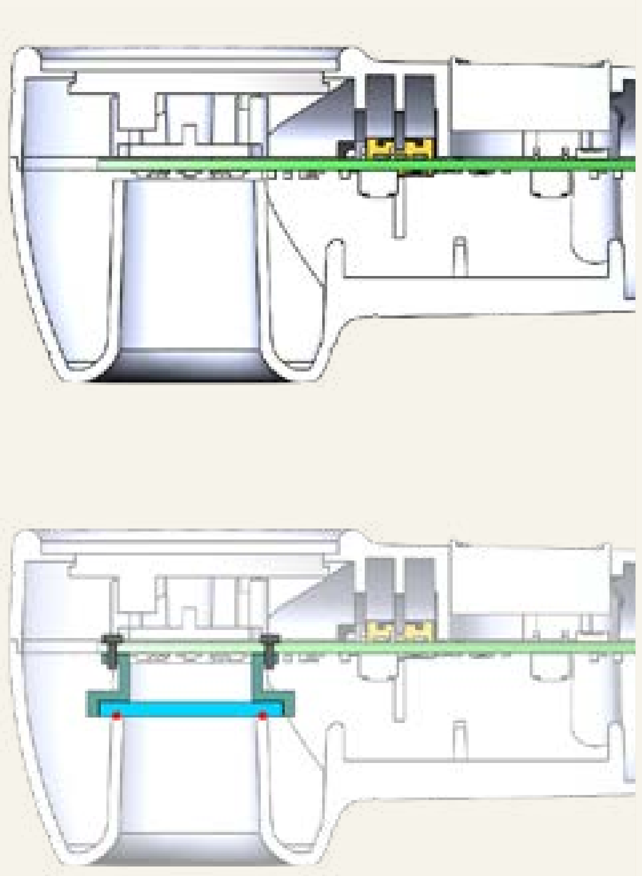


Figure 98: Class carrier gasket

The second important area of the design to be revisited is making sure the enclosure does not let water or dust enter. We recommend the addition of gaskets in the enclosure halves. Figure 87 shows in red the proposed gaskets placement and the proposed geometry changes, to allow for this.

The final area are the components that need to be accessible by the user on the outside of the enclosure. There are possible gaps around those components that can allow particles of dust or water to get into the enclosure. Therefore we recommend changing these components to the components on Figure 88. While the shape of the buttons does not correspond with the proposed design, we are sure that these components can be adapted to look like the proposed design.

There is one final recommendation for changes that increase the durability of the Plastic Scanner. Additional rubber should be added on the inside of the enclosure, to act as dampers for vibrations on the electronic components of the product. Electronics are very delicate and cannot handle vibrations very well. Therefore we recommend adding rubber spacers between the enclosure mounting bosses and the PCB.

Figure 100: IP rated off the shelf components

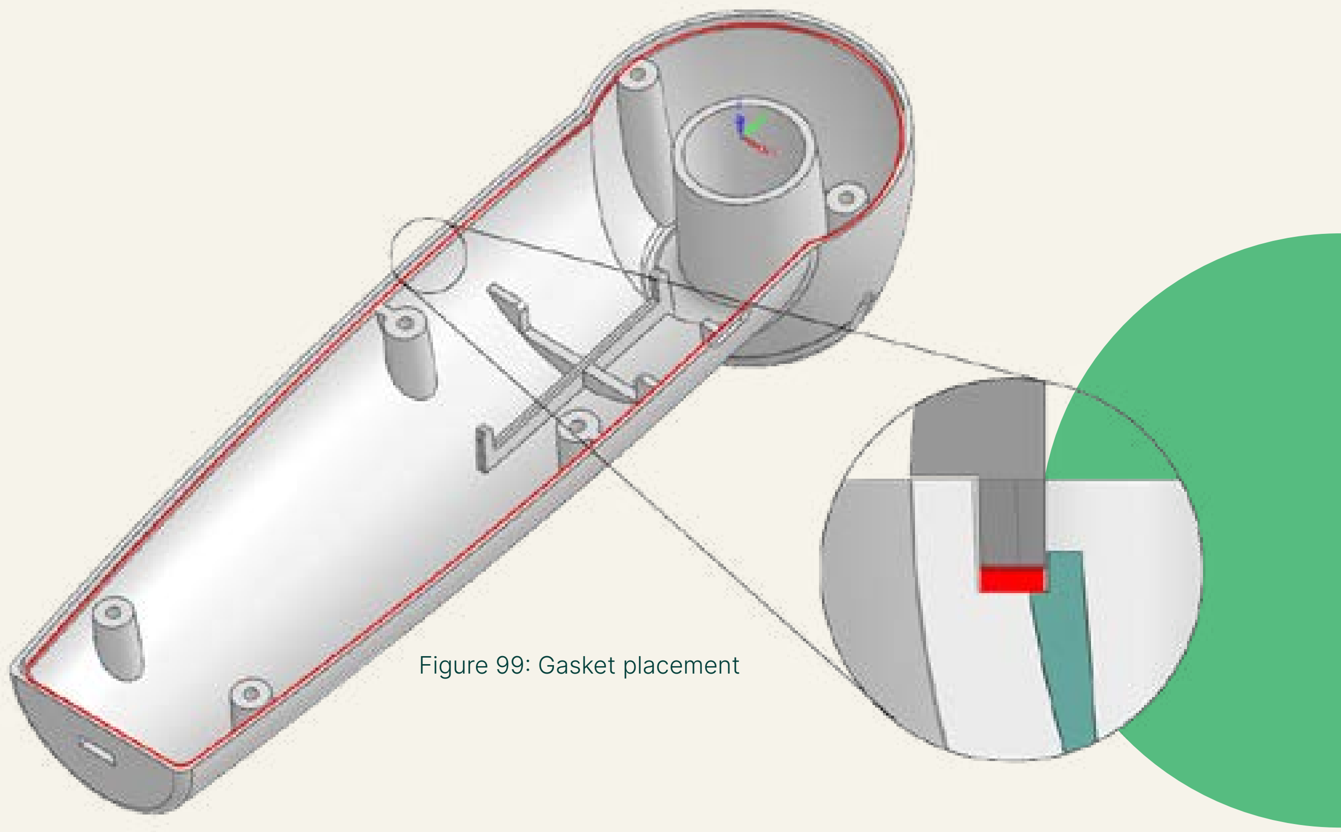


Figure 99: Gasket placement

9.

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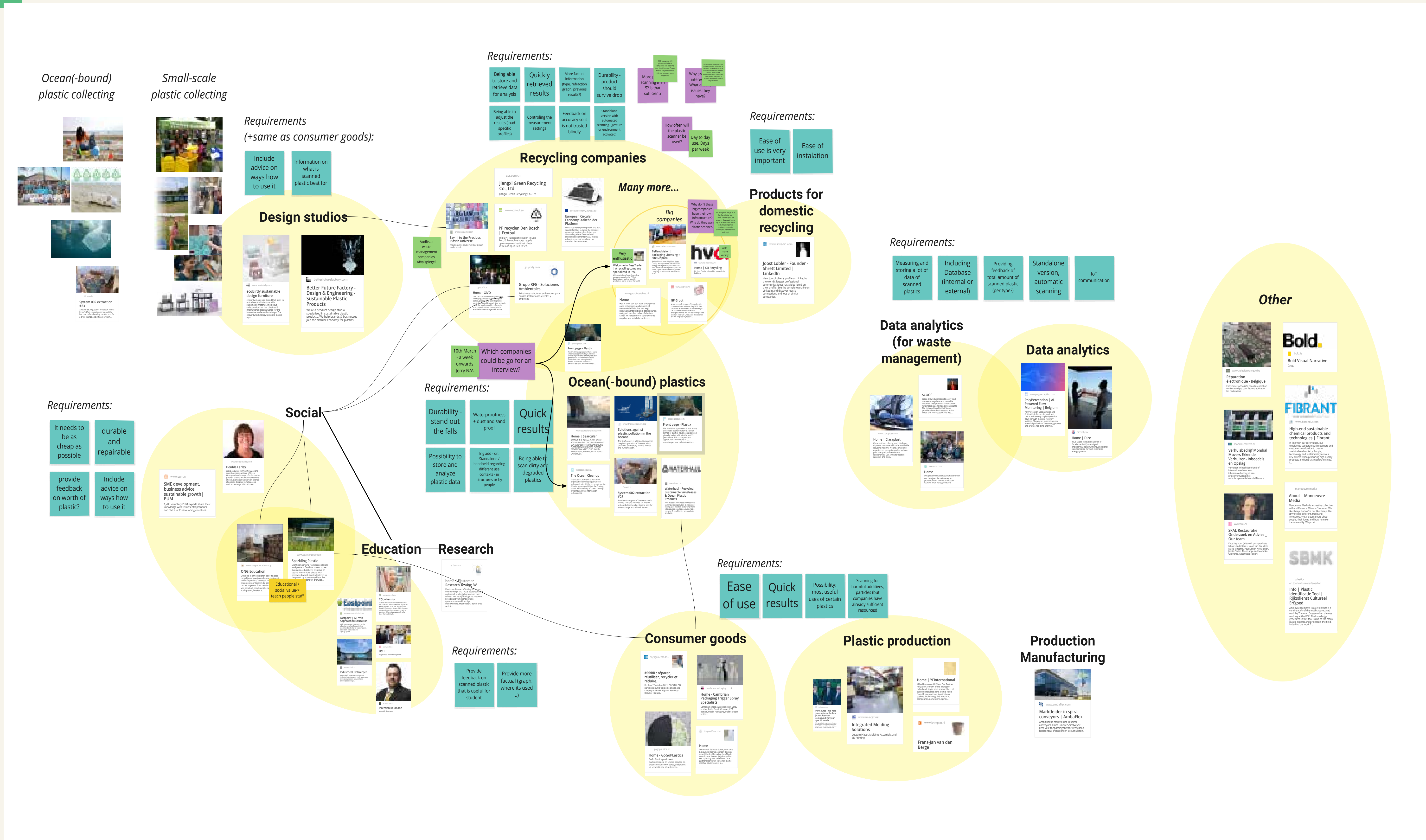
10.

10.1 List of figures

10.2 Appendix A - Stakeholder map


Ocean(-bound) plastic collecting
Small-scale plastic collecting
Requirements (+same as consumer goods):
Include advice on ways how to use it
Information on what is scanned plastic best for
Design studios
Requirements:
Being able to store and retrieve data for analysis
Quickly retrieved results
Durability - product should survive drop
Recycling companies
Many more...
Requirements:
Ease of use is very important
Ease of installation
Products for domestic recycling
Requirements:
Standalone version, automatic scanning
IoT communication
Data analytics (for waste management)
Data analytics
Other
Bold.
FIBRANT
SBMK
Which companies could be go for an interview?
Requirements:
Durability - stand out the falls
Quick results
Possibility to store and analyze plastic data
Ocean(-bound) plastics
Requirements:
It needs to be as cheap as possible
durable and repairable
provide feedback on worth of plastic?
Include advice on ways how to use it
Social
Education
Research
Requirements:
Provide more factual (graph, where its used ..)
Requirements:
Ease of use
Quick results
Consumer goods
Plastic production
Production Manufacturing

10.3 Appendix B - PE assignment Q3

10.4 Appendix B - PE Deliverables Q3

Content PE Exercise 1 meanin

Product category
Handheld device
Scanning device
Scanning device for recycling

Overall experience
Intriguing, informative, simplistic, honest, crafty, cheap

Enclosure
Screen
Button
Switch
Raspberry Pi
Breakout Board
Charge IC
Battery
Enclosure
Glass protector

Product analysis

Product in context

Users chosen:

Ocean(-bound) plastic collecting

Medium and large -scale plastic collecting

Influence of external factors (meta level)

What things influence users? In culture, brand ...

Feeling of belonging in a community

Values
- *Good will*
- *Responsibility*
- *Striving for better future*
- *Environmentally aware*

People:
- *Environmental activists,*
- *Greta,*
- *Young (self) educated people*
- *surfers*
- *Social*

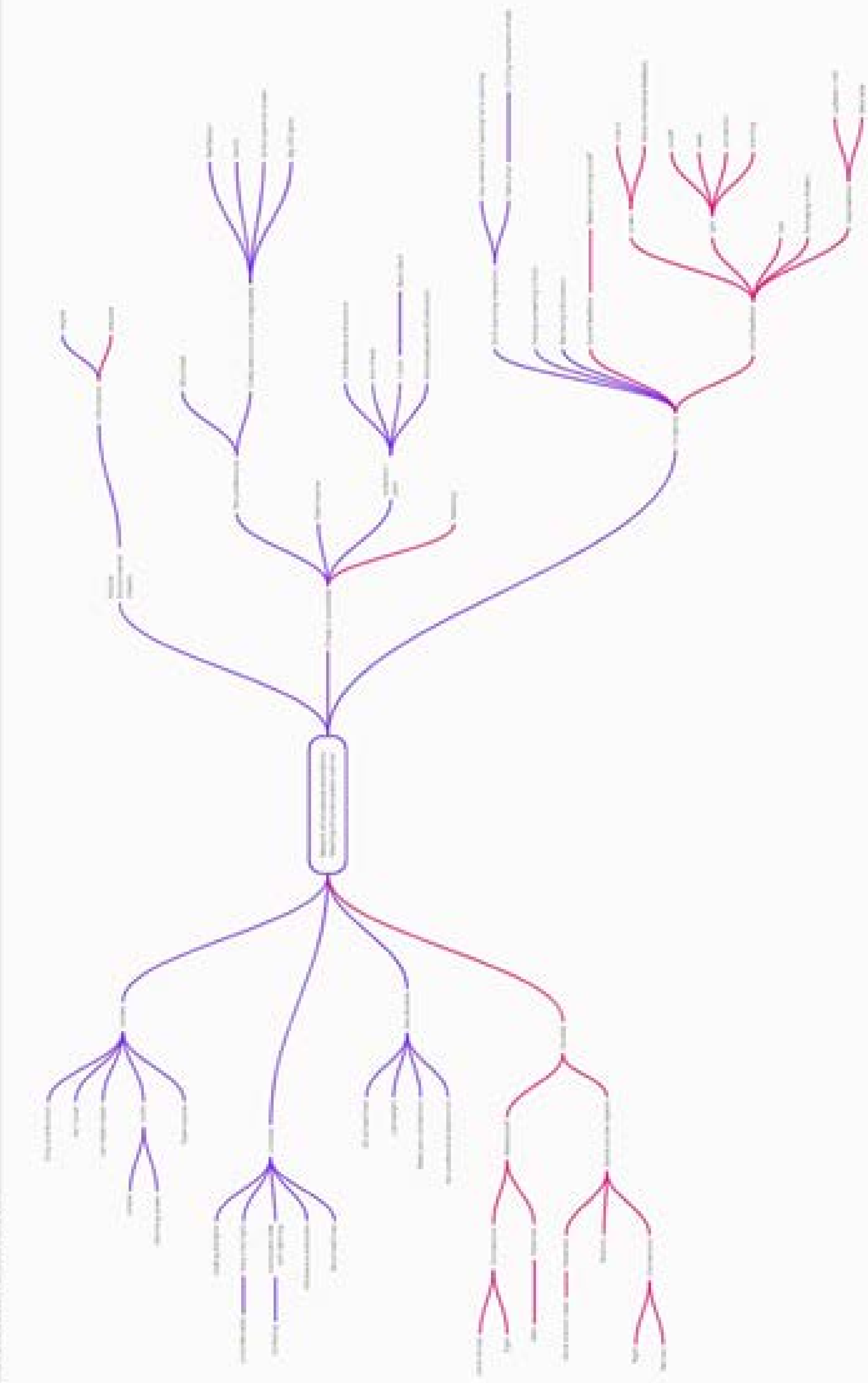
Culture:
- *Responsibility*
- *Sharing (broadcasting) everything. Social media.*
- *Environmentally aware.*
- *Community building*
- *The need for belonging (religion -> initiatives)*

Situations:
- *Dirty environments*
- Constantly confronted with plastic pollution issue
- Harsh work environments (ship or outdoors)

Trends:
- *Being a social / environmental activist*
- *Showing that you care for the planet*
- *Unbounded (progressive) optimism ("we're gonna do it!")*

Marketing:
- Social media,
- Social interaction / spreading
- Collection / donations
- Partnering up with initiatives, NGOs
- Education
- Appearing in news
- Environmental & Social responsibility (or even greenwashing)

Other products and brands:



Network of conceptual associations.

Influence of external factors (meta level)

What things influence users? In culture, brand ..

Feeling of belonging in a community

Values

- *Good will*
- *Responsibility*
- *Striving for better future*
- *Environmentally aware*

People:

- *Environmental activists,*
- *Greta,*
- *Young (self) educated people*
- *surfers*
- *Social*

Culture:

- *Responsibility*
- *Sharing (broadcasting) everything. Social media.*
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Situations:

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- *Being a social / environmental activist*
- *Showing that you care for the planet*
- *Unbounded (progressive) optimism ("we're gonna do it!")*

Marketing:

- Social media,
- Social interaction / spreading
- Collection / donations
- Partnering up with initiatives, NGOs
- Education
- Appearing in news
- Environmental & Social responsibility (or even greenwashing)

Other products and brands:

Click for link to the video

https://youtu.be/oqn-5KZOrUg

Vision for the user:

For ocean plastic workers:
Feeling empowered by using the plastic scanner (because of efficient usability)
Feeling connected - linking value
Providing insights and assurance while scanning plastic to enable postive impact

Intriguing and empowering plastic scanning experience

or

For workers in bigger companies:
An effortless / uncomplicated scanner

Impactful and reliable scanning experience

?

Forming vision for emotions rather than for meaning?

Multi-sensorial materials current product:

- Sound when pushing buttons ("click")
- loading movements Led scanner
- Matte surface and lines (3D) printing of housing
- DIY looking buttons
- Led light feedback at transparent lining
- Lightweigh - feels empty
- Different surfaces - rough (case) to smooth (button)

Materialization ideas future product:

Emotions before entering the design context

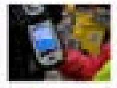




Trigger/cause	positive emotions	negative emotions	Needs (which need is met / which need is hindered)
by the amount of waste trash	feel actived	feeling overwhelmed (when you can't keep up with the tempo), feeling dirty, disappointment, alarmed, sad	Purpose / Comfort, competence
collectively taking on this task	feeling of belonging in a community, feeling of connection, inspired, joy	Feeling overwhelmed, insecure, irritated (when someone distracts or doesn't do their job properly	Community / Autonomy
Sorting trash on the ship, with waves and movement out in the ocean	Feeling activated, in action, adventurous,	sickness (by the waves), scared	Stimulation / Competence
sorting	in control, competent	boredom confusion uncompetitive	Competence / Stimulation
physical work	healthy, activated	tired, pain	Fitness / Comfort

Feeling of doing good for society
vs.
Personal pain points

Emotions resulting from the user product interaction



Trigger/cause	positive emotions	negative emotions	needs
being able to sort unknow plastic	Competence, assurance, feeling autonomous	Feeling overwhelmed, tired	Competence, autonomy, impact / Fitness, comfort
creating a sorted pile	Sense of achievement, feeling needed	shocked, embarrashed	Impact, stimulation, comfort, recognition / Beauty
being able to sell or repurpose plastic	Assured, secure, competent, hopeful, happy	Helpless, insecure, unvalued	impact, competence, purpose, recognition
Finishing a pile/ sending it off	accomplished, satisfied sense of achievement	tired confusion or disappointment (when the deal doesn't go well)	impact, competence, purpose / Fitness
receiving positive feedback	happy, content, astonished, valued	uncomfortable	recognition, impact

Accomplishments: positive when they do happen and negative when they dont.

A sense of accomplishment
vs.
insecurity (not knowing if it has enough impact or result of your work)

Emotions during the user-product interaction

Trigger/cause	positive emotions	negative emotions	needs
looks	interesting, fascinated, inspired and eager, activated	Disgused, confused, disappointed, distrust, sad	Purpose, Stimulation / Beauty
recognition of features and elements and haveing expectation about the function of the product	Interested, assured, curious, eager to try	confused	Stimulation / Competence
Turning device on (holding)	Activated, curious	impatient, confused, disappointed	Stimulation / Competence
Calibrating the device	competent, assured, happy	impatient, consufed, angry, frustrated	Comfort + stimulation / Competence, Comfort
taking the plastic to scan	Activated, determined, powerful, optimistic, calm&active, curious	Disgused, frustrated, dirty, irritated	Stimulation, Competence, Autonomy / Beauty, competence
Scanning the plastics	Strenghtened, assured, optimistic, supported, empowered, feeling free (autonomous)	Impatient, frustrated, insecure, confused, disappointed	Stimulation, autonomy, comfort, competence / Comfort, competence, autonomy
Comprehending the results	Competent, assured, calm,	Confused, angry, disappointed	Competence / Competence, comfort, autonomy
turning the device off	Calm, satisfied	fed up, angry	Competence, comfort
charging the device	Hopeful, competent, content	Unsecure, afraid, angry	competence, comfort
storing the device	competent, content, satisfied	Lost, confused	competence, comfort

First time use
vs.
Mastered use

When it works
vs.
When it doesn't

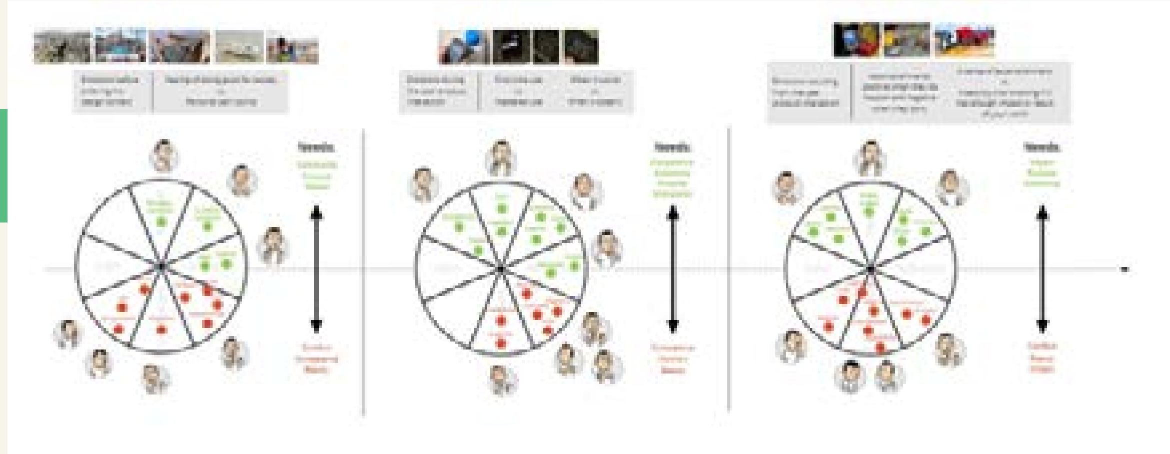
Intended user behaviour that the product encourages

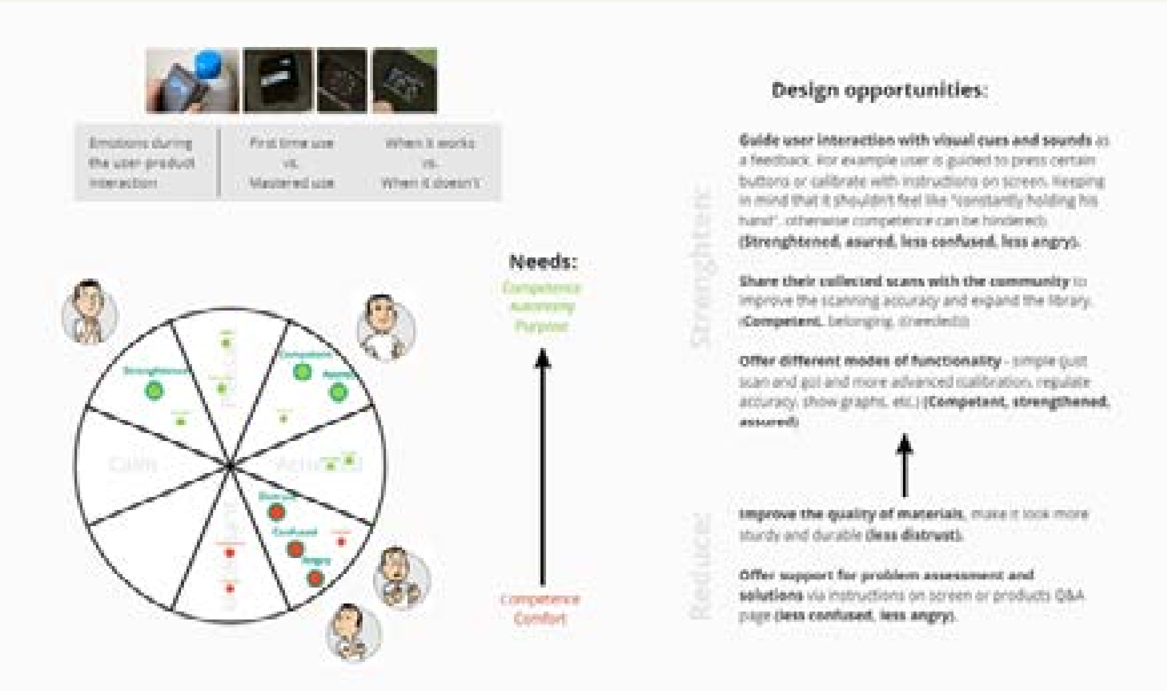
End goal: Able to be informed enough to recycle/do tasks

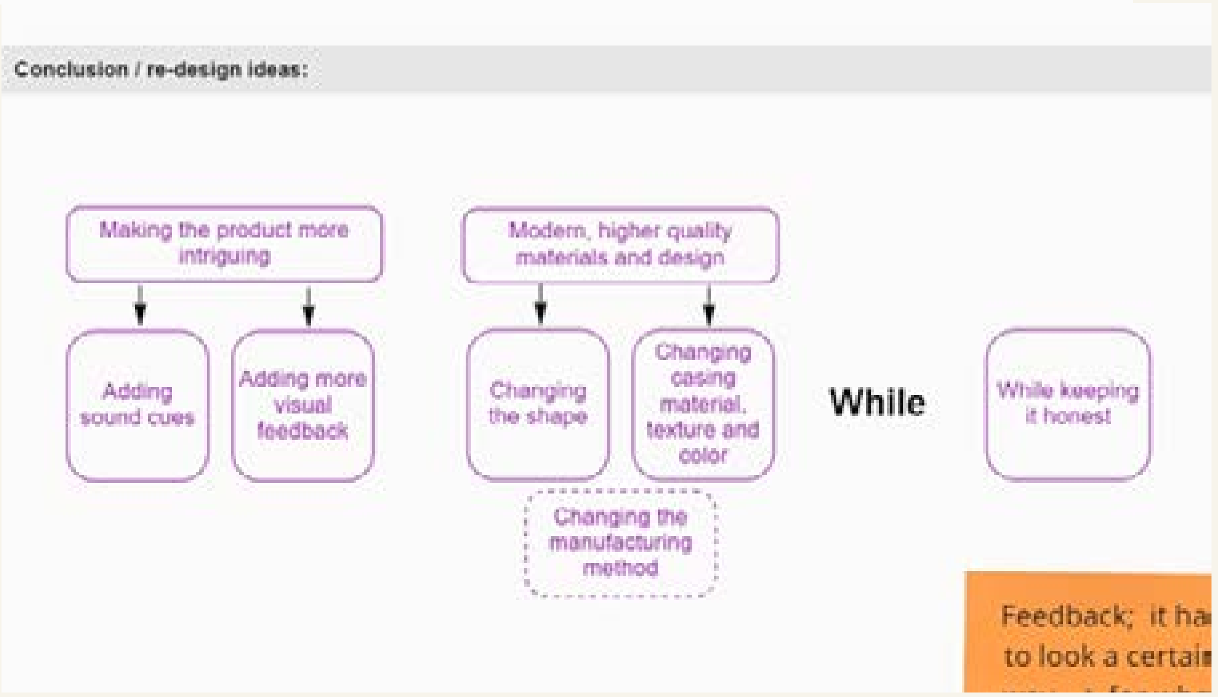
Behaviour around the product:
- purposefull to achieve their goals (= to be able to distuinguish the plastics)
- Quick and effective plastic sorting

Long term: habitual patterned behaviour with the device.

Desired Emotions: Calm & Activated, Satisfied, **Assured, Competent, Capable**
(Confident)



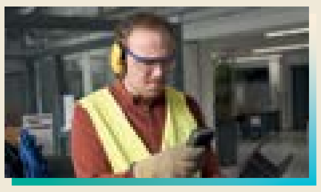




10.5 Appendix B - PE Deliverables A3

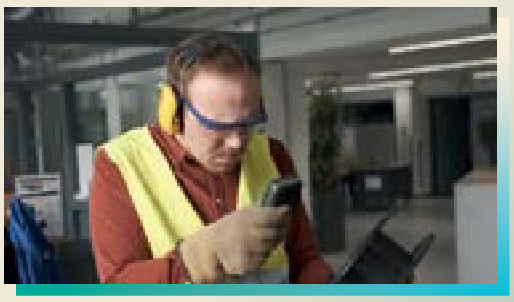
Experience map

Of the current product

Persona	Key goals and needs	Key pains and constraints	Key activities and tasks
Mark & the scanner 	*Creating accurate, high quality sorted batches* *Certainty and knowledge on consisisty of waste samples*	*Mixed plastics* *Human errors* *Unknowns*	*rough sorting* *Scanning unknows* *Creating piles* *Document and share results (what types of plastic, to make database)*



Time	**8.00**	**8.30**	**10.00**
Action	***Arrival***	***Confrontation***	***Sorting***
Trigger	Preparing for work	New batches of waste	Scanning the piles
Story	It is early as I step inside the changing room. I gather my stuff and put on my uniform, helmet, face-mask, glasses and when I am finally done put my safety gloves and headphones on. I am swea-ting a bit and see my glasses getting foggy already.	I got the job to verify the new batches on materials and quality along with my teammates. I look at the amount we need to get through today, since covid we only received more and it is hard to keep up with. Lucklily, we are doing this together.	I am quickly sorting through a pile and recognize a lot of PVC tiles. However I see a lot items that are not separated and items that could be mixed/layered plastics. I am not sure whether we can sort these.. I have to take the plastic scanner to sort this out!
Feelings	Agitated	Overwhelmed, connected	Uncertain, Competent
Reason	Process of getting ready	Feeling pressure, Huge amount of waste, Teamwork	(un)recognizing waste


Time	**13.30**	**15.00**	**16.30**
Action	***Calibration***	***Friction***	***Finishing***
Trigger	Starting up the scanner	Frustration towards the working process	Finalising the working day
Story	It took me some time to find the device but I am glad that I now can take it with me! The scanner is so lightweight and crafty, I guess it will not take long before we need a new one. The calibartion of the device takes a while though..	The first half went rather easy but now I have a lot of items that are hard to process. The scanner shows different results when scanning the same items. I am not longer sure on how to sort these anymore.. But this may because my eyes are starting to get tired of reading the small screen and arms by holding the scanner picking the waste.	Okay, great today is almost over. I am happy to have sorted that much today. O wait.. I still need to report to my manager about todays results.. I can not remem-ber all the results anymore
Feelings	Competent, impatient, distrust	Tired, unfocused, uncertain	Content, uncertain
Reason	Device that can remove uncertainty, waiting time, looks make it seem undurable and fragile	Small screen, heavy work, hard to process results	impact, not being able to remember all scanned data

Experience map

Of the future product

Persona	Key goals and needs	Key pains and constraints	Key activities and tasks
Mark & the scanner 2.0	*Creating accurate, high quality sorted batches* *Certainty and knowledge on consisisty of waste samples*	*Mixed plastics* *Human errors* *Unknowns*	*rough sorting* *Scanning unknows* *Creating piles* *Document and share results (what types of plastic, to make database)*

Time	***8.00***	***8.30***	***10.00***
Action	***Arrival***	***Confrontation***	***Sorting***
Trigger	Preparing for work	New batches of waste	Scanning the piles
Story	It is early as I step inside the changing room. I gather my stuff and put on my uniform, helmet, face-mask, glasses and when I am finally done put my safety gloves and headphones on. I am swea-ting a bit and see my glasses getting foggy already.	I got the job to verify the new batches on materials and quality along with my teammates. I look at the amount we need to get through today, since covid we only received more and it is hard to keep up with. Lucklily, we are doing this together.	I am quickly sorting through a pile and recognize a lot of PVC tiles. However I see a lot items that are not separated and items that could be mixed/layered plastics. I am not sure whether we can sort these.. I have to take the plastic scanner to sort this out!
Feelings	Agitated	Overwhelmed, connected	Uncertain, Competent
Reason	Process of getting ready	Feeling pressure, Huge amount of waste, Teamwork	(un)recognizing waste

Time	***13.30***	***15.00***	***16.30***
Action	***Calibration***	***Scanning***	***Finishing***
Trigger	Starting up the scanner	Frustration towards the working process	Finalising the working day
Story	I get the scanner with me which is plug-ged in the holder at the wall in the main area. The scanner is sturdy and will serve us for a long time which is nice because it makes my work much easier. The device guides me through the calibration process quickly with light cues. I can start scanning now without errors.	The scanners shows what kind of plastic is present via a big screen. I can recognize this quickly and it is easy to read while working. I'm confident to use the results of the scanner to sort the plastics. I can hold and interact with the device comfortably while wearing my gloves. The device feels stable in my hand.	Okay, great today is almost over. I am happy to have sorted that much today! When talking with my manager, I can quickly show him the results of my scans. I can automatically import the scanned data into the companies database. With this data we can collaborate with our partners and expand knowledge together.
Feelings	Competent, trust, certain	confident, relaxed, comfortable	Proud, belonging, relaxed
Reason	Device that looks durable also brings more trust, and incorporated light cues give certainty during interaction	Bigger multicolor screen, comfortable device housing, easy interaction	Data storage, collaboration with others, making impact

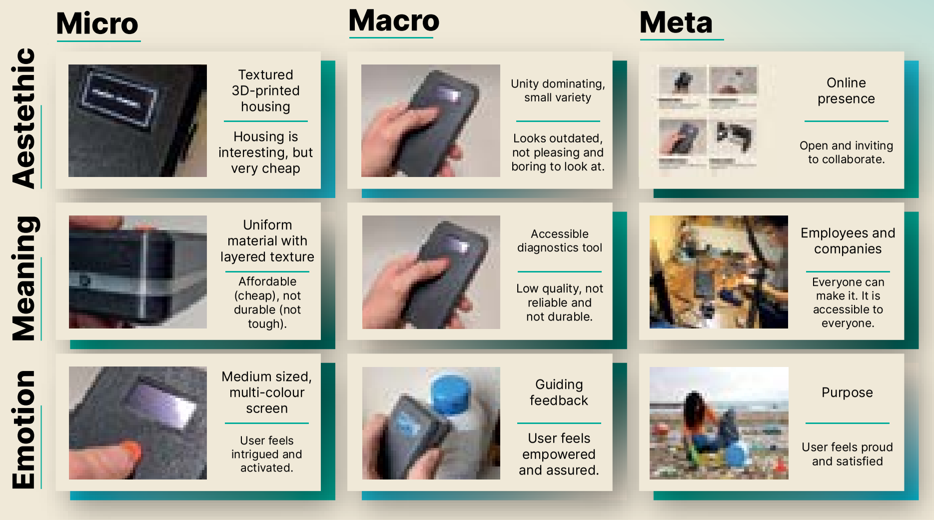
PlasticScanner

Group proposal

The plastic scanner is a handheld device which can indentify different types of plastic. The current Plastic Scanner is aimed at low income countries. This helps people to make an income of selling them to be used for recycling, while tackling the pollution problem. For this AED project, we design an improved version of the plastic scanner, to be sold to interested parties in high income countries. Companies with the focus on are medium size recycling facilities.

Current scanner

Analysing the strenghts and weakness of the 9 moments matrix lead to the : following group vision.



"Reliable and empowering plastic scanning experience, while making a positive impact on the company and the world through collaboration"

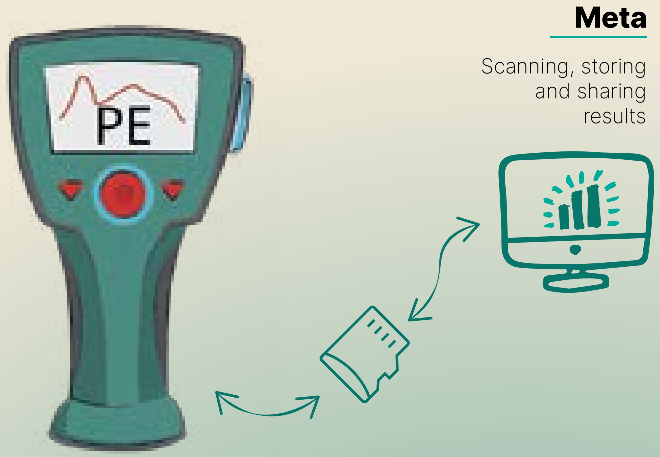
Implementation

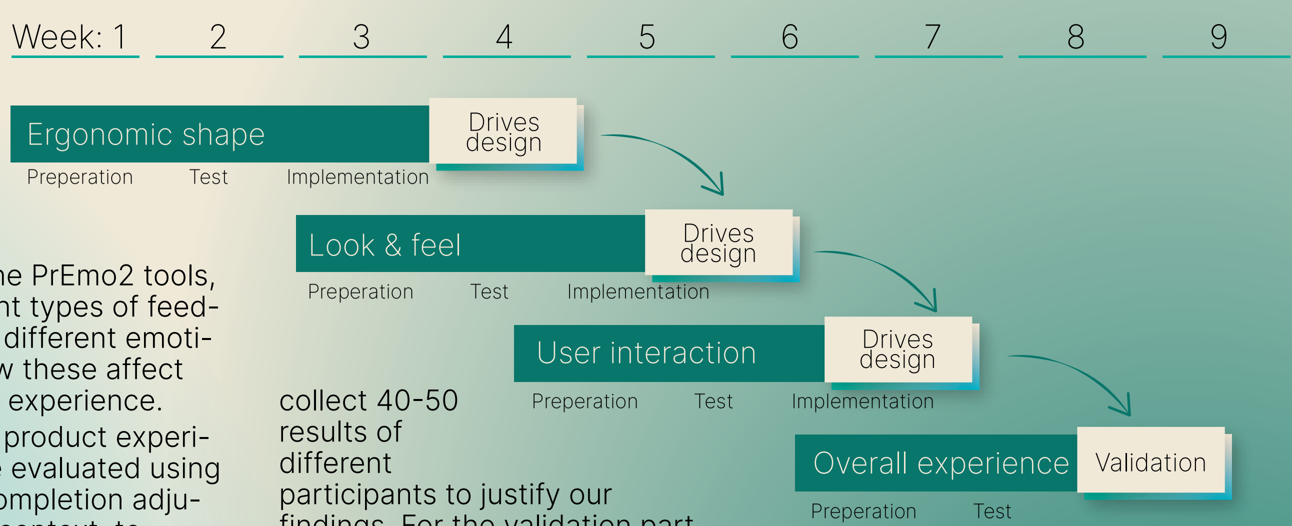
To improve the scanner we will implement our vision on various levels. Additionally we will diminishing the negative findings and enhancing the positive findings out of the experience matrix of the current scanner. this will be done by changing the looks on a micro level and by adding a larger screen. On a macro level the shape will be alternated to provide more unity. Also, detailing will be used to enhance the durability of the product and more guided feedback will be added to facilitate for a better interaction. On a meta level, the scanner will now be able store and share the results. This to enhance the collaborative experience of the product.

Micro
Texture (smooth)
Color (avoiding dark colors)
Using recycled plastics
Big color screen

Macro
Unity in variety
Ergonomic shape
Rugged body
Guiding feedback

Meta
Scanning, storing and sharing results





Plan

The improvement will be measured and implemented in Q4 by several tests.

1) Different shapes will be designed for comfort which will be used as guidance.
2) The look & feel of the housing will be evaluated on different materials, textures and color (cominations) and meaning will be tested using sentence completion to determine which variants are in line with the vision.
3) Test with the PrEmo2 tools, how different types of feedback evoke different emotions and how these affect the product experience.
4) The overall product experience will be evaluated using sentence completion adjusted to our context, to validate how reliable and empowering the product feels.

The test will be translated into surveys which can be filled in by participants. We aim to collect 40-50 results of different participants to justify our findings. For the validation part of the overall experience same participants shall be questioned in order to validate whether the improvements have been integrated accordingly.

10.6 Appendix C - ADE Systems Engineering

ADE1: Systems Engineering- assignment

Group 4

Group members

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Introduction

The current version of the plastic scanner is a product that is aimed at low- and middle-income countries to help identify and separate different kinds of plastics. This helps people to make an income from selling these sorted plastics to be used for recycling. For this AED project, our group will work on a new and improved version of the plastic scanner, this second version can be sold to interested parties in high-income countries (Ocean plastic collection companies and small to large scale recycling companies). The current embodiment is relatively simple and consists of 3D-printed enclosure, electronics, switches, battery and bolt connectors.

Figure 1 shows the exploded view of all parts that are in the current Plastic scanner version, while figure 2 demonstrates the working principle: using LED lights and IR sensor, plastic refraction patterns are analyzed for the plastic types to be chemically differentiated.

Figure 1: Exploded view plastic scanner. (Plastic Scanner, 2021)

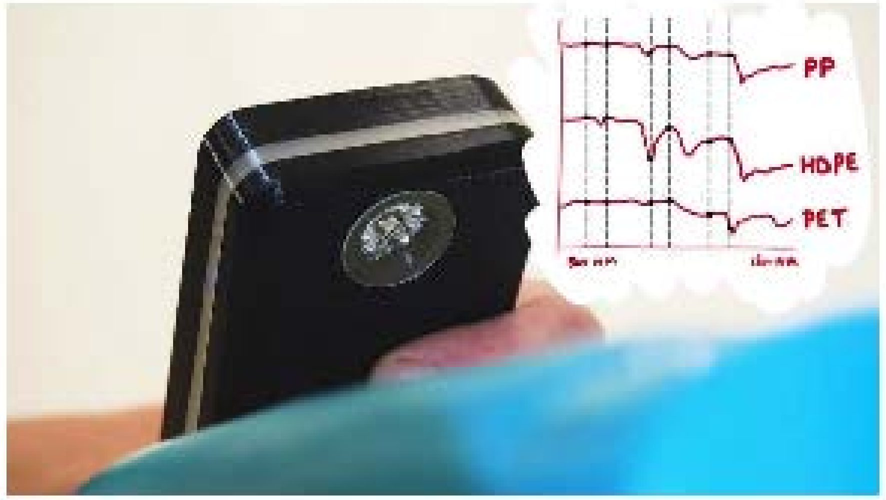


Figure 2: Working principal plastic scanner. (Plastic Scanner, 2021).

The Plastic Scanner is a device to make plastic sorting in developing countries simpler. Currently, most plastic sorting is done by hand, which is labor intensive and prone to error. Sorting plastic by type is essential to take a step towards a circular economy, keeping materials pure.

Development of version 2 for commercial B2B use in high-income countries and production of larger quantities, used by companies active in the garbage collecting & recycling industry. It will be used for initial identification of the plastic in the sorting stage as well as for quality assurance in later stages.

The Plastic Scanner is currently a prototype, a demonstrator of new technology. In order to implement this in various places around the world, we need to bring it to a higher TRL level (minimum level 7 - 8)

A. Contextual analysis

The current use case in developing countries is different to the intended use case for this project in a B2B setting. Therefore, we have set out to define the future use scenario by looking at companies that are interested in the Plastic Scanner and their field of work. We have defined two areas of focus within the plastics recycling loop (highlighted in Figure 3), in which companies have similar needs.

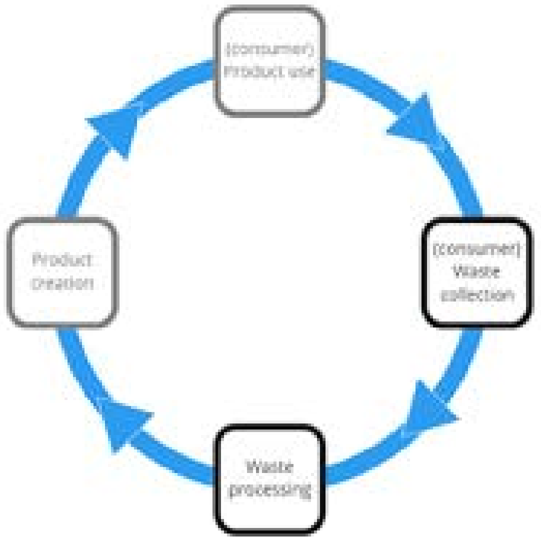


Figure 3: Plastic recycling loop with focus areas highlighted in black.

The context of use for this product is varied but will be mainly used in recycling facilities and beach or ocean clean up places, where collected plastic will be sorted into separate types for further processes. In order to find out the context factors in these focus areas, we have visited Bestrade PVC recycling, a Dutch recycling company focusing on recycling of PVC. In the company visit we have analyzed their operations, needs and similarities with other companies in the recycling loop. We also analyzed The Ocean Cleanup for a more naval environment for the Plastic Scanner to function in. From this analysis the results have been visualized in Figure 4.

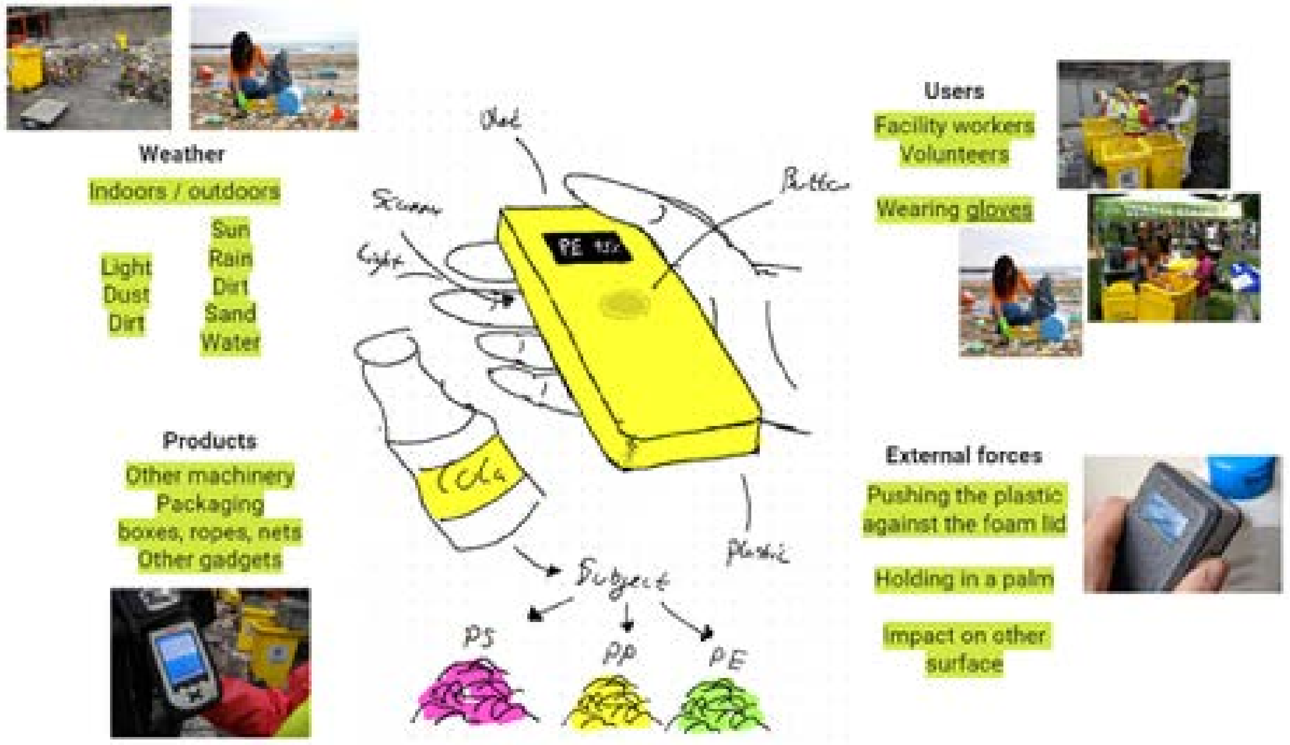


Figure 4: Context factors for Plastic Scanner in use.

The analysis shows clearly that the product will need to function in tough environments, where there is dirt, dust also water (if plastic scanning will be used in the ocean plastic clean-up boats). There are no significantly strong forces affecting the product, because it is held in the hand, and the user only needs to touch the plastic with the scanner for successful scanning. However, because the product is handheld, there are risks of accidental falling on the ground or some water getting onto it. Therefore, durability and waterproofness are of high priority for Plastic Scanner to operate in these environments. The additional products surrounding the environment are mainly from the collected plastic waste, consisting of packaging products, boxes, ropes, nets and other types, which can also be of decayed quality, also additional machinery for transporting, shredding or remanufacturing collected plastic, other auxiliary equipment can be found in the environment. Another important factor is that the workers that will be using the Plastic Scanner are wearing safety gloves.

The stakeholder map (Figure 5) shows which parties have most interest and influence regarding the use and design of the plastic scanner. From our analysis, the key players which need the most attention are the current Plastic scanner owner Jerry, who is developing the second version, recycling companies (large- and small –scale), ocean (or ocean-bound) clean up companies and NGOs, such as The Ocean Cleanup. Other key players hold a lot of power but are less interested. From this stakeholder list, we took the actors which will be closely related to the product (through buying it, using it or installing legislations which can impact product design). These stakeholders have different roles and requirements for the product (Figure 6).

Figure 5: Stakeholder mapping around plastic scanner.

Figure 6: Main stakeholders, their role and their requirements for the product.

B. Function analysis, physics principles and state machine

Function tree

Function tree (Figure 7) is used to analyze what type of functions take place while using the scanner. We used this to systemize these functions into categories and then diverged on possible function 'solutions' (how each function could be worked out on more defined level). Therefore, the function tree acts as a systemic overview of all necessary parts and as a tool to discover and think of different ways on how each function could be delivered. Because the project is in a very early stage of development, many functions are not yet strictly defined. For example, scanning results could be delivered in many ways: via sound, via screen, via lights. Therefore, functions which are still not fully defined are marked in gray, and functions which are fully defined are marked in color (fully automatic in blue, fully manual in brown). The full resolution function tree can be found in Appendix 1.

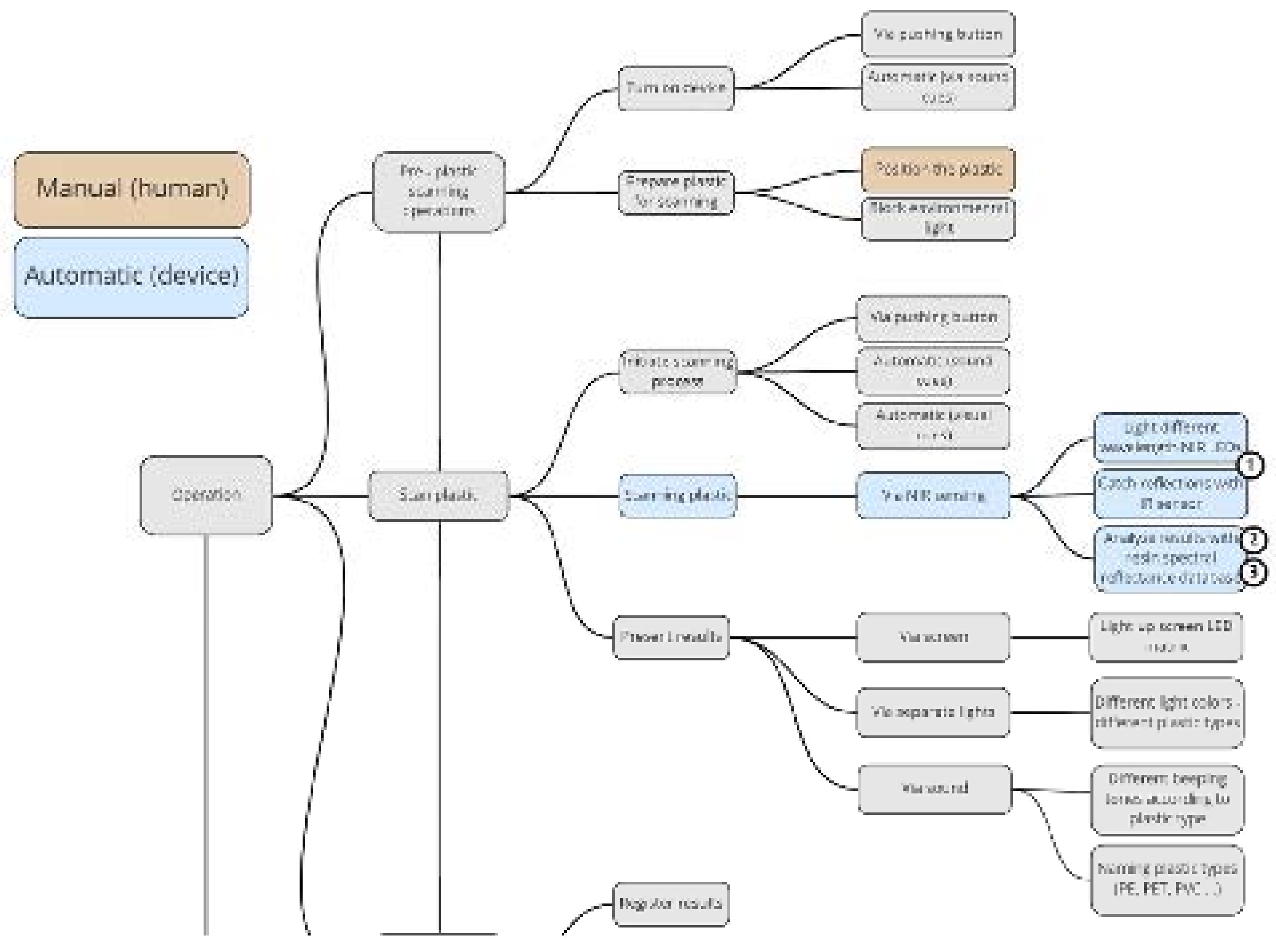


Figure 7: Fragment of plastic scanner function tree about "Operation" branch. Full function tree in Appendix 1.

We took organizational thinking to elaborate more on the functions that would enable product improvement and maintenance. The product's software should be able to be improved, because the mainstream plastics can change, their properties can change, or the plastic scanner could be updated to improve the accuracy of scanning. Also, the possibility to save the scanned results and collect data from different devices into the main data – this would help to expand the knowledge library, which could really help to train the software and improve plastic scanning accuracy. In addition, repairability is important to improve product's lifetime (organizational and sustainability thinking)

With this perspective we add "Communication" and "Maintenance" branches to the function tree, which can be found in Appendix 1

Relevant physics principles

The main physics principles regarding the core working principle of this device are in the category of optics. Principles presented below are concerning the numbers in function tree (figure 8).

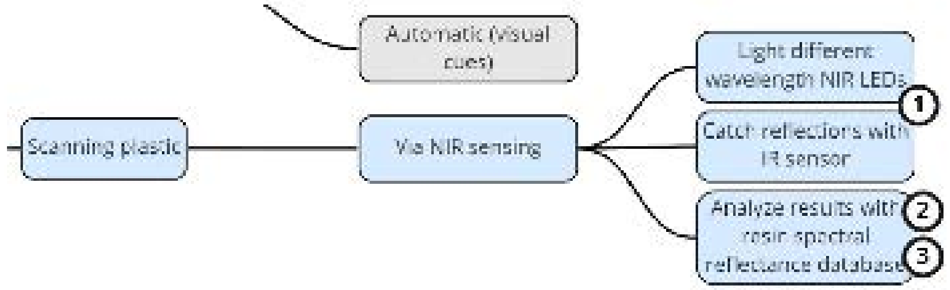


Figure 8: Fragment of function tree. Physics principles are numbered.

Reflection of infrared light

Objects can absorb and reflect different wavelengths of light, because of their surface properties and molecular structure. While mainly this principle is known for enabling us to see different colors, the same applies to other light wavelengths – objects absorb and reflect various types of infrared light. Devices that sort plastics using infrared spectroscopy are based on this principle (figure 9): the different wavelengths from the IR transmitters are reflected to the IR receiver, where the received energy is measured (Shetty, 2018). The position of the infrared receiver must be correct to catch the reflected electromagnetic waves, therefore diffuse reflection, specular reflection principles, Lambertian reflectance must be considered (figure 10).

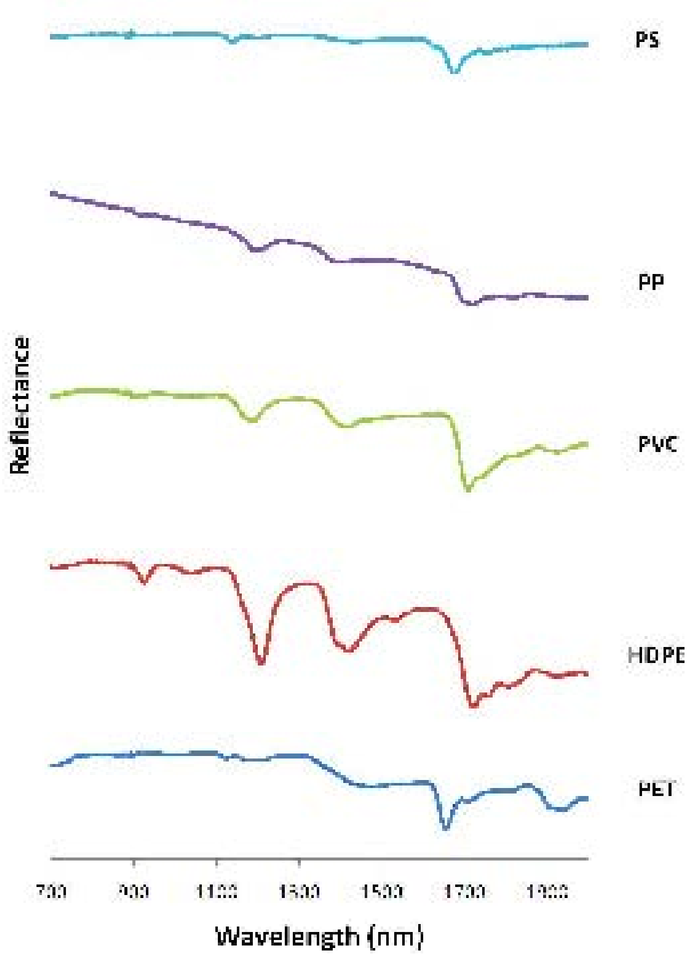


Figure 11: The reflectance spectra of five resins (H. Masoumi et al. a, 2012a).

Difference of reflectance between lightness of colors of one resin type

Bodies and surfaces of darker color absorb wide spectra of electromagnetic waves and reflect very little, therefore scanning the dark-colored plastics via infrared spectroscopy becomes challenging (close to impossible), because the differences in reflectance between different wavelengths are very small (figure 12). For this project, finding a way to improve the reading of dark plastic reflectance would really improve the product, but affordable methods for improving this aspect are still to be researched.

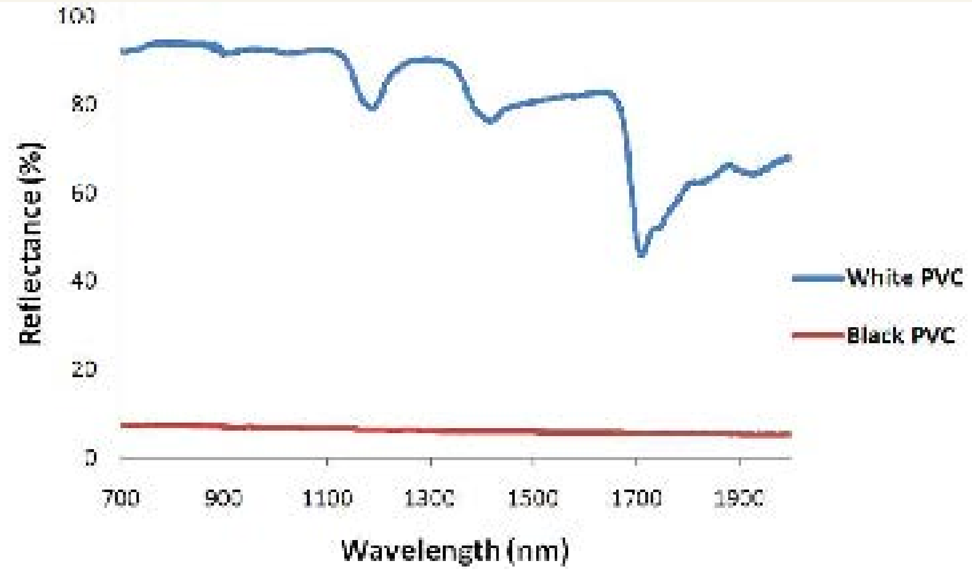


Figure 12: Differences between black and white PVC reflectance (H. Masoumi et al., 2012b).

State machine Diagram

In figure 13 a state machine diagram is shown of the plastic scanner. The technical functionalities of the scanner are also shown within this diagram, ranging from analysis, diagnostics to feedback.

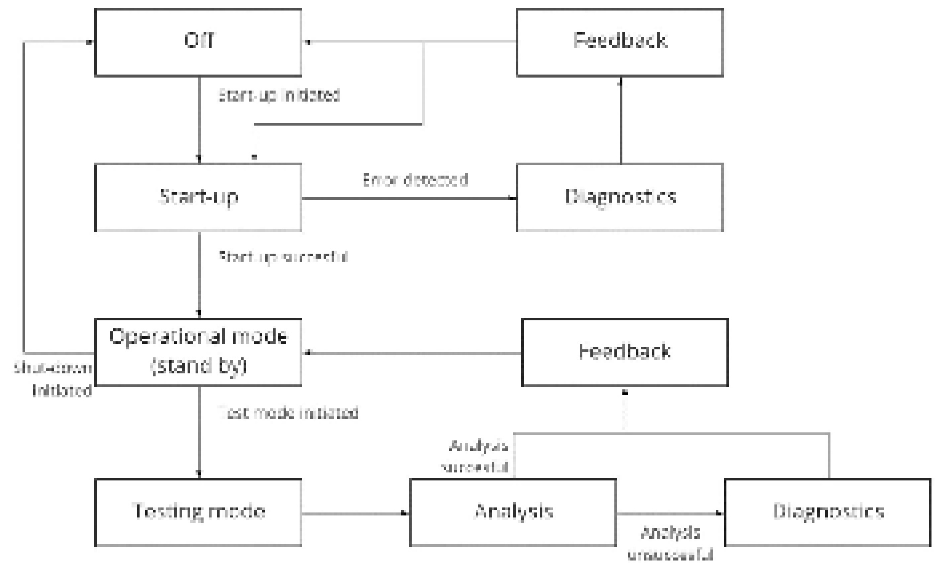


Figure 13: State machine Diagram of plastic scanner including technical functionalities.

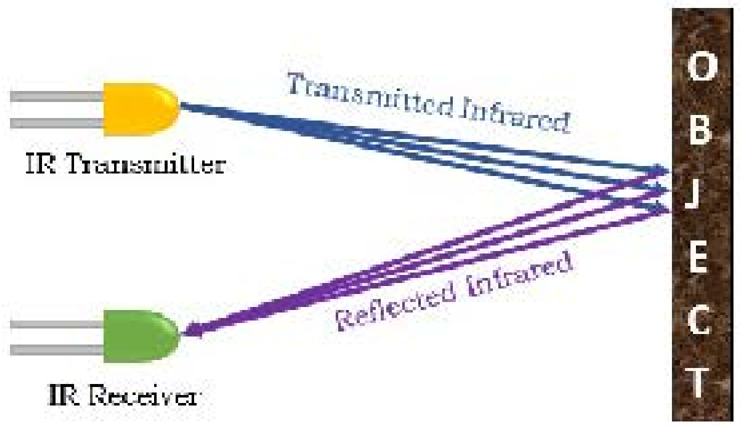


Figure 9: Working principle of spectroscopy (Shetty, 2018).

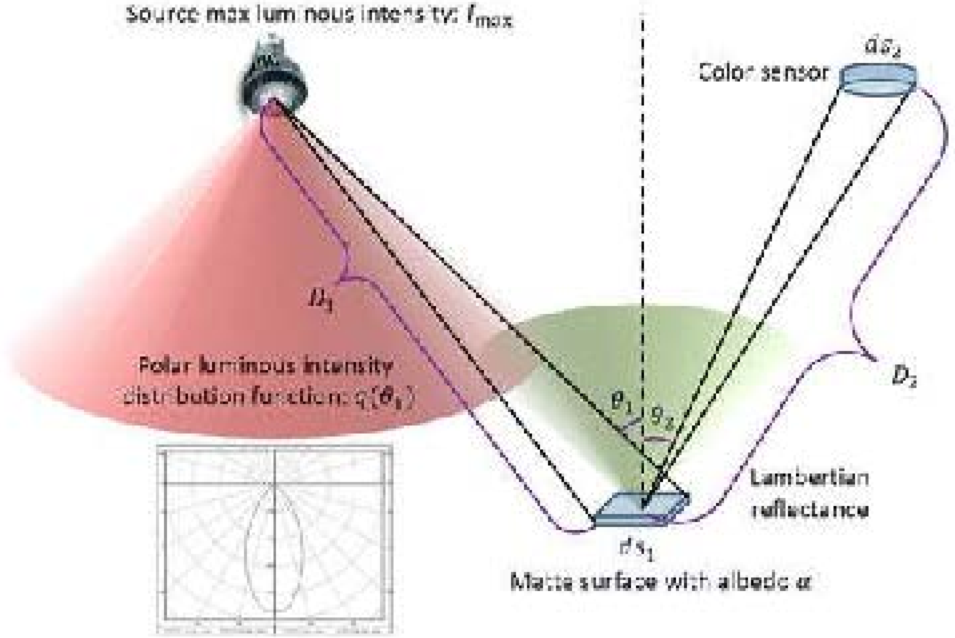


Figure 10: The reflection kernels of two fixture-sensor pairs (Wang et al., 2014).

Difference of spectral reflectance of 5 mainstream resins

Reflectance is a function of electromagnetic energy from a certain wavelength. Spectral reflectance is a curve representing the relation between % of reflectance and different wavelengths (in nm) (Electrical4U, 2020). Figure 11 represents the spectral reflectance of 5 main plastics, various colors either reduce or improve reflectance, but the main graph shape does not change. Even if the plastic type is the same the spectral reflectance can vary slightly according to different additives in the plastic. Therefore, extensive libraries are needed to identify plastics accurately. For this case the 8 IR LEDs for current plastic scanner range from 850 to 1650nm in wavelength, which is classified as near infrared radiation (NIR) (Plastic Scanner, 2021a; ScienceDirect, n.d.).

C. Systems tree and subsystems interaction

The system tree of the plastic scanner is shown in Figure 14, ranging from SEL 1 to 3 and the current components. One of the components, the input sensor, is not fully defined as both options can accomplish the need. Further research will determine which of the sensors will be used in the final scanner. The main subsystems and the interfaces between these subsystems are described in Figure 15.

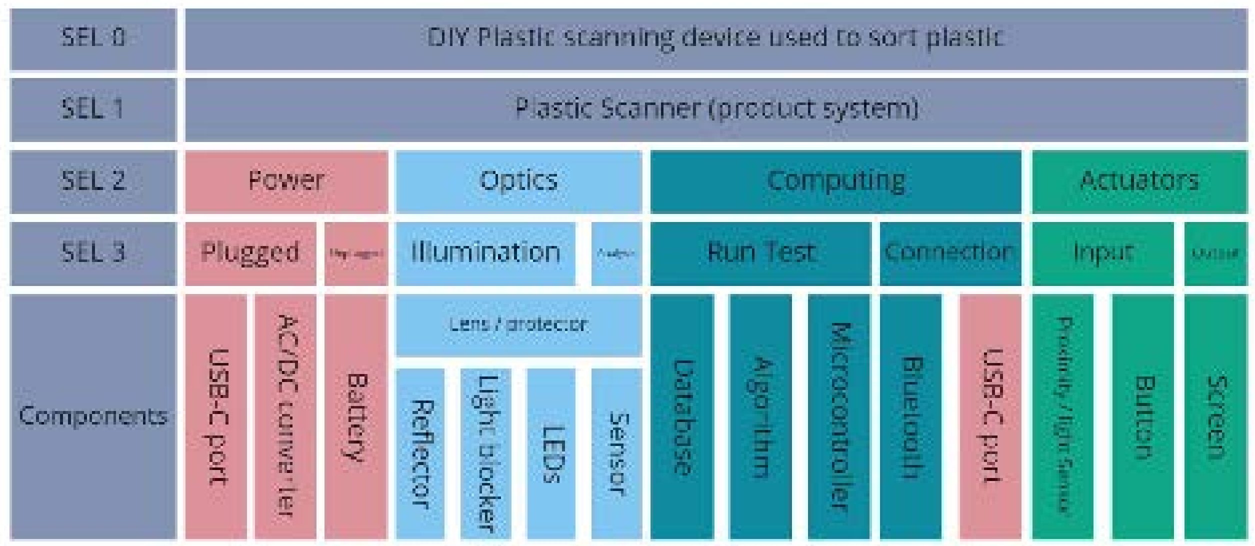


Figure 14: System tree of plastic scanner.

Between all the subsystems, energy is transferred. Next to this, between the actuators and computing, data is being transferred to process user commands as well as provide feedback to the user. Information transfer is happening between the computing and optics to start the scanning process and return its sensor data. The final transfer of information is between computing and power, an exchange on the rate of discharge needed to fulfil all the other subfunctions.

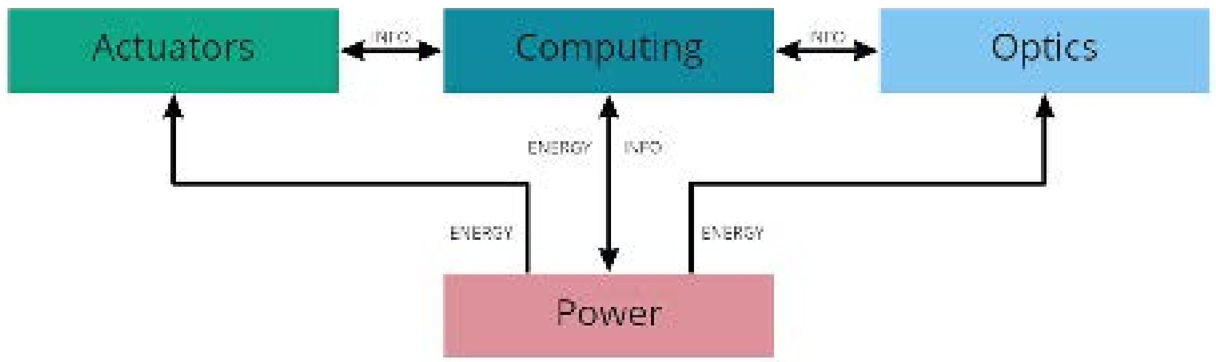


Figure 15: Sub-systems and interface diagram of plastic scanner.

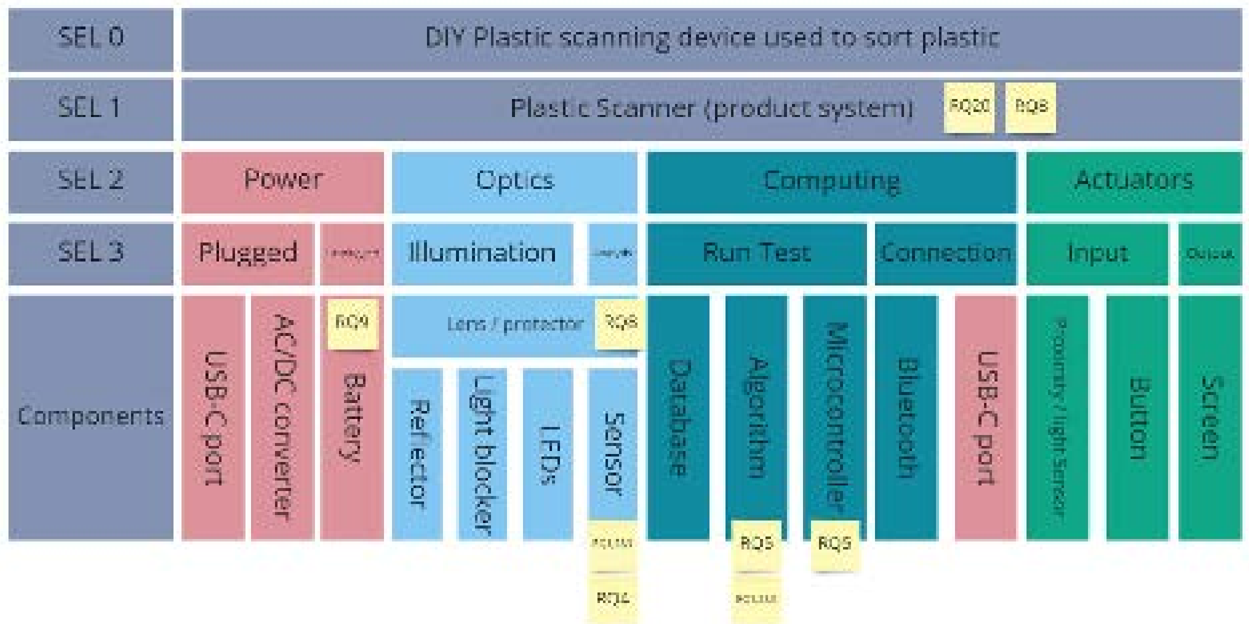
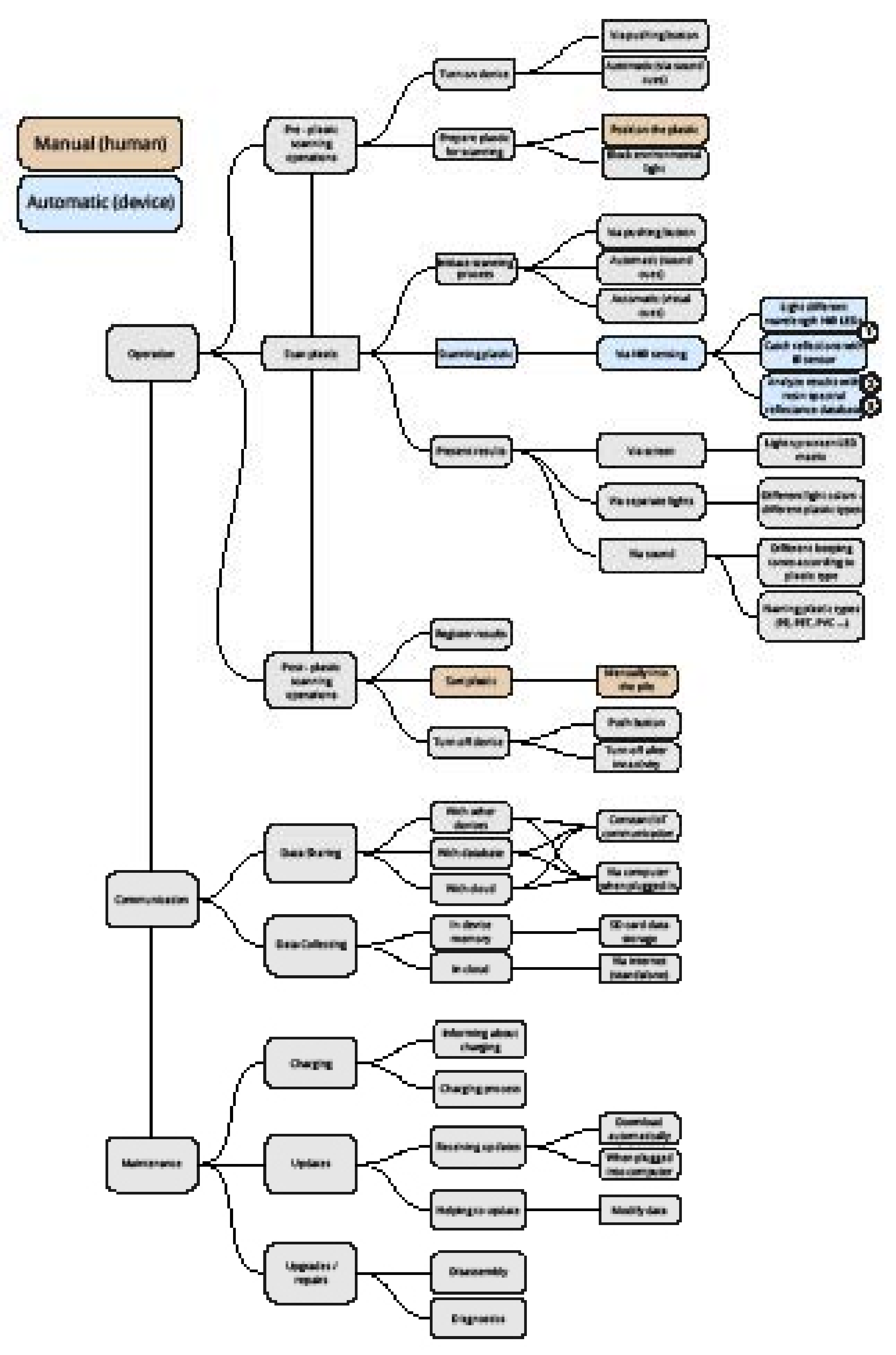


Figure 16: Requirements allocated to specific parts of plastic scanner.

Our analysis shows that most of the requirements already formed are about the product in general and are not specified for individual components. This is in part as this project has been mostly concept design up to this timepoint. Therefore, in a future stage of the project, where focus will be on embodiment design, having specific requirements on component level will be important. This allows for justification of choice between different component options.



D. Program of Requirements

In the table below (Table 1) 20 of our product requirements can be found. They are divided into several categories and if applicable an elaboration is given. Some of these requirements are allocated to specific parts (shown in figure 16).

Type of requirement	#	Requirement definition	Elaboration
Performance	1	Product must identify 5 most common types of plastic (PP, PE, PVS, PS, PET)	
	2	Product must identify above mentioned types of plastic with 90% accuracy when scanning virgin materials.	
	3	Product must identify above mentioned types of plastic with 75% accuracy when scanning heavily decayed materials.	
	4	Product must be able to identify plastic samples that are 4cm or larger.	Minimal size of plastic found in ocean. (Lebreton et al., 2018)
	5	Product must identify the sample within two seconds.	PlastiTell (competitor) does it in two seconds. (Matoha, 2021)
Environment	6	Product must work in environments ranging from –20 up to 50 °C	
	7	Product must be waterproof	Still to define IP-rating requirement
	8	Product must withstand an impact from at least 2 meters.	Product is used standing upright, therefore 2 meters is chosen.
Life in service	9	Product must work with full functionality for at least 8 hours before charging.	
Maintenance	10	Product must be able to be disassembled by a customer within 2 minutes.	
	11	Product components must be connected only by replaceable materials.	No adhesives.
	12	Product must be disassembled with the 2 most used screwdrivers.	
	13	Product needs to be modular for at least 75%.	
Target product cost	14	Product must cost between 500 and 2000 euros.	
Materials	15	The housing must consist of 90% recycled plastics if constructed from plastics.	Practice what you preach.
Product life span	16	Product must last at least 5 years without upgrades.	
Ergonomics	17	Product must be easy to handle with gloves.	
	18	Product must have option be secured to operator (or environment).	To prevent sinking.
	19	Product must not tire or damage operator's wrists.	
Standards, rules & regulations	20	Product must adhere to CE-certification standards.	

Table 1: Product requirements plastic scanner.

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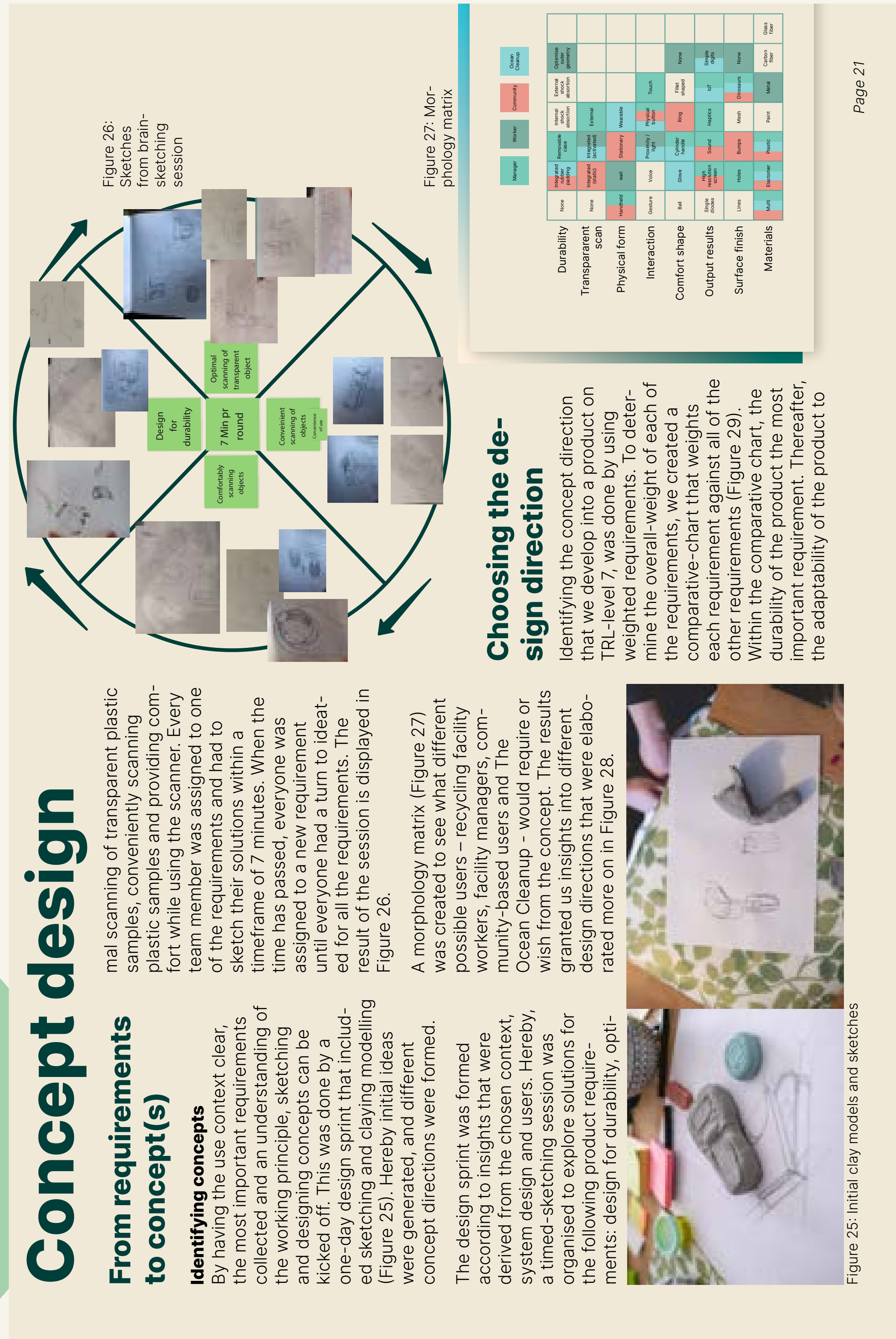
10.7 Appendix D & E - Midterm results



Concept design

From requirements to concept(s)

Identifying concepts
By having the use context clear, the most important requirements collected and an understanding of the working principle, sketching and designing concepts can be kicked off. This was done by a one-day design sprint that included sketching and claying modelling (Figure 25). Hereby initial ideas were generated, and different concept directions were formed.

The design sprint was formed according to insights that were derived from the chosen context, system design and users. Hereby, a timed-sketching session was organised to explore solutions for the following product requirements: design for durability, optimal scanning of transparent plastic samples, conveniently scanning plastic samples and providing comfort while using the scanner. Every team member was assigned to one of the requirements and had to sketch their solutions within a timeframe of 7 minutes. When the time has passed, everyone was assigned to a new requirement until everyone had a turn to ideated for all the requirements. The result of the session is displayed in Figure 26.

A morphology matrix (Figure 27) was created to see what different possible users – recycling facility workers, facility managers, community-based users and The Ocean Cleanup - would require or wish from the concept. The results granted us insights into different design directions that were elaborated more on in Figure 28.

Figure 25: Initial clay models and sketches

Figure 26: Sketches from brain-sketching session

Figure 27: Morphology matrix

Choosing the design direction

Identifying the concept direction that we develop into a product on TRL-level 7, was done by using weighted requirements. To determine the overall-weight of each of the requirements, we created a comparative-chart that weights each requirement against all of the other requirements (Figure 29). Within the comparative chart, the durability of the product the most important requirement. Thereafter, the adaptability of the product to

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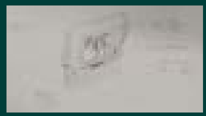
different operational environments is important. This, to increase the size of the target market as well as the ease-of-use of the product.

Validating each of the concepts with the weighted requirements (Figure 30) showed that concept 2 scored the highest overall, but after that, concept 1 and concept 4 end up with near the same results. However, we will continue with the most dominant concept 2 while adding features from the other concepts that improve the functionality of concept two.

Concept 1

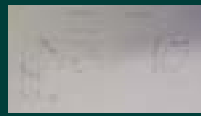


- Extremely rugged AC-connected, no battery
- Low cost components
- Simple in operation Proximity activated
- Integrated reflector

Concept 2

- Large touch screen > many data accessible on device
- IoT connected Familiar/professional design
- Multimodal feedback
- Handheld
- Proximity activated

Concept 3

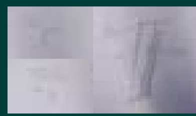


- Adaptable: Hand held and wall
- IoT device Integrated reflector

Concept 4

- Unique casing
- Adaptable through add-ons
- IoT
- Optimized for use with glove

Concept 5



- Connected to phone
- Only data, no sorting
- Cheap
- Physically connected to the user

Figure 28: Main concepts ant their main selling points

Figure 29: weighing of requirements

	Low cost	Durability	Professional look	Comfort	Ease of use	Sustainability	Info feedback	Adaptability	
Low cost		0	0	0	0,5	1	1	0,5	3
Durability	1		1	1	1	1	1	1	7
Professional look	1	0		0	0,5	0,5	1	0	3
Comfort	1	0	1		0,5	1	0	0	3,5
Ease of use	0,5	0	0,5	0,5		1	1	1	4,5
Sustainability	0	0	0,5	0	0		0	0	0,5
Info feedback	0	0	0	1	0	1		0	2
Adaptability	0,5	0	1	1	0	1	1		4,5

Figure 30: Weighing of concepts

	Low cost	Durability	Professional look	Comfort	Ease of use	Sustainability	Info feedback	Adaptability	
Concept 1	4	5	4	3	4	1	3	1	98,5
Concept 2	3	4	5	4	4	1	3	1	101,5
Concept 3	2	2	3	3	3	2	3	5	82,5
Concept 4	3	4	4	3	3	3	3	4	98,5
Concept 5	3	3	3	4	2	2	3	3	82,5
Weight	3	7	3	3,5	4,5	[illegible]	2	4,5	

Goals for the concept

The final product should be in line with our use context:

The context in which the product will be used is inside a recycling company and the operations of The Ocean Cleanup (on land and the oceans in the rivers). Both contexts are chosen, because they share the requirements dictated from the recycling company, With the addition waterproofing, making it UV radiation resistant and enabling data recording and sharing.

What is important with designing for more than one context, is that the product should be more adaptable to different environment settings. We focus on designing a handheld plastic scanner, but to make more diverse, we enhance adaptability through add-ons to mount the scanner on the wall or make it wearable.

The final concept should meet our determined product requirements:

From the expertise areas and additional research that is performed, many requirements and wishes were formulated. Next to that, the performance and status on the requirements have been tracked with the traffic light system. The total list of requirements and wishes (incl. traffic light evaluation) can be found in Appendix H.

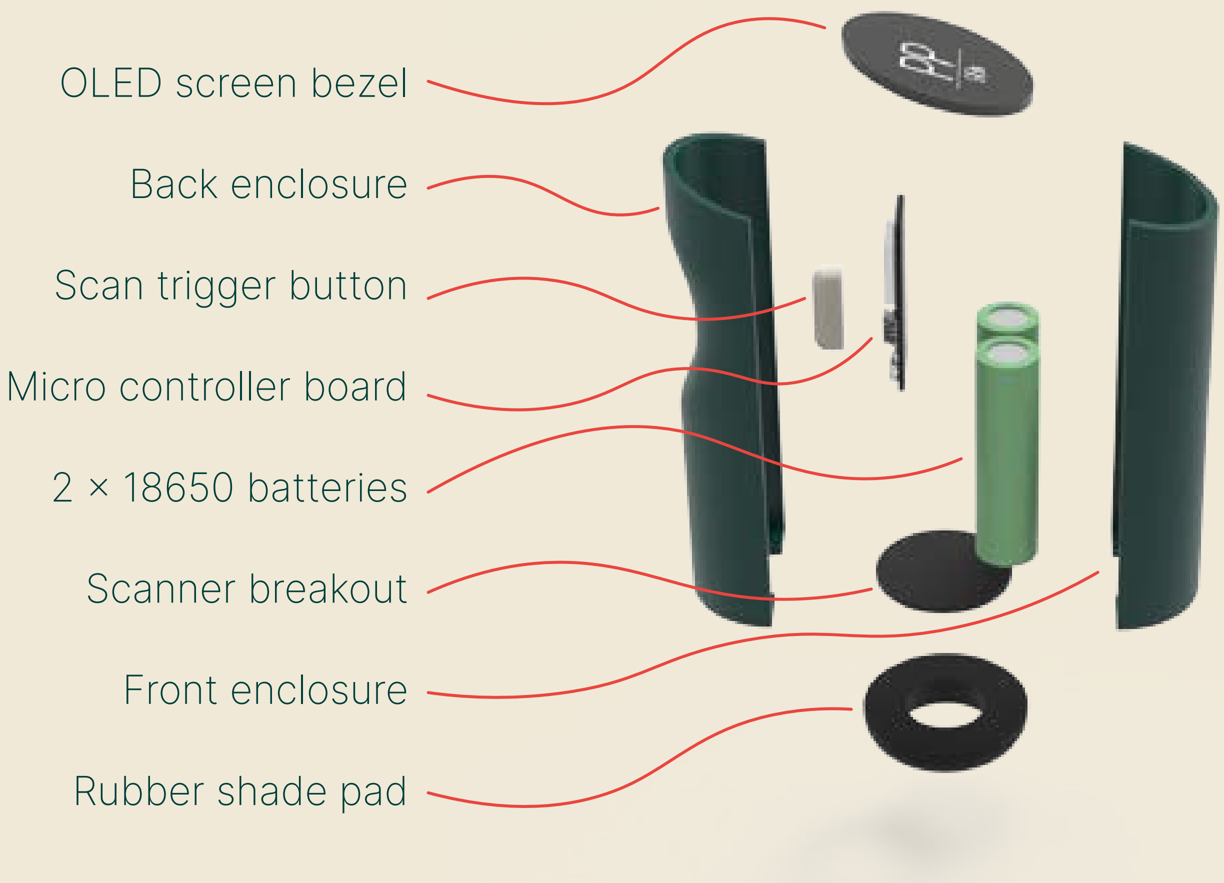


Figure 33: 3D rendering of digital space exploration

Concept for Q4

The concept direction most fitting for the project is concept 2, initially created with the wishes of facility managers in mind (as can be seen in Figure 27). This design direction is deemed the most high-tech of all concepts and most versatile. To understand what could be im-proved on the proposed concept, a concept analysis was conducted. The results of the concept analysis are displayed on figure 30. The other concepts were also analysed further to see what features have potential to be transferred into concept 2. It was then chosen to elaborate on concept 2, the hand-held device, with adaptability in mind.

To find an interesting and fitting shape, shape explo-ration was conducted using reference sketching (Figure 31). The shape was further refined and validated using clay modelling (Figure 31) and detailed, digital sketches (Figure 32) (high-er resolution sketches can be found in Appendix I). To validate whether all com-ponents would fit this design direction, a 3D-model with the most space consuming compo-nents was also created (Figure 33).

Figure 32: Digital sketches made from clay model prositions

Figure 31: Initial sketches and clay model

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10.8 Appendix F - PE measurement report

10.9 Appendix G - Exterior Shape Evaluation

10.10 Appendix H - Design Sketches A & B

10.11 Appendix I - Implementation paper AEF

10.12 Appendix J - Preperation and insights visit Besstrade

10.13 Appendix K - List of Requirements

10.14 Appendix L - FEA Report (ADE)

10.15 Appendix M - Technical Data Package Drawings